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Soil Health and Climate Smart Agriculture (CSA) for Resilient Food Security System

29th July - 2nd August, 2024

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Prof. O. J. Jayeoba

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FOREWARD

It is with immense pleasure and a profound sense of duty that I extend my warmest greetings to all participants, stakeholders, and partners that gathered for the 48th Annual Conference of the Soil Science Society of Nigeria (SSSN), hosted by the Department of Agricultural Land and Climate Change Management Services (ALCCMS): Federal Ministry of Agriculture and Food Security, (FMAFS), Abuja and held at the prestigious International Women Development Centre, Abuja, Nigeria, from 29th July to 2nd August 2024. The conference was a testament to the unwavering commitment of soil scientists and stakeholders in ensuring Nigeria's agricultural sector thrives through improved soil management practices and innovative solutions.

The theme of this year’s conference aptly underscores the critical role of soil health and fertility management in addressing some of the most pressing global challenges, including climate change, food security, and environmental sustainability. As our nation intensifies efforts to boost agricultural productivity and achieve food security for our growing population, soil scientists are key players in providing practical solutions that will enhance soil resilience, optimize land use, and promote climate-smart agriculture.

Soil serves as the foundation of our agricultural systems and ecosystems. Therefore, ensuring its health and fertility is paramount to sustaining productive farmlands, improving crop yields, and enhancing the livelihoods of our farmers. As such, the Federal Ministry of Agriculture is committed to supporting initiatives that promote sustainable soil management practices. In this regard, innovations such as the Nigerian Farmers Soil Health Scheme (NFSHS), offer a promising solution for improving soil fertility, enhancing crop productivity, promoting sustainable agricultural practices and reducing environmental impacts.

I take this opportunity to commend the leadership and members of the Soil Science Society of Nigeria for their dedication to advancing soil science research and promoting sustainable land use practices. Your contributions have remained invaluable in guiding policymakers, agricultural practitioners, and development partners toward solutions that ensure improved soil productivity and environmental sustainability.

The proceedings of this conference are expected to provide critical insights, recommendations, and strategies that will shape the future of soil science, enhance sustainable agricultural development, and contribute to Nigeria’s food security agenda.

On behalf of the Federal Ministry of Agriculture, I commend all stakeholders for their commitment to improving Nigeria’s soil resources and promoting sustainable agriculture.

Sen. Dr. Aliyu Sabi Abdullahi CON
(Baraden Borgu)
Honorable Minister of State for Agriculture and Food Security,
Federal Republic of Nigeria

ACKNOWLEDGEMENT

On behalf of the Federal Ministry of Agriculture, I extend my heartfelt appreciation to all individuals and organizations whose contributions have made the 48th Annual Conference of the Soil Science Society of Nigeria (SSSN) a resounding success.

I wish to commend the leadership and members of the Soil Science Society of Nigeria for their tireless efforts in organizing this impactful event. Your dedication to promoting soil science research, capacity building, and sustainable land management practices is deeply appreciated.

Special thanks go to the keynote speakers, facilitators, and presenters who have shared invaluable knowledge and insights throughout the conference. Your contributions are instrumental in advancing soil science knowledge and developing practical solutions to address challenges in agriculture and environmental sustainability.

I also express gratitude to our esteemed partners, sponsors, and collaborating institutions for their generous support, which has significantly enhanced the success of this conference. Your commitment to fostering scientific exchange and agricultural innovation is commendable.

Finally, I acknowledge the participation of farmers, extension agents, researchers, and policymakers who engaged actively during this event. Your collaboration is crucial in translating research outcomes into impactful solutions that will improve soil productivity and promote sustainable agriculture in Nigeria.

Once again, thank you all for your dedication and invaluable contributions. May the knowledge shared during this conference inspire meaningful actions toward achieving food security, environmental sustainability, and economic growth in our country.

Olanipekun Oshadiya	**Bello Mohammed**	**Jayeoba Olumuyiwa J**
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SECTION ONE

Soil Survey and Classification for Sustainable Land Resources Management and Remediation "A"

SUSTAINABILITY ASSESSMENT OF SOME DIFFERENT SOIL MANAGEMENT SYSTEMS FOR GINGER PRODUCTION IN KAGARKO LOCAL GOVERNMENT AREA, KADUNA STATE, NIGERIA

[1]Joshua, D. A; [2]Maniyunda, M. L. [3]Jibrin, A;

[1 and 3] Department of Geography and Environmental Management, Ahmadu Bello University, Zaria, Nigeria.

[2]Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria.

*Corresponding author email: *josdogara2@gmail.com*

Abstract

A two staged soil survey that involved reconnaissance and semi-detailed methods were carried out to delineate site into soil management units. Five soil units identified include: KG1 was well-drained forested (virgin) soils, KG2 moderately drained forested (virgin) soils. KG3 well drained intensively cultivated soils, KG4 moderately drained intensively cultivated soil and KG5 poorly drained soils. In each soil unit, soil profiles were excavated, described and sampled according to standard procedures. Soil samples for fertility assessment were collected at 0 to 15 cm and 15 to 30 cm in each soil unit for routine analysis. Rain fed ginger was planted in each soil units and crops performance indices were collected. Result revealed soil pH varied between very strongly acidic and moderately acidic (4.97and 5.84). Exchangeable bases: Ca and Mg were between high (10.40 and 4.80 cmol(+)kg^{-}1) and low. Organic carbon was between high (16.83gkg^{-1}) and low. Ginger harvested indicated that soil unit KG1 had the highest yield with the total weight of 123,500 kgha^{-1} against KG2, KG3, KG4 which had 120,250 kgha^{-1}, 22,800 kgha^{-1} and 24,300 kgha^{-1} total weight respectively; however, no harvest was done in KG5 due to hydromorphic conditions. Ginger harvested from two plots of unit KG3 separately treated with cow dungs and poultry droppings had total weight of 87,200 kgha^{-1} and 86,150 kgha^{-1} respectively; this quadrupled the total weight 22,800 kgha^{-1} harvested in the controlled soil unit KG3. The post-harvest assessment showed decreased in essential nutrients against soil units KG1 and KG2 due to the leaching potential of the virgin soils after cultivation. There was increase in both ginger yield and post-harvest nutrients assessment in the two plots of farm unit KG3 that were separately treated with cow dungs and poultry droppings than the controlled soil unit. The cow dungs had higher ginger yield and ability to buffer soil OC than poultry drops.

Key Words: Rain-fed, Agriculture yield, Nutrients Supplements, and Sustainability.

Introduction

Soil is the major source of food and fiber for man and animals; and raw materials for operation of industries (Soil Science Division Staff, 2017). Soil is in intense pressure to wrongful utilization in the developing countries where fallowed system had faded away and soil inventory is not being prioritized for efficient utilization (Chukwu *et al,* 2014; Anedo *et al*, 2017, Data *et al*, 2018 and Maniyunda *et al,* 2019). Soil inventory, pre-planting potentials and regular soil fertility assessment are invaluable in to ensure food security in a world of ever increasing population, couple with low soil nutrients and dwindled farm land (Chukwu *et al.,* 2014; Maniyunda *et al.,* 2015; Nwaogu and Muogbo, 2015; Abagyeh *et al.,* 2022; Joshua *et al.,* 2022).

Bakayoko *et al.* (2009) and Tanimu *et al.* (2012) reported gross decline in soil nutrients of continuously cultivated soils of tropical Africa; however, animals waste addresses nutrients deficiency for optimal crops yield. Bada *et al.* (2019) and Ndzeshala *et al.* (2022) stated that cow dungs and poultry drops have the potentials to amend organic carbon (OC), potassium (K), total nitrogen (TN), available phosphorus (P) and zinc (Zn) in nutrients impoverished soils. On the other hand, intercropping system of farming with leguminous crops amends N and OC deficient soils for improved yield and sustainability; nevertheless, cattle dung has low mineralization than poultry drops (Nwogu and Muogbo, 2015).

According to FAO (2019) and Kaduna State Ginger Investment Policy and Strategy (GIPS) (2021), ginger (*Zingiber officinale*) is a perennial underground rhizome that is grown in the tropical humid climate. Nigeria is the second largest producer and exporter in the world market behind India. Also, a leading producer in Africa, as the continent produced 888,859.05 metric tons (MT) of ginger on 102,098.00 ha in 2021; Nigeria contributed 768,304.92 (MT); equivalent of 86% of the total production on 86,911.00 ha (Unguwanrimi *et al.*, 2023 and UNFAOstat, 2024).

Ejechi *et al.* (2018), Olaghere *et al.* (2022) and Tomide (2023) revealed that the Nigeria's ginger is in high demand not only because of the high quality of its pungent aroma; but also, its high oil and Oleoresin content distinguish it to serve as spice to garnish food, beverages, confections and medicinal raw materials in both local and modern pharmaceutical industries. Adegboye (2011), Ayodele and Sambo (2014), Marcus (2019), GIPS (2021) and Tomide (2023) reported ginger as a major cash crop in Kagarko Local Government Area in Kaduna State. The area is ranked second leading producer of ginger in Nigeria (Adegboye, 2011). Ginger cultivation is done in an open parkland of clay loam, sandy loam, black rich clay and lateritic soils, with depth between 25 and 150 cm as the rhizome is shallow rooted (Anedo *et al*, 2017; Srinivasan *et al.,* 2018). Ginger propagates optimally in well-drained none-saline soils, but moderately drained soils give good yield provided there is adequate surface drainage after cultivation (Olaniyi *et al.,* 2012; FAO, 2019; Adivappar and Naik, 2021).

Srinivasan *et al.* (2018), Nwaogu and Muogbo (2015) and Data *et al.* (2018) opined that ginger is highly nutrients exhaustive; however, Maniyunda *et al.* (2015), Anedo *et al.* (2017), Data *et al* (2018), FAO (2019), Maniyunda *et al.* (2019), Adivappar and Naik (2021), and Tarfa *et al.* (2022) Jibrin *et al.* (2022) asserted that to resuscitate nutrients deficient soil, traditional soil management techniques should be adequately incorporated with the modern.

Literatures reviewed showed that several studies had been conducted by Adegboye (2011), Ejechi *et al.* (2018), Chidiebere-Mark and Ibe (2018), Ibrahim (2018), Marcus (2019), Ibrahim *et al.* (2019), Nmadu and Marcus (2020), Sodangi (2020), GIPS (2021), Olaghere, *et al.* (2022) and Unguwanrimi *et al.* (2023) on how to upscale ginger production in the study area. Therefore, by using soil survey to delineate the soil units of the study area, this study was aimed at assessing the potentials of the soil units delineated, productivity of the soil units and the best farming management system that will improve yield and sustain ginger production in Kagarko Local Government Area.

Study Location

Kagarko Local Government Area (LGA) is bordered with Kachia LGA to the North, Jaba LGA and Nasarawa State to the East, Federal Capital Territory to the South and Niger State to the West. It lies between latitude 9^0 35′N and 9^0.08′N and longitude 7^0 6′E and 8^0 00′E with a total area of 4,400 km^2 on the southern tip Kaduna State, Nigeria as shown in Figure 1. Ginger is the major cash crops in Kagarko LGA besides turmeric, cassava, groundnut, pepper, tobacco and artisan services. The geology of the area is the Northern Basement Complex which is consisted of gneiss and migmatite (Raji *et al*., 2011). The area lies on a gently undulating topography; with elevation that varied between 573 and 643 m above sea level. The climate of the site was classified by Koppen

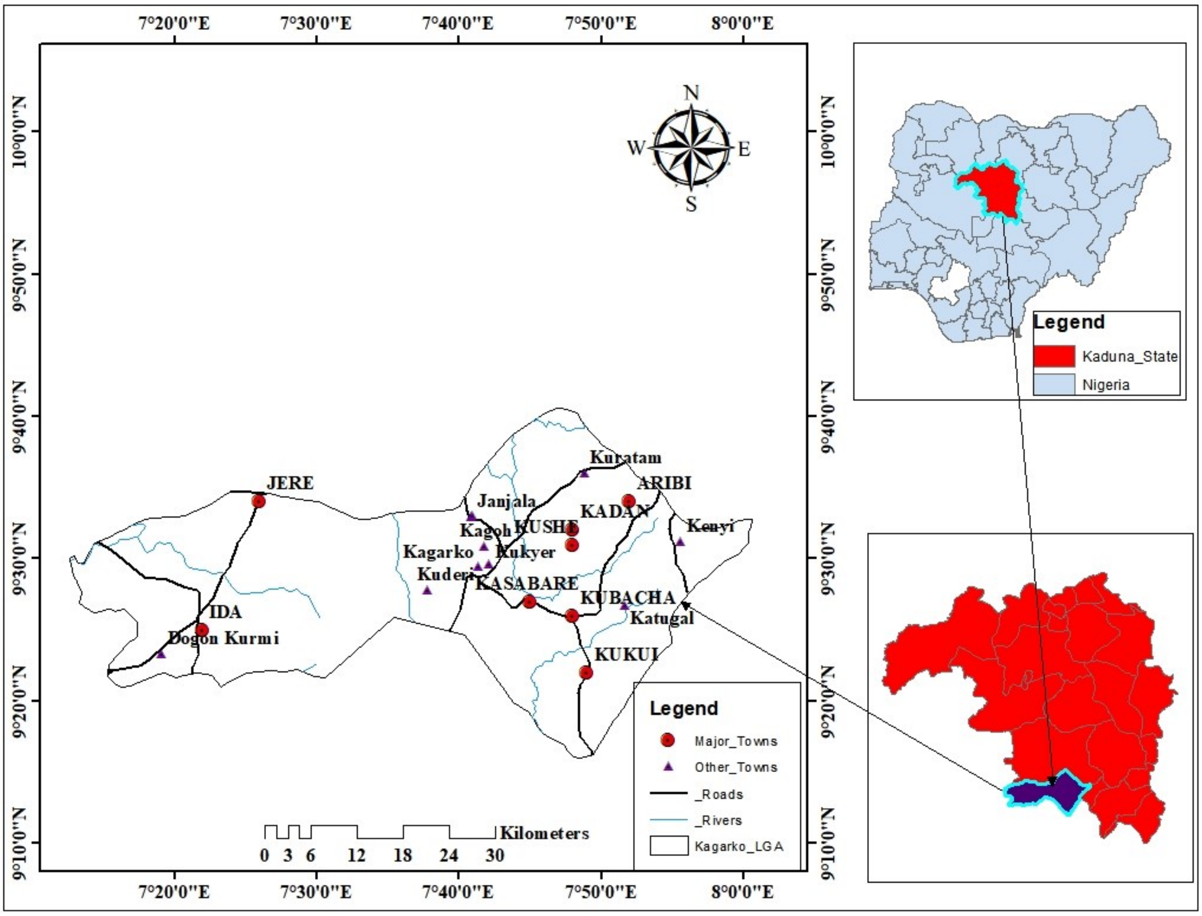

Figure 1: Map of the Study Area Source:

As Aw with the onset of rainfall in April: a period the South-westerly commences its dominant role and ginger farming begins. The rain reaches its peak by July and August with a single maximum annual average of 1,300mm (Abaje *et al*., 2010). **Materials and Methods**

Field activities

A reconnaissance and semi-detailed soil survey involved systematic and multi-stage were used to observe the morphological properties of the soils. Soil samples were collected from the delineated soil units for pre-planting assessment of both physical and chemical properties. (Soil Science Division Staff, 2017; Carter and Gregorich, 2006). The soil samples were taken for routine laboratory analysis.

Rain fed ginger cultivation was carried out on the soil units delineated on well drained virgin soil, moderately drained virgin soil, intensively cultivated well drained soil, intensively moderately drained soil and poorly drained soil. The fresh weight of the ginger of each grid was assessed after cleaning the ginger; while the dry weight was assessed after it was dried split in a room temperature. Post-harvest soil samples were collected to assess the chemical properties of the different ginger farms.

Laboratory Activities

Pre-planting and post-harvested soil samples collected were air-dried, grounded and passed through a 2 mm sieve. The percentage particle size distribution of less than 2 mm soil samples were carried out using bouyoucos hydrometric method. The soil textural triangle was used to determine the soil texture. Bulk density of the soil was determined by oven drying of undisturbed soil samples in a core; soil porosity was determined gravimetrically; Soil organic carbon (OC) was determined by the Walkey-Black method, total nitrogen (TN) was by Kjedahl method, soil pH was by electrical potentiometer in 1:2.5 soil-water ratio, electrical conductivity was taken from the saturate using the Wheatstone bridge, exchangeable acid was extracted using 1 N KCl_2; available phosphorus (AP) was determined by Bray No 1, monovalent exchangeable bases: potassium (K) and sodium (Na) were determined by flame photometer after extraction with ammonium acetate (NH4OAc) while calcium (Ca) and magnesium (Mg) were determined by titration (Hillel, 1971) and Carter and Gregorich, 2006).

Results and Discussion

Morphological Properties of the Soil Units

The results of soil survey delineated five soil units KG1, KG2, KG3, KG4 and KG5 with distinct soil morphological properties as shown in Table 1. The soils units were between very shallow <25 cm and very deep >150 cm. soil drainage was between well drained and poorly drained; while soil colour was between pale brown (10YR 6/3) and brown (2.5Y5/1) in the surface soils; and yellowish brown (10YR 5/8) and gley (5YR 5/1) in the sub soils. The presence of mottle and gley condition in some soil units indicates permanent and periodic hydromorphic condition that restrict effective depth. Soils depth in KG1, KG2, KG3 and KG4 was restricted by either underlain impervious layers of bed rocks or petro-plinthite with concretions of Fe and Mn oxides

Table 1. Morphological properties of the soil

	Horizon	Depth	Munsel colour		Mottle		Texture	Structure	consistence		
		Cm	dry	moist	Colour				wet	moist	dry
KG1 Well Drained Virgin Soil	Pedon										
	A	0-23	10YR 6/3 pb	10YR 4/3 b	-	-	L	2mmsbky	ss	fr	h
	BA	23-49	10YR 6/7 by	10YR 3/4 b	-	-	CL	2smsbky	vs	f	vh
	Bt	49-102	10YR 5/6 yb	10YR 4/6 dyb	-	-	SCL	2smsbky	vs	vf	vh
	Bcvt	102-158	10YR 5/8 yb	10YR 3/7 dyb	-	-	CL	2smsbky	vs	vf	vh
KG2 Moderately Drained Virgin Soil	Pedon										
	A	0-19	10YR 6/4 lyb	10YR 5/4 yb	-	-	L	2msbky	ss	f	h
	Bt	19-51	10YR 6/3 pb	10YR 4/3 b	-	-	CL	2smsbky	vs	vf	vh
	Bcvt	51-105	10YR 5/2 yb	10YR 5/3 dyb	Few	fine, faint	CL	Om	vs	vf	vh
KG3 Well Drained Intensively Cultivated	Pedon										
	Ap	0-14	10YR 5/4 yb	10YR 5/6 dyb	-	-	L	2msbky	ss	fr	sh
	Bt	14-57	10YR 6/8 by	10YR 5/6 yb	-	-	SiL	2scsbk	vs	f	vh
	Btcv	57-125	5YR 5/6 yr	5YR 4/7 yr	-	-	CL	2scsbk	vs	vf	vh

Morphological properties of the soil

	Horizon	Depth Cm	Munsel colour dry	moist	Mottle	Colour	Texture	Structure	consistence wet	moist	dry
KG4 Moderately Drained Intensively Cultivated Soil	Pedon										
	Ap	0-18	10YR 7/2 lg	10YR 5/2 gb	-	-	SL	2msbky	Ss	f	h
	Bt1	18-51	2.5Y 7/3 pb	2.5Y lob	-	-	SiL	2smsbky	S	f	h
	Btcvg	51-98	2.5Y 7/2 pyb	2.5Y 6/2 bg	Few	fine, faint	CL	Om	Vs	vf	vh
KG5 Poorly Drained Soil	Pedon										
	Ap	0-17	-	2.5Y 5/1 b	com/prom	10YR 5/6 dyb	SiL	Om	Vs	vf	vh
	BCtg	17-64	-	5YR 5/1 g	com/prom	10YR 4/6 dyb	L	Om	S	fr	vh
	Cgw	64-118	-	5YR 5/1 g	-	-	L	Om	S	fr	vh

Key: **Munsel Colour**: yb = yellowish brown, lg= light gray by = brownish yellow, gb = grayish brown, g = gray, b = brown, dyb = dark yellowish brown, yr = yellowish red, pb = pale brown, b = brown, lob = light olive brown, pyb = pale yellowish brown, **Mottle**: com = common, prom = prominent. **Texture**: L = loam, SiL = silty loam, CL = clay loam, SL = sandy loam, SCL = sandy clay loam. **Structure**: 2msbky = medium sub-angular blocky, 2scsbky = strong coarse sub-angular blocky, 2mmsbky = moderate medium sub-angular blocky, smsbky = strong medium sub-angular blocky, Om = massive. **Consistence**: ss = slightly soft; fr = friable; sh = slightly hard; h = hard; vh = very hard; vs = very sticky, f = firm; vf = very firm. **Boundary**: gs = gradual smooth, cs = clear smooth, ds = diffuse smooth.

Sand particle size dominated the surface horizons of soil units KG1, KG2, KG3 and KG4; however, as profiles depth increases silt particle size gradually dominates, until clay particle size completely dominates the sub soils which is as a result of soil pedogenic activities: translocation, transformation and deposition; which caused eluviation of suspended clay materials from the surface horizons with corresponding illuviation in the sub soils. On the other hand, horizons of soil units KG5 were strata of deposited material of the flood plains with prominent cutans in the surface horizons and pale grayish sub surface horizons due to gley condition of underlain water table.

Soil Physical Properties

The bulk density of the soil units was between 1.33 and 1.53 gcm^{-3} in the surface horizons; and between 1.54 and 1.72gcm^{-3} as shown in Table 2. The particle size distribution of soil units KG1, KG3 and KG4 were dominantly sand; and ranged between 430 and 670 gkg^{-1}; whereas, silt particle size dominated soil units KG2 and KG5 in the range between 530 and 550gkg^{-1}. The sand particle content decrease with increased in depth of the horizons; whereby clay particle size dominated the sub soils. The soil textural classes were loam in KG1, KG2 and KG3; sandy loam in KG4 and silty loam in KG4; while the sub soils where between clay loam and silty loam.

Pre-planting Chemical Properties of the Soil Units

The soil pH of the soil units was between very strongly acid to moderately acid (4.97 and 5.84) as shown in table 3. The values of electrical conductivity were less than 2dSm^{-1}which indicates a none-saline soil. The level of exchangeable bases were in the trend Ca>Mg>K>Na. Ca and Mg were high10.40 and 4.80 cmol(+)kg^{-1}; and 2.81 and 1.01 cmol(+)kg^{-1}; 14.80 and 5.03 cmol(+)kg^{-1}; and 3.04 and 1.01 cmol(+)kg^{-1} respectively; and low in soil units KG3, KG4 and KG5. SOC was moderate (11.15gkg^{-1}) in KG1; and high (16.83gkg^{-1}) in KG5; but low in soil units KG2, KG3 and

Table 2. Physical Properties of the Soils

Soil	Depth	BD	PD	Porosity	Particle Size gkg^{-1}			Textural
	(cm)	gcm^{-3}	gcm^{-3}	%	Clay	Silt	Sand	Class
KG1	0-15	1.53	1.35	28	150	350	480	L
	15-30	1.54	1.47	21	390	390	230	CL
KG2	0-15	1.49	1.47	29	140	450	410	L
	15-30	1.54	2.00	16	350	380	270	CL
KG3	0-15	1.48	1.84	31	150	420	430	L
	15-30	1.55	2.05	25	290	540	170	SiL
KG4	0-15	1.44	1.85	27	120	210	670	SL
	15-30	1.72	2.40	14	140	590	270	SiL
KG5	0-15	1.33	1.27	34	190	530	280	SiL
	15-30	1.61	2.00	28	280	450	270	L

KG4. Soil available P was between low and medium (15.97 and 12.01 mgk^{-1}). Soil total nitrogen was low (0.11 and 1.02 gkg^{-1}). Available Fe and Mn were high; and between

39.51 and 118.94 $mgkg^{-1}$; and 2.18 and 63.82 $mgkg^{-1}$ respectively.

Yield of Ginger from the Different Soil Units

The output harvested in $2m^2$ of each ginger farm indicated that soil unit KG1 had the highest dry split weight (37,450 $kgha^{-1}$) and total weight (123,500 $kgha^{-1}$) against KG2, KG3+cow dung, KG3+poultry drops, KG3 and KG4. Soil unit KG2 has the highest fresh weight (94,450 $kgha^{-1}$) as shown in Figure 2 and Table 4. However, ginger yield in farm KG3+cow dungs and KG3+poultry drops, increased to 22,950 $kgha^{-1}$ dry split and 87,200 $kgha^{-1}$ total weight; and 21,300 $kgha^{-1}$ dry split and 86,150 $kgha^{-1}$ total weight respectively; against the yield of 7,600 $kgha^{-1}$ dried split and 22,800 $kgha^{-1}$ total weight produced in farm KG3 (controlled farm). Albeit, no ginger was harvested in farm KG5 due to intolerant to poorly drained soils (FAO, 2019)

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Table 3. Pre-planting Chemical Properties of the Soil Sampled

Soil	Depth	pH		EC_e	Exchangeable Bases				EA	OC	OM	TN	AP	Trace Nutrients	
	(cm)				(cmol(+)kg^{-1})					(gkg^{-1})		(gkg^{-1})	($mgkg^{-1}$)	($mgkg^{-1}$)	
		H_2O	$CaCl_2$	dSm^{-1}	Ca	Mg	K	Na	Al+H					Fe	Mn
KG1	0-15	5.81	5.27	0.16	10.40	2.81	0.12	0.13	1.00	11.15	19.22	0.92	4.97	58.81	28.73
	15-30	5.71	4.58	0.40	4.8	1.30	0.15	0.16	1.04	6.34	10.93	0.39	3.94	42.41	15.4
KG2	0-15	5.84	5.12	0.11	14.8	3.04	0.24	0.26	1.02	9.41	16.22	0.85	4.01	78.32	51.09
	15-30	5.03	4.71	0.21	5.03	1.01	0.41	0.16	1.13	4.87	11.84	0.29	1.93	49.71	20.26
KG3	0-15	5.81	5.02	0.09	1.58	0.41	0.08	1.95	0.96	3.02	5.21	0.24	8.93	69.72	13.98
	15-30	4.97	4.02	0.03	1.2	0.29	0.10	2.00	1.02	1.91	3.29	0.3	3.25	39.51	9.86
KG4	0-15	5.73	4.72	0.50	1.85	0.58	0.12	0.13	1.74	2.25	3.88	0.37	2.95	89.92	63.82
	15-30	5.49	4.31	0.10	0.94	0.31	0.22	0.15	1.92	1.97	3.4	0.21	2.03	48.76	23.81
KG5	0-15	5.75	4.36	0.40	0.95	0.35	0.46	1.78	1.63	16.83	29.01	1.02	3.00	118.94	4.01
	15-30	5.27	4.3	0.13	1.2	0.22	0.86	1.21	1.29	2.95	5.09	0.11	2.01	101.13	2.18

The result showed that highest yield was recorded in well drained virgin soils. On the other hand, ginger produced in imperfecty drained virgin soil has the highest fresh weight because of the moisture status of the soil, which caused the ginger to have higher moisture content at the harvest time than the ginger in soil unit KG1, but lower in dry split and total weight

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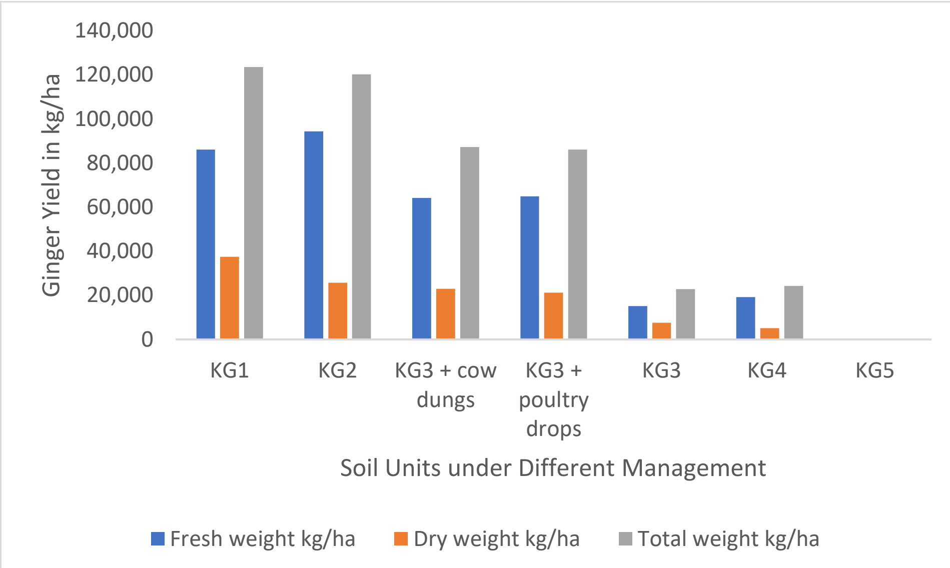

Figure 2. Yield of Ginger of the soil units

Table 4. Yield of Ginger under Different Soil Management Techniques

Soil Management Techniques	Size of grid m^2	Wet weight kgm^{-2}	Dried weight kgm^{-2}	Total weight kgm^{-2}	Fresh weight kg/ha	Dry weight kg/ha	Total weight kg/ha
KG1	2	17.21	7.49	24.70	86,050	37,450	123500
KG2	2	18.89	5.16	24.05	94,450	25,800	120,250
KG3 + cow dungs	2	12.85	4.59	17.44	64,250	22,950	87,200
KG3 + poultry drops	2	12.97	4.26	17.23	64,850	21,300	86,150
KG3	2	3.04	1.52	4.56	15,200	7,600	22,800
KG4	2	3.85	1.01	4.86	19,250	5,050	24,300
KG5	2	NH	NH	-	0	0	0

NH: No harvest

Farm KG3+cow dung produced ginger with higher fresh, dry split and total weight than farm KG3+poultry drops; because cow dungs has higher organic content to amend nutrients deficient soils for crops optimal yield, than poultry drops (Bakayoko *et al,* 2009, Bada *et al,* 2019, Tarfa *et al,* 2022 and Ndzeshala *et al,* 2022). Therefore, it will be advantageous for farmers to cultivate ginger in soil units KG1; however, due to paucity of virgin soils to satisfy large scale cultivation, it becomes imperative that the intensively cultivated soils to be either treated with cow dungs or poultry drops; or both in order to buffer and resuscitate the inherent low soil nutrients for increment in ginger yield, quality, environmental security and sustainability

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Post-harvest Soil Chemical Properties

The post-harvest assessment of the chemical properties of the soil units indicated that the status of Ca, SOC and available P decreased from 10.40 to 6.40 cmol(+)kg^{-1}, 11.15 to 7.69 and 15.97 gkg^{-1} to 7.37 $mgkg^{-1}$ in surface horizon of soil unit KG1 as shown in Table 5. Also, the values of Ca, SOC, and available P decreased from 14.80 to 6.97 cmol(+)kg^{-1}, 9.41 to 6.86 gkg^{-1} and 12.01 to 9.86 $mgkg^{-1}$ in the surface horizon of farm KG2. On the other hand, Ca, SOC, and aP increasesd in the two separately treated soil unit KG3. Ca, SOC and available P increased from 1.58 to 6.20 cmol(+)kg^{-1}, 3.02 to 14.11 gkg^{-1} and 8.93 to 13.32 $mgkg^{-1}$ in farm KG3+cow dungs, and 1.58 to 5.60 cmol(+)kg^{-1}, 3.02 to 11.60 gkg^{-1}, and 8.93 to 15.78 $mgkg^{-1}$ in the respective surface horizons. The decline in the surface soil nutrients of KG1 and KG2 indicated that virgin soils of the tropical climate are susceptible to swift mineralization and leaching of essential nutrients immediately they are cultivated due to disturbance of biomass which reduces the rate of carbon sequestration in the soil (Jibrin *et al.,* 2022) and mining of soil nutrients by crops (Anedo *et al.*, 2017; Adivappar and Naik 2021; Bakayoko *et al.,* 2009)

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Table 5. Post-harvest Chemical Properties of the Soil Sampled

Soil unit	Depth (cm)	pH H_2O	pH $CaCl_2$	EC_e (dSm^{-1})	Exchangeable Bases ($cmol(+)gkg^{-1}$) Ca	Mg	K	Na	EA	OC (gkg^{-1})	OM	TN (gkg^{-1})	AP ($mgkg^{-1}$)	Trace Nutrients ($mgkg^{-1}$) Fe	Mn
KG1	0-15	5.51	4.81	0.80	6.40	1.73	0.11	0.10	0.80	7.69	13.26	0.73	7.37	38.81	25.73
	15-30	5.01	4.15	0.25	6.00	1.62	0.14	0.14	1.02	7.05	12.15	0.34	5.32	49.41	12.40
KG2	0-15	5.87	5.10	0.09	6.97	2.1	0.91	0.11	1.08	10.11	17.43	0.96	9.86	72.32	48.09
	15-30	5.01	4.65	0.11	3.72	1.02	2.05	0.16	1.51	5.81	10.02	0.48	4.64	49.71	20.26
KG3 + Cow dungs	0-15	5.10	4.43	0.70	6.20	1.67	0.12	0.10	1.01	10.60	18.27	0.56	11.32	71.32	34.09
	15-30	5.13	4.47	0.31	5.80	1.57	0.14	0.15	1.03	7.88	13.59	0.45	5.15	49.71	10.26
KG3 + Poultry drops	0-15	4.88	4.21	0.37	4.60	1.24	0.18	0.18	1.51	6.23	10.74	0.78	15.78	61.72	18.98
	15-30	5.12	4.46	0.25	5.80	1.57	0.11	0.13	1.94	6.14	10.59	0.25	4.97	33.51	11.86
KG3	0-15	5.85	5.13	0.41	2.03	0.64	0.12	0.14	1.05	3.42	5.90	0.37	6.41	58.94	14.01
	15-30	5.20	4.50	0.08	1.52	0.39	0.19	0.16	1.25	2.35	4.05	0.17	2.83	71.13	12.18
KG4	0-15	5.02	4.89	0.16	1.93	0.42	0.11	0.13	1.04	3.51	6.05	0.39	5.84	64.30	7.89
	15-30	4.99	4.31	0.10	1.08	0.51	0.20	0.16	1.40	2.07	3.48	0.13	1.99	74.02	12.60
KG5	0-15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	15-30	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS: No sampled

On the other hand, essential nutrients in ginger farm KG3+cow dungs and KG3+poultry drops increased compared to the values of pre-planting controlled soil (KG3) as organic manure has the capacity to stabilize soil biota and nutrients (Tanimu *et al.,* 2012; Bada *et al.,* 2019). Farm KG3+cow dungs has the higher values of Ca and SOC due to its ability to produce durable substrates that chelate and aggregate the soil physical properties than poultry drops (Data *et al.,* 2018 and Tarfa *et al.,* 2022). The result showed that soils treated with cow dungs have higher agriculture returns and ability to buffer soil OC than poultry drops, because the rate of mineralization in cow dungs is slower than in poultry drops (Ndzeshala *et al.,* 2022).

Conclusion

The study showed that the soil of the study site was heterogeneous as five soil units KG1, KG2, KG3, KG4 and KG5 were delineated with distinct morphological properties with soil depth between very shallow and very deep soils. Soil drainage was between well drained and poorly drained. Sand dominate the soil particle size distribution in the surface while the sub soil were replaced by silt and clay particle size due to pedogenic processes. The soils are none-saline with electrical conductivity <2dSm^{-1}. Soil pH was between very strongly acid and moderately acid as H^+ and Al^+ dominated the exchange site.

The well drained virgin soils had the highest ginger yield; however, the imperfectly drained virgin soil had the highest fresh weight which become less after dried split. Soil unit KG3+cow dungs and KG3+poultry drops had a ginger yield that quadrupled the yield of the controlled farm KG3 as a result of the effect of organic amendment. Nevertheless, no ginger was harvested in far KG5 as a result of poorly drained condition which is not suitable for ginger production. The post-harvest soil assessment showed that soil nutrient declined in soil unit KG1 and KG2 as a result of leaching and nutrient mining by crops. However, farm KG3+cow dungs and KG3+poultry drops had appreciable increased values of exchangeable bases, SOC, TN and available P than the controlled farm (KG3) due to the positive effects of organic manure amendment.

Therefore, farmers should cultivate the virgins soil with caution to avoid soil degradation; the intensively cultivated soil units should be adequately managed with animal manure to sustain optimal production and environmental health; and other uses such as cultivation of paddy rice should be assigned to the poorly drained soil units for sustainability.

References

Abagyeh, S.O.I., Ibrahim, F and Adaikwu, A.O. (2022). Land Evaluation for the Cultivation of Ginger, Pepper and Maizeat the Department of Soil Science Farms, Joseph Saawuan Tarka University, Makurdi. IAR *Agriculture Research life Science*. 3(4): 18-24.

Abaje, I. B.; Ishaya, S. and Usman, S. U. (2010). An Analysis of Rainfall Trends in Kafanchan, Kaduna State, Nigeria. *Research Journal of Environmental and Earth Sciences,* 2(2): 89-96.

Adegboye, M.A. (2011). Evaluation of Farmers' Response to Extension Services on Ginger Production in Kagarko Local Government Area of Kaduna State. Scientific Research and Essay 6(6):1166-1171.

Adivappar, N. and Naik, M.K. (2021). Effect of Folliar Application of Micronutrients on Ginger productivity. *Journal of Spices and Aromatic Crops* 30(2): 200-203.

Anedo, E.O.; Amadi, C.O. and Nwaogu, E.N. (2017). Strategies for Maintaining Soil Fertility in Ginger

Production. Book of Readings in Honour of Dr. J.C Okwonko. Theme: Structural Transformation in Root and Tuber Research for Value Change Development and Employment Generation in Nigeria *ASURI, NRCRI* June 2017 305-314.

Ayodele, T.J. and Sambo, B.E. (2014). Ginger *(Zingiber offinale ROSCOE)* Production Effeciency and Constrains among Small-scale Farmers in Southern Kaduna, Nigeria. *Journal of Agricultural Science* 6(8)141-148.

Bada, B.S, towolawi, A.T., Adkin Sola, O.E., Arowolo, M.N., Odufuye, A.O., Adeleke, O.S., and Oguntade, M.A. (2019). Quality assessment of six Animal Dungs in University Teaching and Research Farm *FUTY Journal of the Environment* 13(2):85-97.

Bakayoko, S., Soro, D., Nindjin, C., Dao, D., Tschannen, A., Girardin, O. and Assa, A. (2009). Effects of Cattle and Poultry Manures on Organic Matter Content and Adsorption Complex of a Sandy Soil under Cassava Cultivation *(Manihot esculenta Crantz)*. *African Journal of Environmental Science and Technology*. 3(8): 190-197.

Carter, M. R. and Gregorich, E.G. (2006). *Soil Sampling and Methods of Analysis* / edited 2nd ed. p. CRC Press Taylor and Francis Group 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487-2742;S593.S7425 2007 631.4'1--dc22 2006102606cm.

Chidiebere-Mark, N. M. and Ibe, G.O. (2018). Economics of Ginger Production. In Ikwuano Local Government Area of Abia State, Nigeria. *International Journal of Plied Research and Technology* 3(4): 39-50.

Chukwu, G.O., Tarfa, B.D. and Amapu, I.Y. (2014). Linking Pedology and Extension: Emerging Trend in Optimizing Fertilizer Recommendations and Sustaining Soil Health in Nigeria. *Sky Journal of Soil Science and Environmental Management.* 3(5):42-49.

Data, S., Jana, J.C., Bhaisare, P.T., Thapa, A. and Islam, S. (2018). Effect of Organic Source of Nutrients and Bio-fertilizer on Growth, Yield and Quality of Ginger (*Zingiber officinale ROSC.)* Journal of Pharmacognosis and Phytochemistry; 7(6): 23011-23014.

Ejechi, M.E.; Madu, T.U.; Lenka, D.M. and Mbadiwe, M.N. (2018). Gender Analysis of Invovement in Ginger Production among Farmers in Abia and Imo States, Nigeria. *Nigerian Agriculturre of Journal.* 49(1):240-246.

FAO, (2019). Ginger Farming Guide. (GCP/RAS/296/JPN).

Hillel, D. (1971). *Soil and Water. Physical Principles and Processes.* Acad. Press, New York.

Ibrahim, A.M. (2018). Ginger Farming Practice in Jaba Region, Kaduna State, Nigeria. *Dutse Journal of Pure and Applied Science (DJOPAS).* 4(2): 155-168.

Ibrahim, M., Abdullahi, I.I., Yakubu and Yisa, K.M (2019). Assessment of Adoption of Improved Ginger Production Technologies in Kajuru Local Government Area of Kaduna State, Nigeria. Journal of Agriculture and Environment 15(2):83-89.

Jibrin, A., Mukhtar, I., Muhammad, M. and Saba, A.L. (2022). Soil Organic Carbon Stock and Carbon Sequestration Potential in Southern Guinea Savanna Ecological Zone Nigeria. SSSN ABU Zaria 46th 439-446).

Joshua, D.A., Jibrin, A., Maniyunda, M.L., Isaiah, A.I. and Fatihu, M.R. (2022). Soil Survey for Precision Agriculture, Morphological Variability of Soil properties and Suitability Assessment for Pepper Irrigation along Lower River Kushe, Southern Guinea Savanna Kaduna State Nigeria. 46th SSSN ABU Zaria 2022 (60-74).

Kaduna State Ginger Investment Policy and Strategy (GIPS) (2021).

Maniyunda, L.M., Raji, B.A., Odunze, C.A and Malgwi, W.B. (2015). Forms and Content of Sesquioaxides in Soil on Basement Complexes of Northern Guinea Savanna Nigeria. *Journal of Soil Science and Environmental Management*. 6(6):148-157.

Maniyunda, L.M., Ya'u, S.L and Malgwi, W.B. (2019). Characterization of Soils Developed on Nupe Sandstone and their Suitability for Sugarcane (*Saccharum officinarum L.*) in Soiuthern Guinea Savanna, Nigeria. *Journal of Agriculture and Environment* 15(1): 211-229.

Marcus, P.L. (2019). Analysis of Supply Response and Trend of Ginger Production in Benue and Kaduna State, Nigeria. PhD. Thesis, Department of Agricultural Economics and Farm Management School of Agriculture and Agricultural Technology, Federal University of Technology, Minna, Niger State.

Ndzeshala, S.D., Obalum, S. E. and Igwe, C.A. (2022). Some Utilisation Options for Cattle Dung as Soil Amendment and their Effect in Coarse-textured Utisols and Maize Growth. *International Journal of Organic Waste in Agriculture.* Doi:10.3486/*IJROWA.*

Nmadu, J.N. and Marcus, P.L. (2020). Efficiency of Ginger Production in Selected Local Government Areas of Kaduna State, Nigeria, *International Journal of Food and Agricultural Economics (IJFAEC)*. 1(2):39-52.

Nwaogu, E.N. and Muogbo, P.C. (2015). Effect of Ginger-grain Legume Cropping System and Spatial Arrangement on Soil Fertility Management and Yield of Intercropped Ginger in the Guinea Savanna of Nigeria. *International Research Journal of Agricultural Science and Soil Science* 5(1): 1-7.

Olaghere, I. L.; Osasona, O. A.; Omotesho, O. A. and Adesina, I. T. (2022). Economic Potentials of Ginger Value Chain in Kaduna State Nigeria WBJAERD 4(2):135-147.

Olaniyi, J.O., Modupeola, T.O., and Olubode, S.O. (2012). Effect of Tillage Method and Fertilizer (Potassium) on the Growth, Yield and Nutritional Value of Ginger *(Zingiber offinale)* in a Forrest-Savanna Transitional Zone of Nigeria. *Continental Journal of Agronomy* 6(2):6-12.

Raji, B. A., Malgwi, W. B., Berding, F. R. and Chude, V. O. (2011). Integrating Indeginous Knowledge and Soil Scienc Approches to Detailed Soil Survey in Kaduna Nigeria. Journal of Soil Science and Environmental Management. 2(3), pp. 66-73.

Sodangi, I. A. (2020). Evaluation of the Performance of Ginger (Zingiber officinale ROSC.) germplasm in Kaduna State, Nigeria.

Soil Science Division Staff. (2017). *Soil survey manual*. C. Ditzler, K. Scheffe, and H.C. Monger (eds.). USDA Handbook 18. Government Printing Office, Washington, D.C.

Srinivasan, V., Thankamani, C.K, Dinesh, R., Kandiannan, KHamza, S., Leela

N.K. and John Zakariah, T. (2018). Variation in Soil Properties, Rhizomes Yield and Quality as Influence by Different Nutrient Management Schedules in Rain fed Ginger. *Springer Agric Res.*

Tanimu, J., Uyovbisere, E.O., Lyocks, S.W.J. and Tanimu, Y. (2012). Assessment of Some Handling Practices on Cow Dung: Calcium and Magnesium Content and Total Microbial Population in Northern Guinea Savanna of Nigeria. *Greener Journal of Agriculture Science*. 2(6): 246-250.

Tarfa, B.D., Amapu, I.Y., Daudu C.K. Shero, I.A. (2022). Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Nigeria. Research Gate.

Tomide, B. (2023). Ginger Production in the Tropics: a Paradigm shift for the non-oil Export. Article: Ecology Health Fairness, Agrifood Network.
UNFAOstat, 2024). The World Ginger Statistics.

Unguwanrimi, Y.A.; Abdulsalam, A. and Ibrahim, S. (2023). Assessment of Current Practices Involved in Handling and Storage of Ginger in Kaduna state Nigeria. *Nigeria Journal of Engineering Science Research* (NIJESR), 6(3):19-30

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COMPARATIVE ANALYSIS OF SOIL MOISTURE RETENTION CURVE BETWEEN SOILS DERIVED FROM BASEMENT COMPLEX AND SANDSTONE PARENT MATERIALS IN PARTS OF BAUCHI STATE. NIGERIA

[1]*Ekle, A.E., [2]Babaji, G.A., [2]Hassan, A.M., [2]Voncir, N.
[1]Department of Soil Science Technology, Federal College of Land Resources Technology, Kuru, Jos, Plateau State, Nigeria
[2]Department of Soil Science, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria
Corresponding author email: ekleademu7@gmail.com

ABSTRACT
This study was undertaken to evaluate soil moisture retention and released characteristics in parts of Bauchi State under soil derived from basement complex and sandstone parent materials with the view to reveal the major cause of moisture inadequacy in soil derived from basement complex parent material. Triplicate core samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm using 5.0cm diameter and 3cm high rings of known weight (W_1) and volume (V).Soil moisture contents at pressure of 0.33bar, 1.00bar, 3.33bar, 7.00bar, 10.00bar and 15.00bar were determined using pressure plate extractor. These moisture contents on mass basis were graphed against their corresponding tension values to give a soil-specific curve known as the soil moisture characteristics (SMC) curve. The study showed that moisture retention and released characteristics depended on soil texture. Findings revealed that soils derived from sandstone exhibited higher plant available moisture at all tension levels evaluated compared to soils derived from basement complex parent materials. The result also showed that plant available moisture was rapidly lost at lower tension level of 1bar in soils of basement complex while it was slowly and steadily released till tension of 15bar in soil of sandstone origin. Therefore, the use of organic manure, early planting or maturing varieties of crop are recommended for planting in soil derived from basement complex to avoid complete loss of crops.
Keywords: agricultural productivity, Bauchi State, irrigation, parent materials, Soil moisture retention,

Introduction
The mineral part of the soil is inherited from the parent materials but it is modified under the influence of different factors and processes. The Earth's crust contains almost 100 elements and only 8 of them (O, Si, Al, Fe, Ca, Na, K, and Mg) form 98.5% of the crust and compose the base of the soil body. Most of the soil types contain 60% of all existing minerals where the silicates and aluminosilicates are the most dominant ones. They are present in a form of primary and secondary minerals. The primary minerals originated as a result of weathering of igneous, sedimentary, and metamorphic rocks' while the secondary minerals originated as a result of chemical weathering of the primary minerals. Theoretically, the soil contains all the different types of minerals but the real number and type of the minerals that constitute one type of a soil is quite limited. The clay minerals are large group with common silicate characteristics.

The soil water retention is a result of two forces; adhesion (soil particle attract the water molecules) and cohesion (mutual attraction of the water molecules). The adhesion is stronger than the cohesion. The force which retains the water in the soil is called capillary potential and is closely related to the water content. The free-flowing water in the soil has a capillary potential equal to zero, a condition where all the soil pores; both capillary and non-capillary are filled with water. Soil water potential can be determined indirectly by recourse to measurement of soil water content and soil water release or soil moisture characteristics curve that relate volumetric or gravimetric content to soil water potential. The measurement of water potential is widely accepted as fundamental to quantifying both the water status in various media and the energies of water movement in the soil plants atmospheric continuum Mukaetov (2004) underlines that by decreasing the water content in the soil the value of the capillary potential is increased. In order to assess the humidity of the soil using the capillary potential, Vucic, (1987) has proposed the pF value where the force of the water in the soil is expressed on the height of a water column in cm (1bar = 1063cmwater/cm^2). The pF values are affected by the mechanical content and according Vucic, (1987) the bigger the participation of the fine fractions the greater the pF values, especially under pressure of 0.33bars.

Differences in soil properties (texture and structure) affect the water content at saturation, field capacity, and permanent wilting point. Texture and structure determine pore size distribution in soil, and therefore, the amount of plant available water (PAW) (O'Geen, 2013). Coarse textured soils (sands and loamy sands) have low PAW because the pore size distribution consists mainly of large pores with limited ability to retain water. Although fine textured soils have the highest total water storage capacity due to large porosity values, a significant fraction of water is held too strongly (strong matric forces/low, negative water potentials) for plant uptake. Fine textured soils (clays, sandy clays and silty clays) have moderate PAW because their pore size distribution consists mainly of micropores (O'Geen 2013). Loamy textured soils (loams, sandy loams, silt loams, silts, clay loams, sandy clay loams and silty clay loams) have the highest PAW, because these textural classes give rise to a wide range in pore size distribution that results in an ideal combination of meso- and micro-porosity. Soil structure can increase PAW by increasing porosity. Soil depth and rock fragment content also affect water holding capacity because bedrock and rock fragments are assumed to be unable to hold plant available water and/or accommodate plant roots.

The Northern Guinea/Sudan Savanna of Nigeria commonly witness poor rainfall distribution, dry spells, surface wash and runoff on farms (Kowal and Knabe, 1972), and result in soil moisture deficiency that depress crop yield or complete crop failure at the uplands (Odunze *et al*., 2010). Also, the upland soils have very low moisture retention capacity, poor inherent fertility status and are dominated with low activity clays; in particular kaolinitic clays Lombin, 1987; Odunze, 2006). Crops grown at the uplands in the zone include maize, sorghum, upland rice, cowpea, groundnut and soybeans, and these suffer moisture stress following insufficient soil moisture during their growth phase. This implies that field crops would experience insufficient soil moisture to undergo proper growth and production processes, resulting in low yields or complete crop failure in some cases in the area. This problem of inadequate moisture for plant growth is worst in parts of Bauchi State, Nigeria that had their soil derived from basement complex parent materials.

Widespread occurrences of crop failure towards the dry season which has caused farmers nightmare in Bauchi State have prompted this investigation into the causes of such early dry spell in the area. Affected areas include parts of Bauchi, Toro, Tafawa Balewa and Dass Local Government Areas of Bauchi State. The crop failure starts with the leaves showing signs of moisture stress a week or two (depending on the severity of the problem) after cessation of rainfall. This problem had left so many farmers in these areas with famine throughout the season since most of them lack the capacity to provide water inform of irrigation to the crops in the field.

One possible way of investigating the cause of this moisture stress in these areas is through an assessment of soil moisture retention and release characteristics. Such an assessment of water retention and release characteristics was not available in agriculturally potential Bauchi State, Nigeria. Keeping this in view, this study was undertaken to evaluate the soil water retention and release characteristics in parts of Bauchi State under soils of basement complex and sandstone origin with the view to reveal the major cause of moisture inadequacy in soil derived from basement complex.

Materials and Methods

Location of the study area

Four sample locations were used in the study with two from each Local Government Areas in Bauchi State. The Local Government were Toro Local Government under soil derived from Basement Complex and Alkaleri under soil derived from Sandstone parent materials. Bauchi State occupies a total land area of 49,119km^2 representing about 5.3% of Nigeria's total land mass and is located between latitudes 9^0 30^1 and 12^0 30^1 North and longitudes 8^0 45^1 and 11^{0}0' East (UNDP Report 2018). The state is bordered by seven states; Kano and Jigawa to the north, Taraba and Plateau to the south, Gombe and Yobe to the east and Kaduna to the West

.

Table 1: Sample Locations and their Coordinates

Site	Latitude	Longitude	Evaporate (m.a.s.j)
Gar	N10º 04' 46''	E10º 15' 26''	379m
Yankari Road	N10º 03' 05''	E10º 17' 20''	361m
Gumau	N10º 15' 8''	E09º 0' 55''	830m
Buzaye	N10º 14' 53''	E09º 39' 38''	667m

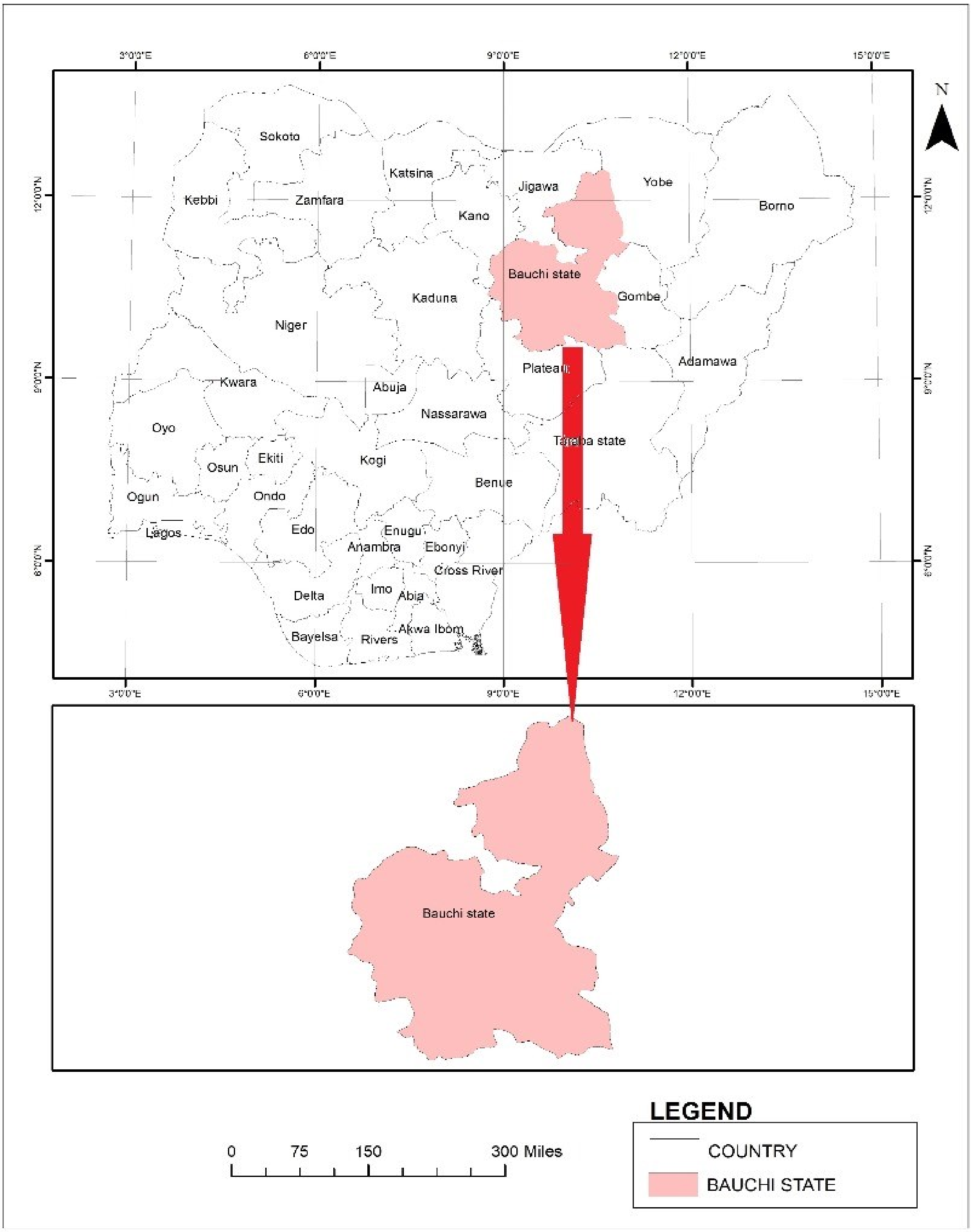

Fig. 1: The Study Area

Climate of the Study Area

The state experiences two main seasons; rainy and dry season. The rainy season usually commenced from May and ends in September with minimum rainfall of about 700mm per annum in the north to a maximum of about 1300mm per annum in the South. The vegetation is typically Sudan Savanna type comprising widely dispersed trees (Ibrahim, 2010).

Geology of Bauchi State.

Lithologically, soils in Bauchi State are formed from Basement Complex Rock (BCR) and the Sedimentary Rocks comprising the Kerri-Kerri Formation (KKF) and the Chad Formations (CF) (Macleod *et al*., 1971). The BCR covers most part of the State. Bauchi is basically composed of crystalline rocks, basement complex mostly Precambrian to the early Paleolithic in age. The rocks include the mixture of granites, gneisses, pegmatite and some amount of charnokite at the margin around the area of Alkaleri. Granites are coarse grained and are composed of quartz, alkali, feldspar, biotite and muscouite with ancestry horn bled and haematite. Pegmatite veins within the gneisses are composed of potash feldspar and very large crystal may form. A charnokitic rock occurs around the margin where it forms small out crops. Bauchi metropolis lies within the undifferentiated basement complex with older granites outcrops and young granites out crops. The basement complex is best described as crystalline rocks of the area (Macleod *et al*., 1971).

Sampling Technique

The samples were taken from two different locations within a local government area. One local government area was used each in the two soil formations. Triplicate core samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm using 5.0cm diameter and 3cm high rings of known weight (W_1) and volume (V). A total of 54 samples were used in each location given rise to 216 samples in all. The names of the specific locations where samples were taken and the coordinates marked using Geographic Positioning System (GPS) were presented in

Field Procedure

The collection of soil samples was done starting from the upper layer (0 – 20cm). The excavation of the soil to allow for taking of soil samples was carried out by the use of digger while shovel was used to move out the soil particles. After the excavation of the pit to 1m, a measuring tape was used to measure the depth at which the samples were taken (0 – 20cm, 20 – 40cm and 40 – 60cm) depth. The undisturbed samples were collected using the core samplers while the disturbed samples were taken using a hand trowel into sampling polythene bags. All the samples collected were labeled and the same procedure was used in collecting the samples from all locations and depths. Materials used in the field were Cutlass, Digger, Shovel, Meter rule, Sampling rings, Auger, Polythene bags, Hammer, Global Positioning System (GPS), Rubber ban, Piece of cloth.

Laboratory Procedure

Particle Size Determination

Soil samples were air-dried and served through a 2mm mesh. Particle size analysis was carried out by hydrometer method (Juo, 1979) using sodium hexametaphosphate as the dispersant.

Bulk density

Soil bulk density was determined by undisturbed core method (Klute, 1986). Three core samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm using 5.0cm diameter and 3cm high rings of known weight (W_1) and volume (V). The samples were put in an even at 105^0C for 24hours and its weight (W_2) was recorded. Bulk density was calculated at each tension levels as shown in Appendix i.

Determination of Soil Hydraulic Properties.

Soil moisture content on mass basis

Soil moisture content on mass basis (mass wetness) was determined by weight of water at a given tension level divided by weight of oven dried soil. The water content was then expressed on percent basis, thus: Mass of water/mass of soil solids x 100 as described by Anderson and Ingram, (1993) and presented in appendix i.

Moisture content at field capacity

Moisture content at field capacity was the mass wetness at 0.33bar as shown in appendix i (Anderson and Ingram, 1993).

Moisture content at permanent wilting point

Moisture content at permanent wilting point was the mass wetness at 15bar as shown in appendix i (Anderson and Ingram, 1993)

Available soil moisture in the soil

Available moisture in the soil is the difference between the soil moisture obtained on mass or volume basis at field capacity and permanent wilting point (Israelson and Hanson, 1962).

Soil moisture retention and release characteristics:

Soil moisture retention and released characteristics of the samples was determined using the pressure plate apparatus. A triplicate sample was taken each/depth/pressure head (0.33bar, 1.0bar, 3.3bar, 7bar, 10bar and 15bar) from 0 – 60cm depth at an interval 0 – 20cm for undisturbed samples as described by Smith & Mullins (1991). Each sample was carefully taken and covered at the bottom with a piece of cloth tied by rubber ring to the sampling ring. The rings were 50mm in diameter and 30mm in height. The soil samples while in the rings were soaked in water inside a tray overnight and pressure was applied to the system the next morning. For each depth, a moisture retention determination was carried out in triplicate at all the level of tension chosen. However, the triplicate samples were all place on the equipment at the same time. The amount of moisture was determined after equilibrium was reached in about 3 – 5days depending on the texture of the sample. The samples were even-dried at 105^0C for 24hoursand the results were expressed in percent moisture on a dry weight basis. All the water held between FC and PWP are available to plants, and all tension values from FC to PWP correspond to given moisture contents for any soil. These moisture content on mass basis was graphed against their corresponding tension values to give a soil-specific curve known as the soil moisture characteristics (SMC) curve.

Results

The result of this research work as presented below include the particle size distribution of the study area obtained from a composite samples, the mean hydraulic parameters (field capacity, permanent wilting point and plant available moisture of the study area) and the moisture characteristics of the area as expressed in soil moisture retention curve

Table 2: Particle Size Distribution of Soils of the Study Area.

PM	Location	Depth (cm)	%passing through 2mm sieve	Total sand 0.02-2mm	Silt(0.002-0.02mm)	Clay (<0.002mm)	Texture class
	Gar	0 – 20	93.50	73.60	12.16	14.24	Loamy sand
		20 -40	95.40	69.60	16.16	14.24	Loamy sand
SS		40-60	94.80	75.04	12.00	12.96	Loamy sand
	Yankari	0-20	94.20	73.60	12.16	14.24	Loamy sand
	Road	20-40	95.60	75.04	12.56	10.96	Loamy sand

		40-60	97.53	74.80	11.32	13.88	Loamy sand
	Gumau	0-20	50.46	50.32	29.68	21.44	Sandy clay loam
		20-40	55.09	52.32	21.44	26.24	Sandy clay loam
BC		40-60	49.90	51.68	25.44	26.24	Sandy clay loam
	Buzaye	0-20	78.54	54.32	19.44	26.24	Sandy clay loam
		20-40	83.06	52.32	21.44	26.24	Sandy clay loam
		40-60	84.32	52.32	21.41	26.24	Sandy clay loam

PM = Parent materials. SS = Sandstone. BC = Basement complex

Table 3: Hydraulic Parameters of Soil of Basement Complex Origin (Toro and Bauchi LGA) on Cultivated Land in Bauchi State.

PM	Sample No	Soil Depth	Bulk Density	FC (water%)	PWP (water%)	Available water(%)
	GR (I)	0-20cm	1.36	16.60	29.60	13.00^{a}
	GR(II)	20-40cm	1.14	20.00	34.60	14.60^{a}
SS	GR (III)	40-60cm	1.17	22.00	34.90	12.90^{a}
	YR(I)	0-20cm	1.20	15.00	33.20	18.20^{a}
	YR(II)	20-40cm	1.20	18.00	33.20	15.20^{a}
	YR(III)	40-60cm	1.20	17.00	31.60	14.60^{a}
	GM(I)	0-20cm	1.42	16.10	19.50	3.40^{b}
	GM(II)	20-40cm	1.28	18.10	21.90	3.80^{b}
BC	GM(III)	40-60cm	1.13	22.90	28.60	5.70^{b}
	BZ(I)	0-20cm	1.44	11.90	16.90	5.00^{b}
	BZ(II)	20-40cm	1.10	18.10	23.40	5.30^{b}
	BZ(III)	40-60cm	1.22	18.40	22.40	4.00^{b}

PM = Parent materials, BC = Basement complex, SS = Sandstone

Data values bearing different letters a or b are significant at 5% level of probability

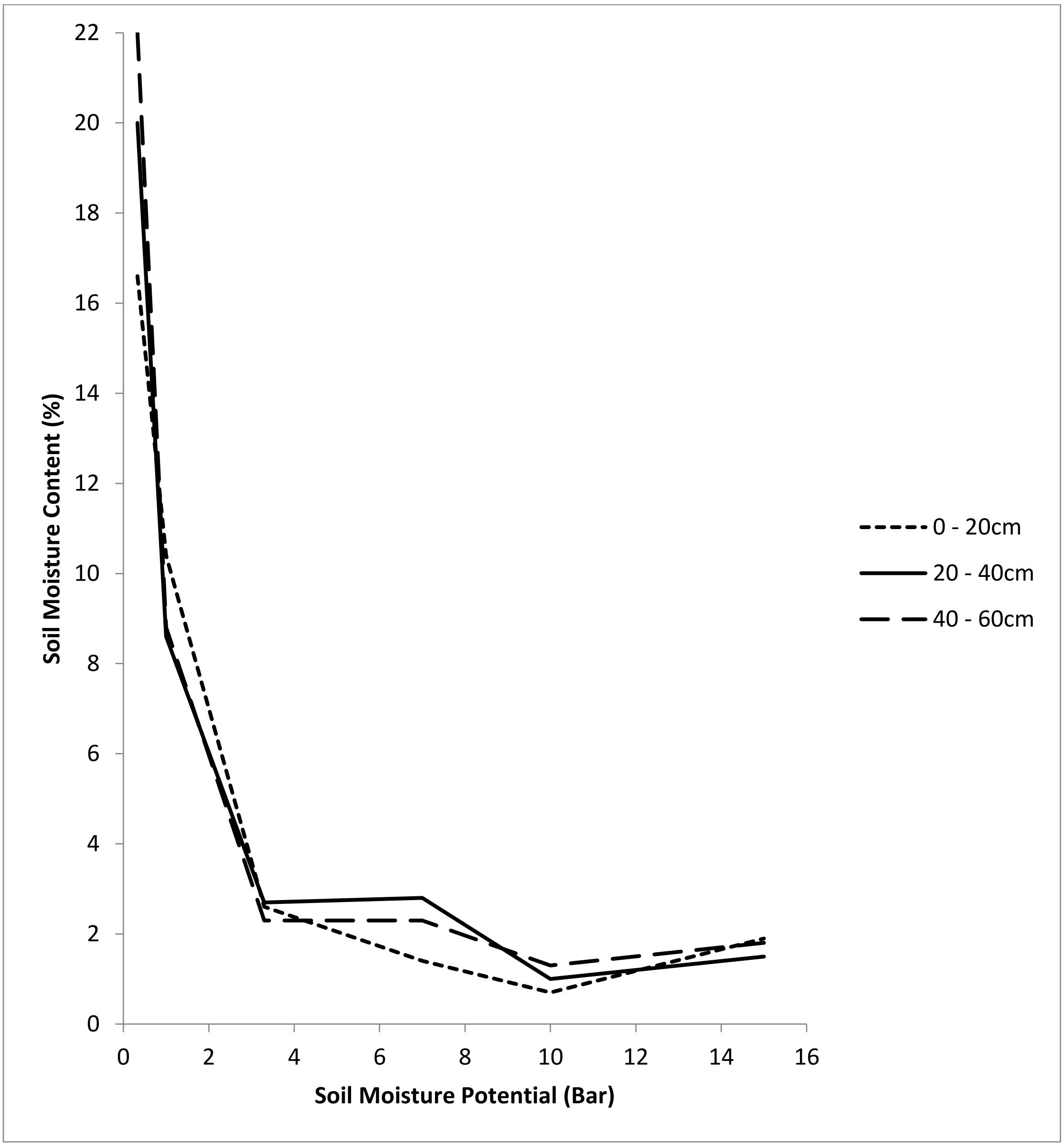

Fig. 2 Soil Moisture Characteristics Curve Of Gar Village in Alkaleri Local Government Area of Bauchi State.

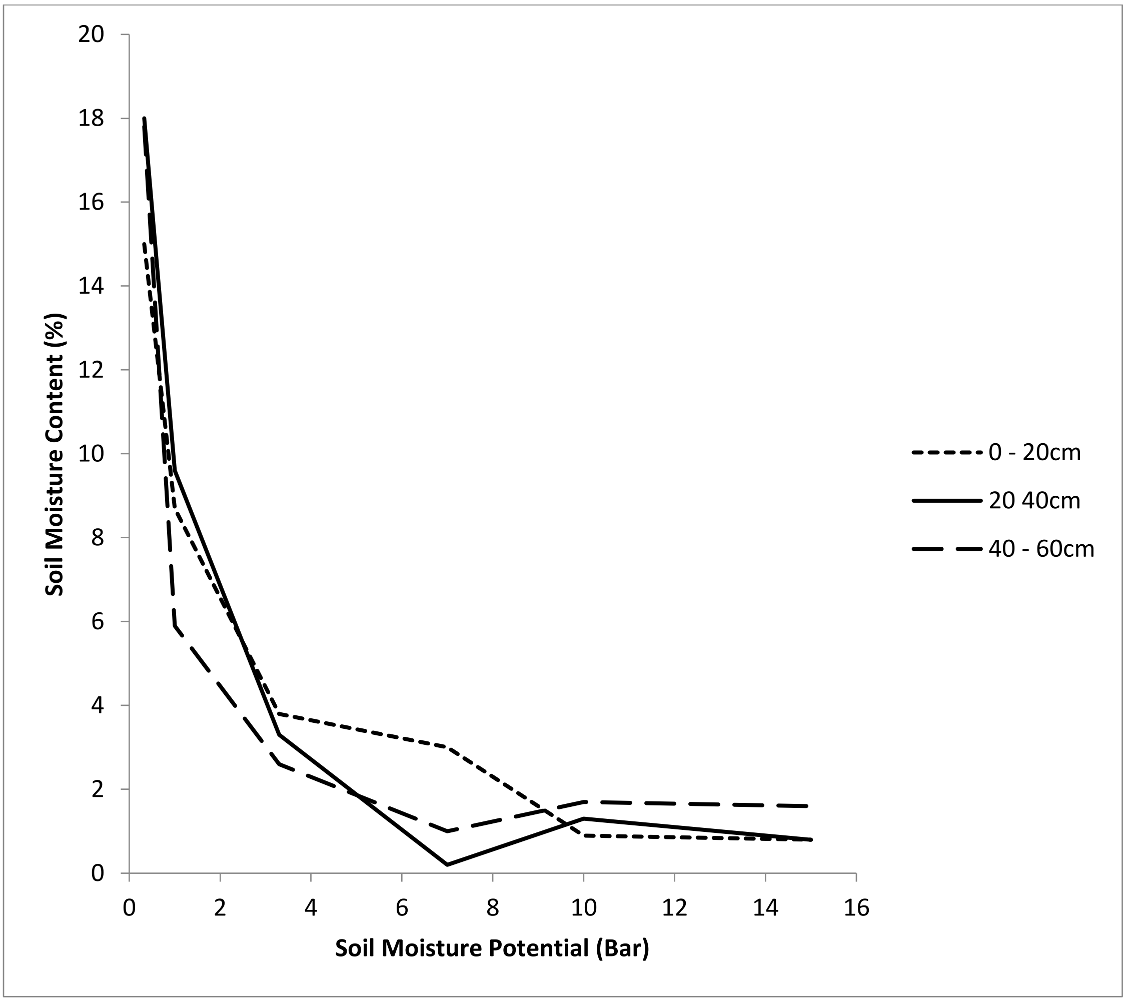

Fig. 3: Soil Moisture Characteristics Curve of Yankari Road in Alkaleri Local Government Area of Bauchi State.

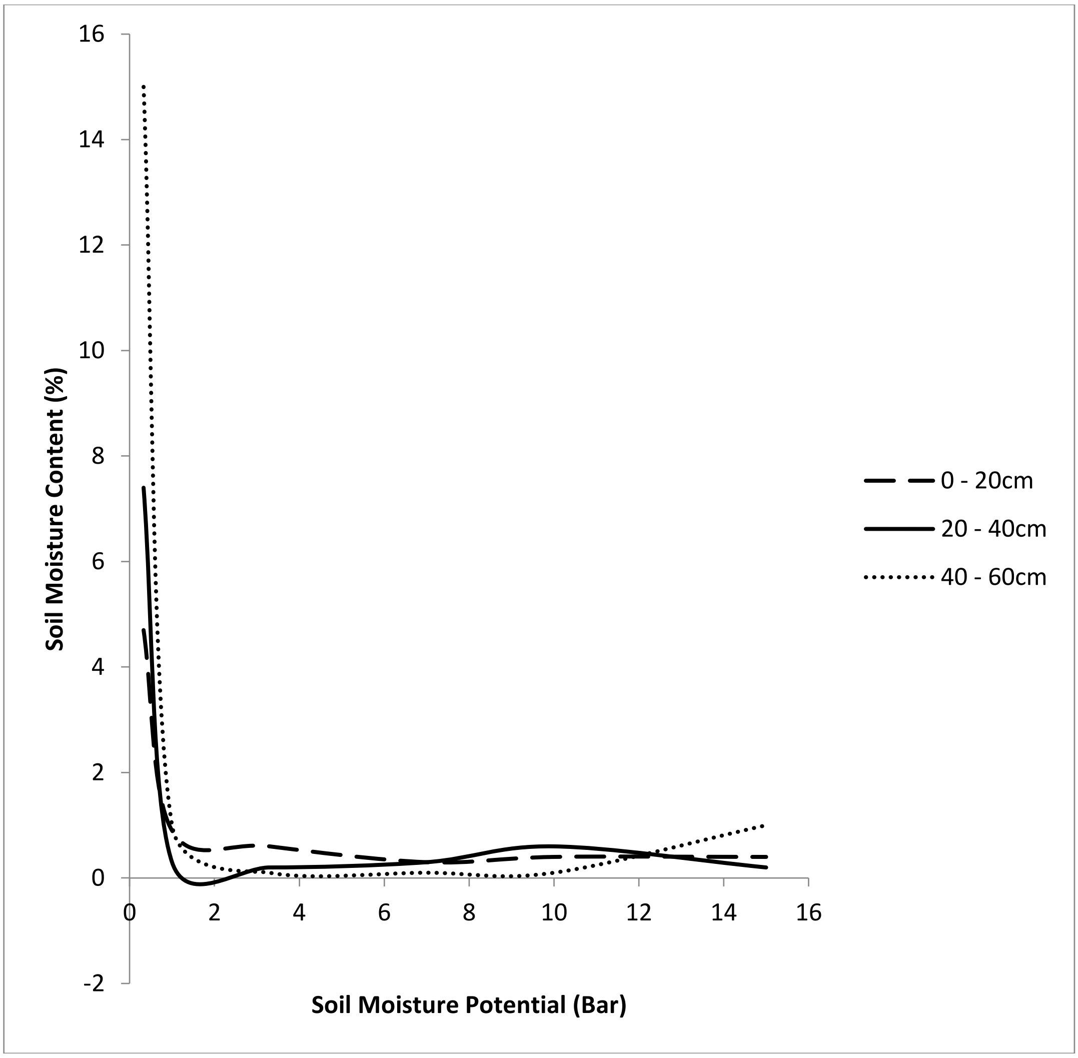

Fig. 4 Soil Moisture Characteristics Curve Of Uncultivated Land of Gumau in Toro Local Government
Area of Bauchi State.

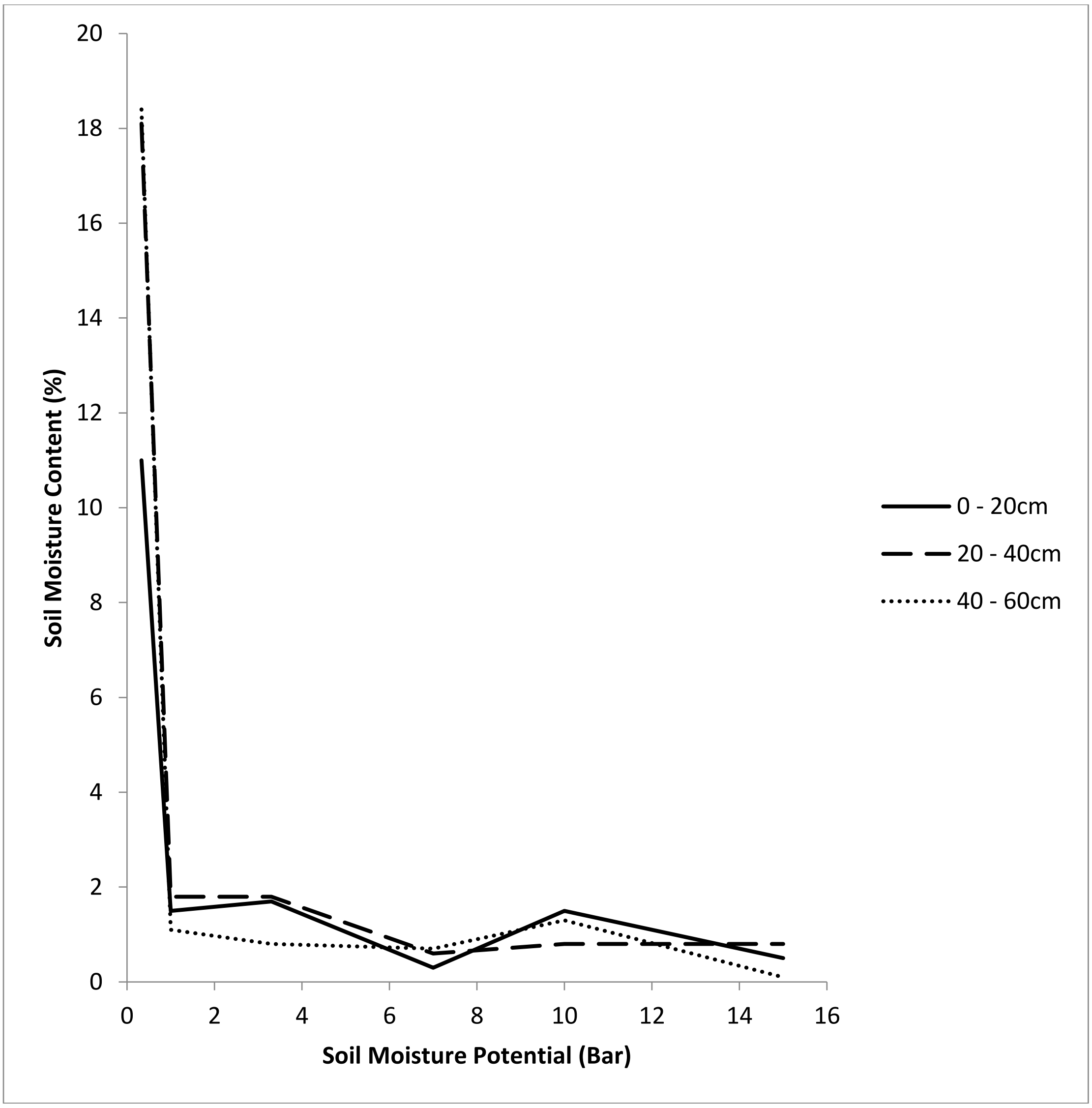

Fig. 5: Soil Moisture Characteristics Curve of Buzaye in Toro Local Government Area of Bauchi State.

Discussion

The particle size analysis of soil of the study area was presented in Table 2. From the table, locations that had soils derived from sandstone parent materials (Gar and Yankari Road) had more sand fractions compared to soils derived from basement complex formation whereas soil derived from basement complex parent material (Gumau and Buzaye) had more clay particles. Also, from Table 2, the percentage of the sample that was coarse in nature (particles above 2mm in diameter) was more in areas of basement complex origin compared to the soil of sandstone origin. Again, Table 2 showed that all the sample locations of soil derived from sandstone were loamy sand in nature. Also observed were sample locations of soil derived from basement complex that recorded sandy clay loam as textural classes. This variation in particle size distribution among samples had implication on moisture retention and release pattern of the area. This result was supported by the work of Vucic, (1987) who opined that pF values are affected by the mechanical content and according to Vucic, (1987), the bigger the participation of the fine fractions the greater the pF values, especially under pressure of 0.33bars.

Table 3 showed the soil hydraulic parameters such as field capacity (FC), permanent wilting point (PWP) and available moisture. From the Table 3, moisture was higher at all levels (field capacity, permanent wilting point and available form) in soil derived from sandstone compared to that of basement complex parent materials. A similar result was reported by O'Geen, (2013) who opined that water storage and redistribution are functions of soil pore space and pore size distribution, which are governed by texture and structure.

The soil moisture retention curve of Gar (Fig. 2) and Yankari Road (Fig. 3) all in Alkaleri Local Government Areas are similar in nature due to similar mechanical content. Both curves showed steep slope from the beginning to 7bar and turn gentle till 15bar. This was an indication of free flow of plant available moisture for plant use at all tension levels. This free available moisture content throughout the curve could be linked with combination of silt and very fine sand. This result was supported by the work of Vucic, (1987) who opined that pF values are affected by the mechanical content and according to the same author, the bigger the participation of the fine fractions the greater the pF values, especially under pressure of 0.33bars. Similar results were found in a study by Filizola *et al*., (2017), in his study of sandy soils with different management practices in an agricultural area. The high moisture released at lower tension between 0 – 7bar was as a result of high fine sand content in this location. As they usually have larger pores, sandy soils are more rapidly emptied at low tensions, leaving only small amounts of water retained at lower potentials. Generally, the curves were not far from each other till 15bar due to similar mechanical properties (equal mineralogical content of the soil, homogeneity of the profile).

From the beginning, the curves of Gumau (Fig. 4) and Buzaye (Fig. 5) experienced a very steep slope at low tension between 0 – 1bar, which was an indication of high available moisture lost at lower tension. Afterwards, the curves ran more or less parallel to the soil moisture tension axis, indicating that little or no moisture was released between field capacity and permanent wilting point. This result was also reported by Obi and Akamigbo, (1981) " when the curve runs more or less parallel to the soil moisture tension axis, it implies that little or no water is released between FC and PWP, as observed for some fine-textured soils; but when the curve slopes down quickly and then subsequently becomes gentle, it implies that much of the AWC of the soil sample is lost at very low tension". Also, the horizontal phase of the curve at high tension may be due to materials with greater particle size heterogeneity, the effective pore size can be reduced by the effect of empty spaces between larger grains being occupied by smaller particles (packaging phenomenon); thus, it is possible for certain particle size distributions to cause soil compaction and minimize pore space as also reported by Donagemma *et al*., (2016).

Conclusion

The result of the study area showed that moisture retention characteristics depend on soil texture. Findings revealed that soils derived from sandstone exhibited higher plant available moisture at most tension levels evaluated compared to soils derived from basement complex. The result also showed that plant available moisture was fast lost at lower tension level of 1bar in soils of basement complex while in soils of sandstone it was slowly and steadily released till tension of 15bar. Therefore, the use of organic manure and early planting/maturing or drought resistance varieties of crop is recommended for planting in soil derived from basement complex parent material to avoid dry spell.

References

Anderson, J.M. and Ingram, J.S. (1993). Tropical Soil Biology and Fertility. A Handbook of Methods. Information Press Eynsham.

Donagemma, G.K. et al., (2016): Caracterizacao, potential agicola e perspectivas de manejo de solos leves no Brazil. Pesq Agropec Bras 51: 1003-1020.

Filizola, H.F, Fontana, A, Donagemma, G.K., Souza, M.D., Bortolon, S.O and Botolon, L. (2017): Qualidadefisica de solos influenciada pela uso e manejonaregiao de Guarai, To. Jaguariuna, Sao Paulo: Embrapa Meio Ambiente, 34 p. (Boletim de Pesquisa e Desenvolvimento/Embrapa Meio Ambiente, ISSN 1516-4675;72).

Ibrahim, O.I. (2010).. Application of VES for Groundwater Exploration in Inkil, Bauchi LGA, Bauchi State. Unpublished Project, Geology Programme, ATBU, Bauchi.

Israelson O.W., and Henson, V.O. (1962)..Irrigation Principles and Practices 3rd Edition, Wiley International Edition, New York, USA.

Jones, M.J., Wild, W. (1975). Soils of the West African Savanna, Technical Communication. No 55: Commonwealth Bureau of Soils. CAB Harpenden. P. 240.

Juo, A.S.R. (1979). Selected Method for Soil and Plant Analysis. Ibadan; International Institute of Tropical Agriculture (IITA), Nigeria.

Klute, A. (ed) (1986). Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods. *American Society of Agronomy*. Madison.

Kowal, J.M., Knabe, D.T. (1972). An Agroclimatological Atlas of Northern States of Nigeria. Ahmadu Bello University, Zaria, Nigeria. P. 111

Lombin, G. (1987). Soil and Climate Constraints to Crop Production in Nigerian Savanna Region. 15th Annual Conference of Soil Science Society of Nigeria (SSSN), Kaduna; 20 – 24th Sept. (1987)

Macleod WN, Turner DC, and Wright EP (1971) The Geology of the Jos Plateau. Bulletin of the Geological Survey of Nigeria 32. 1 – 118.

Mukaetov, D. (2004): Conditions for Formation, Genesis and Characteristics of the Hidromorpfhic Black Soils Spread out in Pelagonija. Doctoral Degree Thesis, Faculty of Agriculture, Skopje, pp. 1 – 162.

Obi, M.E. and Akamigbo, F.O.R. (1981). Water relations of the soil of the Niger-Anambra flood plains of southeastern Nigeria. *Catena, **8**,* 282-288.

Odunze, A.C. (2006). Soil Properties and Management Strategies for some Sub Humid Savanna

Zone. Alfisol in Kaduna State, Nigeria. Samaru. *J. Agric. Res*.; **22**: 3- 14.

Odunze, A.C., Mando, A.J., Amapu, I.Y., Terfa, B.D., Yusuf, A.A, Abu, S.T., Bello, H., Ogbonna, S.U. (2010). Climate Changes and the need for Soil Moisture Stress Mitigation in the Arid and Semi-Arid Savanna of Nigeria. Proceeding of 34th Soil Science Society of Nigeria Conference (Oluwatosin *et al*., eds)

.

O'Geen, A.T. (2013): Soil Water Dynamics. *Nature Education Knowledge*. 4(**5**): 9.

Rawls, W.J., Gish, T.J., and Brakensiek, D.L. (1991). Estimating soil water retention from soil physical properties and characteristics. *Advances in Soil Science, **16***, 213-234.

Smith, K.A, and Mullins, C.E. (1991). Soil Analysis: *Physical Methods*, Marcel Dekker, New York, pp. 161 – 207.

United Nation Development Programme Report (2018). Human Development. *Achieving Human Development in North East,* Nigeria.

Vucic, N (1987). Matter, Air and Thermal Regime of Soil, VANU Department of Natural Sciences. Novi Sad. Pp. 1-320

Appendix i: A Worksheet for Bulk Density and Soil Moisture Content of a Sample Location

			Weight(g)						Volume of core ring (cm^3)		
Sampl e depth (cm)	Rin g No	Suction No(bar)	Wet weight of sample(g) (A)	Dry weight of sample(g) (B)	Weight of ring/cloth & Elastic(g) (C)	Weight of soil water(g) D = A – B	Weigh t of oven dried soil(g) (E)	Weigh t of dry soil(g) . F = E – C	Soil Water content(g/g) . W = D/F	Bulk density(g/cm ^{3} ℓ= F/V	Volume water content(g/cm$^{)}$=wx ℓ
A 0-20	I	0.33									
	2	1									
	3	3.3									
	4	7									
	5	10									
	6	15									
A 20-40	1	0.33									
	2	1									
	3	3.3									
	4	7									
	5	10									
	6	15									
A 40-60	1	0.33									
	2	1									
	3	3.3									
	4	7									
	5	10									
	6	15									

A = Sample locatio

PEDOLOGICAL ASSESSMENT OF DESIGNATED PARCELS OF LAND WITHIN THE TARABA STATE UNIVERSITY FARM SITE

***Kefas, P. K., K. I. Ofem, A. B. Shobayo, S. B. Bisong, H. J. Phillip, D. Kefas, J. K. Samuel, A. Christopher, I. I. Omadewu, J. J. Kussiy and A. B. Sheka.**

[1]*Department of Soil Science and Land Resource Management, Faculty of Agriculture, Taraba State University, PMB 1167, Jalingo, Taraba State, Nigeria*

[2]*Department of Soil Science, Faculty of Agriculture, University of Calabar, Cross River State, Nigeria*

[3]*Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria Kaduna State, Nigeria*

Corresponding author email: pkefas@yahoo.com

ABSTRACT

Appropriate land management is crucial for sustainable agriculture at the Taraba State University (TSU) farm site. However, detailed soil data was lacking to guide optimal land use planning. The study was to characterize the soils with respect to physical and chemical properties. Two soil profiles were dug at approximately 800 m apart within the farm site. The results indicate the extremely acid to neutral soils (pH: 4.0 - 7.1) that are dominated by sand-sized particles and are low in organic carbon (<0.38 g/kg), total N (0.01 – 0.054 g/kg) and available P (3.89 – 6.27 mg/kg) leading to low exchangeable K^+ (0.05 – 0.10 cmol/kg) and moderate exchangeable Mg^{2+} (0.52-1.46 cmol/kg) and Ca^{2+} (2.-5.4 cmol/kg). Furthermore, effective cation exchange capacity was also low (3.59 – 8.02 cmol/kg), while base saturation was high and exceeded 70 %. Such soil property ratings may not favour optimum crop production in the area and the soils may require good soil management practices. Adopting soil conservation practices like cover cropping, mulching and reduced tillage could help maintain soil quality over the long term.

Keywords: Pedology, land management, soil fertility, soil conservation.

INTRODUCTION

The Taraba State University (TSU) farm site is a pivotal hub for agricultural research and production. However, its full potential remains shackled by the absence of pedological assessments. To avoid suboptimal land-use practices that result in reduced agricultural yields, it is essential to have a nuanced understanding of the intricate interplay of soil properties and dynamics within specific land areas (Shobayo *et al*., 2019). While generalized soil assessments offer some insights, the dearth of research tailored to the unique context of the TSU farm site creates a significant knowledge-gap.

Research in the field of agriculture emphasizes the importance of tailored studies to address specific local contexts. Studies like the assessment of seedling vigor in maize genotypes in Taraba State (Ibirinde *et al*., 2022) and the profitability of watermelon production diversification among smallholder farmers in the region (Dauda *et al*., 2022) highlight the significance of localized research in optimizing agricultural practices and enhancing productivity. The absence of such site-specific studies, as observed in the case of the TSU farm site, can impede the development of sustainable and efficient agricultural systems.

Despite numerous existing studies on soil assessment and management practices, there is still a significant gap in identifying specific soil properties and management strategies that are unique to the TSU farm site. This gap not only hinders the development of tailored recommendations for improving soil productivity and sustainability but also weakens agricultural resilience and food security (Obi and Ogunkunle, 2023).

With increasing environmental pressures, exacerbated by climate change and anthropogenic activities, the need to assess soil productivity becomes even more urgent. Studies in Nigeria have highlighted the adverse effects of various factors on soil quality and agricultural sustainability. For instance, research has shown that soil erosion hazards in southeastern Nigeria are influenced by soil properties such as clay content, organic matter levels, and sesquioxides (Igwe, 2012). Additionally, the loss of soil fertility due to factors like leaching of nutrients and changes in soil pH poses significant challenges to agricultural land productivity in oil-producing regions of Nigeria (Amaechi *et al*., 2022). Moreover, the impact of hydro geomorphological characteristics on gully formation in southeastern Nigeria has been noted to exacerbate environmental degradation and limit mitigation efforts (Egbueri and Igwe, 2020). These assessments act as safeguards against degradation, preserving ecosystem integrity, and ensuring the sustainability of agricultural practices. Therefore, this study is of utmost importance in closing this gap and providing site-specific insights that are essential for informed decision-making in promoting agricultural resilience and environmental conservation within the TSU farm site and beyond. This study aimed to conduct a focused pedological assessment, providing tailored recommendations for sustainable land management and increased agricultural productivity.

MATERIALS AND METHODS

Description of the Study Area

The study area is located near the Teaching and Research farm of Taraba State University in Jalingo, Taraba State, Nigeria (Fig. 1). The farm spans approximately 7.5 hectares and is situated

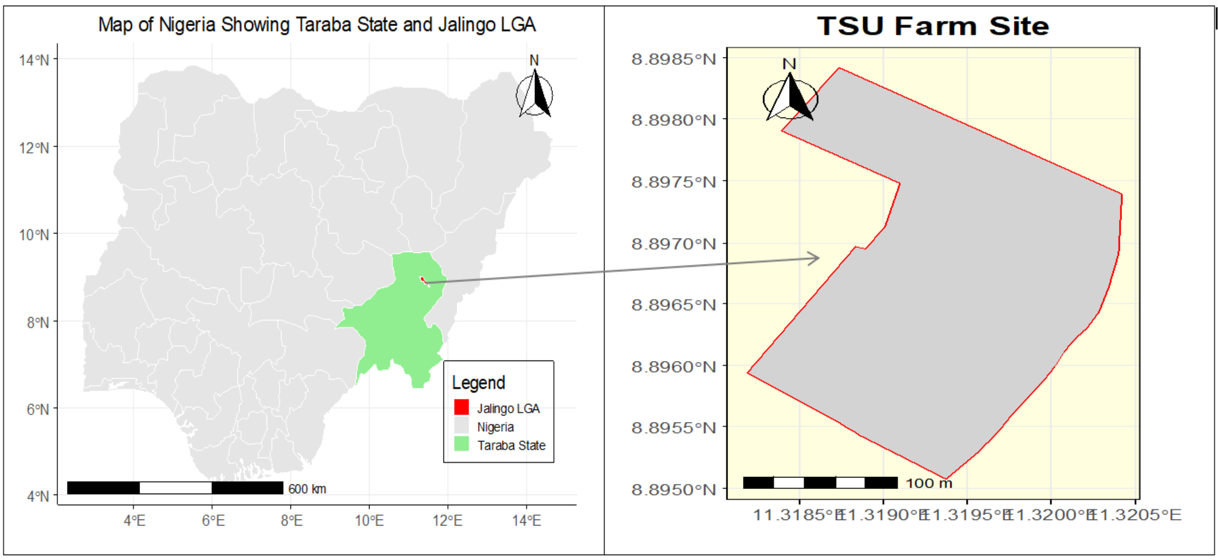

Fig. 1: Map of study area

at latitude 7°41'29.8"N and longitude 10°47'45.5"E. The soils in the area are highly weathered tropical soils, characterized by low fertility. Major soil types include Acrisols, Alisols, Cambisols, Ferralsols (Typic Haplustalfs and Typic

Psammaquent) which are sandy, acidic, and low in organic matter content (Kefas *et al*. 2023).

The topography of the area consists of undulating highlands with elevations ranging from 300 to 1000 meters above sea level. It features isolated hills, mountains, and plains, with a dendritic drainage pattern formed by numerous streams flowing into the Sardauna River (Ofomata, 1975). The region's geology is undifferentiated Basement Complex of metamorphic and igneous rocks (Ogezi, 2002), including gneisses, magnetites, porphyritic-granite, and pegmatite.

Climatic data were obtained from Jalingo airport, the nearest meteorological station (NIMET, 2009). The area experiences peak rainfall in July, August, and September, with high-intensity storms. The wet season lasts for 7 months, while the dry season lasts for 5 months with a mean annual rainfall which ranges from 800 mm in the northern part of the state to over 2000 mm in the southern part (Adebayo, 2012). Precipitation is lowest in January with an average of 217 mm. Mean annual temperature is 34˚C and varies in mean monthly values between 28.4˚C in the coolest month of December and 37˚C in the hottest month of March (NIMET, 2009).

The study area falls between the Southern and Northern Guinea Savannah zone and is characterized by sub-humid, broad-leaved savannah woodland with short to medium grasses. The vegetation has been significantly disturbed due to grazing, burning, tree felling, and cultivation. Major land uses include arable farming, forestry, logging, mining, livestock farming, and industrial and urban development.

Field and Laboratory Studies

Two soil profiles were excavated to length and breadth of 2.0 and 1.5 m, respectively and to depths of 120 and 100 cm (hard pans were encountered at the depths) in pedons 1 and 2, respectively at the Taraba State University Farm Site, Nigeria and horizon boundaries delineated. Pedon 1 was located at 8°53'46.1688"N, 11.19'7.41108"E, while pedon 2 was situated at 8° 53' 51.072"N, 11°19'9.71979"E. Soil samples were collected from the genetic horizons of each pedon and analyzed for particle size distribution and various chemical parameters in the laboratory.

Laboratory Analysis

In the laboratory, the soil samples were air-dried, crushed and sieved using a 2 mm mesh. The fine earth fraction (<2 mm) was used for laboratory analyses. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Soil pH was determined in soil: water and $CaCl_2$ ratio of 1:2.5 and determined with a glass electrode pH meter. Organic carbon was determined by Walkley and Black wet oxidation method (Udo *et al*., 2009), while total nitrogen was determined by the Macro - Kjeldahl digestion method (Udo *et al*., 2009). Determination of available P was carried out by Bray P1 (Udo *et al*., 2009), while exchangeable bases of Ca, Mg, K and Na were extracted in 1 *N* NH_4OAc at pH 7.0. Consequently, exchangeable K and Na were determined with the aid of flame photometer, while Ca and Mg were determined by EDTA titration method (Udo *et al*., 2009). Exchangeable acidity (Al^{3+} and H^+) were determined by using 1*M* KCl as the extracting solution and titrated against 0.01*M* NaOH (Udo *et al*., 2009).

Statistical analysis

Soil data were subjected to correlation analysis using GenStat (Windows 8.1 edition software) at 5 % level of probability.

RESULTS AND DISCUSSION

Particle size distribution

The results of particle size distribution of the soils are presented in Table 1. Sand content exceeded 500 g/kg in all horizons of the soils with values that decreased with soil depth in pedon 2 and irregular in pedon 1, while a range of 80 - 220 g/kg was obtained for clay with a trend that indicates accumulation in the B horizons. Such accumulations or bulges of clay (Fig. 2) in the B horizons are attributed to argillation, especially under such a tropical environment as Jalingo where conditions for fissures development and movement of clay materials in suspension are made possible. Such trends of decreasing sand and increasing clay in the B horizons have been reported in other studies within the Guinea savanna agroecological zone of Nigeria (Adesodun *et al*., 2008; Ige *et al*., 2015). These variations in particle size distribution have resulted in sandy loam surface and sandy loam to sandy clay loam subsurface textural classes, and agree with the findings of Smith *et al*. (2020) that soil texture varies laterally and vertically within landscapes due to differences in soil forming factors. Clay and silt content display a moderate positive correlation ($r = 0.65$, $p < 0.05$, Table 2), implying that as clay content increases, silt content also tends to increase, likely due to similar soil-forming processes affecting both particle sizes, such as weathering and sedimentation. According to Ige *et al*. (2015), application of organic matter is effective in improving soil physical conditions in sandy soils of northern Nigeria, especially as it concerns the incorporation of mulch which increases aggregate stability, infiltration rate and water holding capacity. The soil texture components show varied correlations with depth. Sand content has a weak negative correlation with depth ($r = -0.45$, $p > 0.05$), indicating a slight decrease in sand particles at greater depths, although this correlation is not statistically significant. In contrast, silt and clay contents show positive correlations with depth ($r = 0.57$, $p < 0.05$ and $r = 0.61$, $p < 0.05$, respectively), indicating an increase in finer particles, likely due to clay illuviation processes

Table 1: Particle size distribution of the soils

Horizon	Depth cm	Sand →	Silt g/kg	← Clay	Texture
Pedon 1: 8°53'46.1688"N, 11.19'7.41108"E					
Ap	0-14	680	240	80	SL
AB	14-32	700	200	100	SL
Bt	32-69	680	170	150	SL
BC	69-120	700	120	180	SL
Pedon 2: 8° 53' 51.072"N, 11° 19'9.71979"E					
Ap	0-20	660	220	120	SL
AB	20-38	640	160	200	SL
Bt1	38-53	540	240	220	SCL
Bt2	53-100	540	240	220	SCL

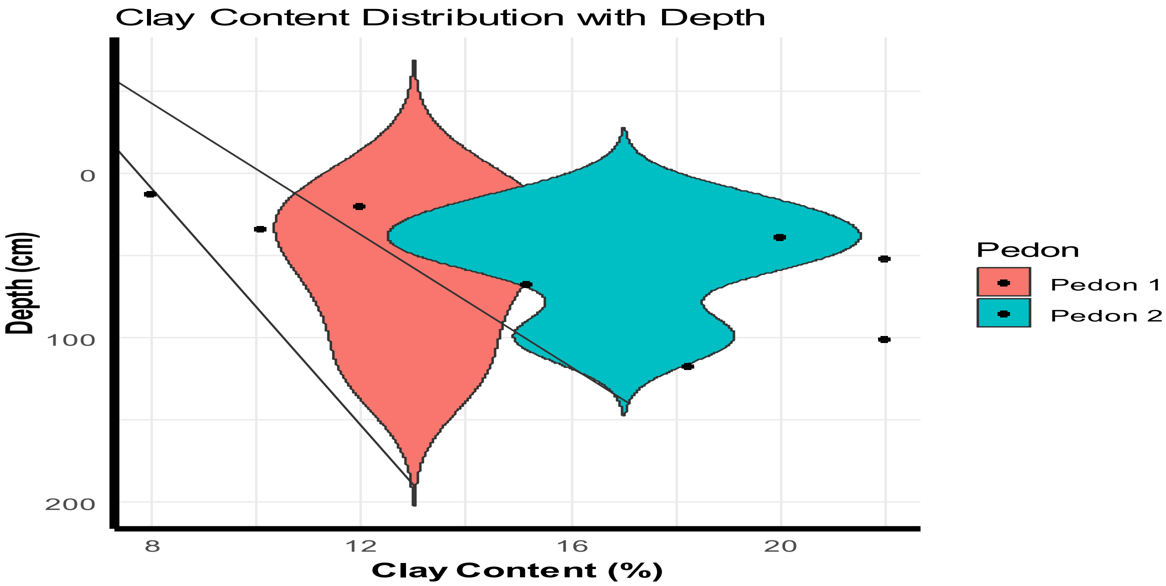

Fig. 2: Violin plot showing clay content distribution with depth

Chemical properties

The chemical properties of the soils are presented in Table 3 and the fertility ratings followed the ranking of Holland *et al.* (1989). Soil pH (water) ranged from 4.0 to 7.1 with values that place the soils in the extremely acid (< 4.5) and neutral (6.6-7.3) class. Irrespective of solution, soil pH values were higher in the surface soils (5.8-7.1) than the subsurface soils (4.0-5.6) with pH (water) appearing approximately 1 pH unit higher than values in $CaCl_2$. Low pH values imply high aluminum (Al^{3+}) saturation of the soil exchange complex which may inhibit root penetration and activities of soil organisms (Esu, 2010). This range of values indicates that the soils were moderately to slightly acid and neutral, and near the optimal range of values (5.5-6.5)

Table 2: Correlation matrix between the soil properties

	Sand	Silt	Clay	pHw	pHs	OC	OM	TN	P	K	Na	Mg	Ca	EA	ECEC	ESP
Silt	0.098															
Clay	-0.741	-0.446														
pHw	0.040	-0.071	-0.313													
pHCaCl2	0.059	0.050	-0.472	0.929												
OC	0.626	0.269	-0.916	0.397	0.489											
OM	0.632	0.275	-0.923	0.399	0.494	0.9990										
TN	0.624	0.276	-0.913	0.389	0.478	0.9990	0.999									
P	0.228	0.587	-0.533	0.445	0.438	0.559	0.559	0.566								
K	-0.143	-0.150	-0.128	0.469	0.555	0.052	0.058	0.038	-0.367							
Na	0.553	0.105	-0.774	0.726	0.820	0.736	0.743	0.725	0.337	0.471						
Mg	-0.577	-0.162	0.421	-0.255	-0.143	-0.439	-0.438	-0.439	-0.065	-0.111	-0.554					
Ca	-0.578	-0.180	0.440	-0.253	-0.149	-0.459	-0.458	-0.459	-0.073	-0.118	-0.563	0.999				
EA	0.464	0.259	-0.328	-0.698	-0.636	0.347	0.343	0.357	0.022	-0.542	-0.227	-0.173	-0.187			
ECEC	-0.592	-0.033	0.352	-0.255	-0.128	-0.341	-0.341	-0.338	0.070	-0.202	-0.543	0.979	0.974	-0.094		
ESP	0.552	0.065	-0.649	0.655	0.665	0.637	0.641	0.628	0.166	0.493	0.930	-0.795	-0.800	-0.180	-0.796	
BS	-0.669	-0.161	0.416	0.185	0.258	-0.473	-0.469	-0.479	-0.043	0.295	-0.266	0.842	0.846	-0.649	0.785	-0.477

Table 3: Chemical properties of the studied soils

Horizon	**Depth**	**pHw**	**pHCaCl$_2$**	**OC**	**OM**	**TN**	**Avail. P**	**K**	**Na**	**Mg**	**Ca**	**EA**	**ECEC**	**ESP**	**BS**
	Cm			**(g/kg)**	**(g/kg)**	**(g/kg)**	**(mg/kg)**	→		**cmol/kg**	←			**%**	**%**
Pedon 1	8°53'46.1688"N, 11.19'7.41108"E														
Ap	0-14	7.1	6.2	3.8	6.6	0.5	5.36	0.10	0.15	0.54	2.0	0.8	3.59	4.18	77.72
AB	14-32	5.0	4.3	2.7	4.7	0.4	6.22	0.06	0.10	0.70	2.6	1.2	4.66	2.15	74.25
Bt	32-69	4.0	3.4	2.5	4.3	0.4	3.89	0.07	0.08	0.92	3.4	1.4	5.27	1.52	73.43
BC	69-120	5.6	4.5	1.2	2.1	0.2	4.28	0.08	0.10	0.89	3.4	0.8	4.47	2.24	82.10
Pedon 2	8° 53' 51.072"N, 11° 19'9.71979"E														
Ap	0-20	5.8	5.1	3.0	5.2	0.4	6.27	0.06	0.10	1.46	5.4	1.0	8.02	1.25	87.53
AB	20-38	5.6	4.3	2.0	3.4	0.3	5.34	0.05	0.09	0.68	2.6	1.0	4.42	2.04	73.38
Bt1	38-53	5.8	4.5	1.3	2.2	0.2	5.12	0.08	0.07	1.18	4.4	0.8	6.53	1.07	87.74
Bt2	53-100	4.9	4.5	0.7	1.2	0.1	4.16	0.08	0.08	1.35	5.0	0.8	7.31	1.09	89.06

OC = Organic carbon, OM = Organic matter, TN = Total nitrogen, Avail. P = Available phosphorus, EA = Exchangeable acidity, ECEC = Effective cation exchange capacity, ESP = Exchangeable sodium percent, BS = Base saturation for microbial activities and plant growth (Esu, 2010). Kefas *et al*. (2020a, b) reported a similar range of pH for comparable soils in Jalingo. Soil pHw and $pHCaCl_2$ show a strong positive correlation ($r = 0.92$, $p < 0.01$, Table 2), indicating that both measures of soil pH are closely related and increase together, reflecting consistent patterns of soil acidity across different measures. With respect to soil depth, both pHw and $pHCaCl_2$ show strong negative correlations with depth ($r = -0.82$, $p < 0.01$ and $r = -0.86$, $p < 0.01$, respectively), suggesting that soil acidity decreases significantly with depth due to leaching of basic cations from upper sand dominated layers, leaving less acidic conditions in deeper layers.

Soil organic carbon was in the range of 3.0 - 3.8 g/kg in the surface soils and decreased continuously with increasing depth to 0.7 – 1.2 g/kg. Such surface values are very low and are a reflection of high temperature and rains in the study area which have enhanced organic matter mineralization. Such low soil organic carbon values are likely to render the soils infertile. This aligns with the report of FAO (2006) that inherently low soil fertility typifies the Guinea savannah agro-ecological zone. According to Udo *et al*. (2009), the high rate of decomposition of organic matter is a major factor controlling its accumulation in soils, while Igwe *et al*. (2007) and Obalum *et al*. (2012) reported that low values of organic matter are due to mineralization of organic matter due to high temperatures in the tropics. Furthermore, Kefas *et al*. (2020a) reported low values of organic carbon for similar well-drained soils, and comparatively higher values for soils at the foot slope position. Crop removal as a result of continuous cultivation over the years without recourse to replenishing lost nutrients via organic amendment could be responsible for the low values. Organic carbon (OC) and organic matter (OM) exhibit a very strong positive correlation ($r = 0.98$, $p < 0.01$), highlighting that organic carbon is a significant component of organic matter, which influences soil fertility, water retention, and microbial activity. Organic carbon (OC) and organic matter (OM) also exhibit strong negative correlations with depth ($r = -0.89$, $p < 0.01$ and $r = -0.90$, $p < 0.01$, respectively), indicating higher concentrations of organic material at the surface, which decrease with depth due to decomposition and root biomass distribution. Total nitrogen (TN) mirrors this pattern with a strong negative correlation ($r = -0.88$, $p < 0.01$), reflecting reduced biological activity and organic inputs in deeper soil layers.

Total N was within the range of 0.43 - 0.54 g/kg in the surface soils and continuously decreased with soil depth. Such values are classified as very low. Similarly, available P values were less than 8.0 mg/kg in the studied soils at all depths and qualified in the category of low. Total nitrogen (TN) also shows a strong positive correlation with organic carbon ($r = 0.90$, $p < 0.01$), suggesting that soils rich in organic carbon have higher total nitrogen content, essential for soil fertility due to its close association with organic matter decomposition. Low total N and available P may have been as a result of the very low organic matter content in the soils. Organic carbon, total N and available P often have similar and related distribution in most soils. This is because they are similarly sourced from organic matter and often have similar rating (Kefas *et al*., 2023). Kefas *et al*. (2020b, 2021) stated low levels of organic carbon, total N and available P in similar soils in Jalingo. Additionally, phosphorus (P) and organic carbon (OC) have a moderate positive correlation ($r = 0.70$, $p < 0.05$), indicating that higher organic carbon levels are associated with increased phosphorus content, reflecting the role of organic matter in phosphorus availability and cycling within the soil. Nutrient content, including phosphorus (P), potassium (K), sodium (Na), magnesium (Mg), and calcium (Ca), generally shows negative correlations with depth (ranging from -0.50 to -0.75, $p < 0.05$ for most), reflecting higher concentrations of these nutrients in the upper soil layers and a decrease with depth. This trend is significant for most nutrients, suggesting their association with organic matter and root uptake near the soil surface.

Exchangeable K^+ and Na^+ were less than 0.20 cmol/kg in the studied soils and classified as low, while exchangeable Ca^{2+} and Mg^{2+} were less than 5.5 and 1.5 cmol/kg, respectively in the studied soil and qualified as moderate. Such values are typical of soils in the humid tropics as most exchangeable cations seem to be leached under high rainfall condition and in soils dominated by sand. These have necessitated a somewhat moderate exchangeable acidity (0.8-1.4 cmol/kg). This is because, in sandy soils influenced by high rainfall, exchangeable basic cations are often lost to leaching leading to the accumulation of H^+ and Al^{3+}. In a study by Kefas *et al*. (2020a), similar levels for all the exchangeable basic cations in some Jalingo soils were obtained, while Ofem *et al*. (2020) intimated that high precipitation and mobility during chemical weathering are factors responsible for low exchangeable K in tropical soils. Effective cation exchange capacity ranged from 3.59-8.02 cmol/kg in the surface soil to 4.47-7.31 cmol/kg in the subsurface soils. These values are in the moderate range indicating a positive response to fertilizer application. Previous study in the region by Egila *et al*. (2011) described the soils of Taraba state as low in fertility condition. Ojeniyi (2000) had recommended the use of soil amendments and fertilizer application for sustainable agriculture in the study area. Notwithstanding the low to moderate exchangeable basic cations and effective cation exchange capacity of the soils, base saturation was greater than 70 % at all soil depths and rated high in the soils. This indicates that despite the low to moderate exchangeable cations, the cations were present in available forms for plant roots uptake (Akpan-Idiok and Ofem, 2014). In a related study in the area, Kefas *et al*. (2020b, 2021) reported low values (< 50%) for base saturation in similar soils. Exchangeable acidity (EA) has a strong negative correlation with depth ($r = -0.80$, $p < 0.01$), while effective cation exchange capacity (ECEC) also decreases with depth ($r = -0.77$, $p < 0.01$), indicating greater nutrient retention capacity in the surface layers due to higher organic matter and clay content. Exchangeable sodium percentage (ESP) shows mixed trends but generally decreases with depth ($r = -0.40$, $p > 0.05$), suggesting more sodium retention in the upper layers, though this correlation is not statistically significant. Base saturation (BS) exhibits mixed trends but is generally higher at the surface ($r = 0.42$, $p > 0.05$), reflecting more available basic cations (Ca, Mg, K, Na) due to organic matter and nutrient cycling, though this correlation is not statistically significant.

CONCLUSION

This study pedologically assessed two pedons within the Taraba State University farm located in Jalingo, Taraba State, Nigeria to characterize the soils with respect to their particle size distribution and chemical properties for sustainable agriculture and land management. The results indicate soils that are dominated by sand-sized particles and are low in organic carbon, total N and available P as well as low exchangeable K^+, Na^+ and moderate exchangeable Mg^{2+} and Ca^{2+}. Furthermore, effective cation exchange capacity was also low, while base saturation was high. Such soil property ratings may not favour optimum crop production in the area and the soils may require mulching, use of compost and adopting other soil conservation practices like cover cropping, and reduced tillage could help maintain soil quality over the long term.

REFERENCES

Adebayo, A. A. (2012). Evidence of climate change in Taraba State: A preliminary report. Paper, Faculty of Science Seminar Series, held 13th September, Jalingo, Nigeria, p. 212

Adesodun, J. K., Agboola, A. A., and Ayotade, K. A. (2008). Effects of particle size composition on water retention capacity of some tropical sandy loam and sandy clay loam soils of Southwestern Nigeria. *World Journal of Agricultural Sciences*, 4(3), 353-357.

Akpan-Idiok A.U. and Ofem K.I. (2014). Physicochemical characteristics, degradation rate and vulnerability potential of Obudu cattle ranch soils in Southeast Nigeria. *Open J. Soil Sci*., 4, 57-63

Amaechi, F. C., Onyekuru, N. A., Odurukwe, S. N., Umeanaeto, P. U., and Nwite, J. N. (2022). Effects of oil exploration on soil fertility in Ohaji/Egbema Local Government Area of Imo State, Nigeria. *Global Ecology and Conservation*, 33, e02069.

Dauda, T. S., Adewumi, M. O., and Oluwatayo, I. B. (2022). Profitability of watermelon production diversification among smallholder farmers in Taraba state, Nigeria. *Journal of Global Agriculture and Ecology*, 9(1), 14-23.

Egbueri, C. C., and Igwe, C. A. (2020). Hydro geomorphological factors influencing gully erosion in Enugu South-eastern Nigeria. *Nigerian Journal of Technology (NIJOTECH),* 39(2), 459-467.

Egila, J. N., Daniel, I. C., and Sallau, A. B. (2011). Evaluation of soil fertility status in Kaltungo and Ardo-Kola Local Government Areas of Taraba State, North-East Nigeria. *Australian Journal of Basic and Applied Sciences*, 5(9), 478-484.

Esu, I. E. (2010). Soil characterization, classification and survey. Hinneman Educational Book Publishers Plc. Nigeria. Pp. 232

FAO. (2006). World reference base for soil resources. A framework for international classification, correlation and communication. World Soil Resources Reports No.103. FAO, Rome. Pp. 128

FAO. (2001). Food and Agriculture Organization of the United Nations. Land and Water Digital Media Series No. 29. Improving productivity and market success (PACKAGE) of agricultural systems. Rome, Italy. Pp. 213

Gee, G. W and Bauder, J. W. (1986). Particle Size Analysis. Methods of Soil Analysis Part I. Physical and Mineralogical Methods. Pp. 404.

Holland, M. D. G., Barton, A. D and Morph, S. T., (1989). Land Evaluation for Agricultural Recommendation of Cross River National Park. Oban Division, prepared by Odwki, in collaboration with INNF, 7: 34 - 76

Ibirinde, A. O., Kwaghe, V. Y., Odeh, M. N., and Makinde, S. C. (2022). Assessment of seedling vigor in maize (Zea Mays L.) genotypes at three locations in Taraba State, Nigeria. *Science Alert*, 9(2), 117-128.

Ige, D. V., Agboola, O. O., and Ogundele, F. O. (2015). Evaluation of Different Tillage and Mulching Methods on Maize Production in Savanna Agro-Ecosystem. *Nigerian Journal of Agriculture, Food and Environment,* 11(1): 45 - 51

Igwe, C. A. (2012). Soil properties influencing erosion hazard in Enugu Southeastern Nigeria. *Agricultural Science Research Journals*, 2(3), 73-85.

Igwe C.A., Ekebosi G.O., Zarei M. and Stahr K. (2007). Mineralogy and pedogenesis in a soil chrono-sequence on a floodplain, eastern Nigeria. *Agro-Science*, 6 (2): 1-15

Kefas P.K., Maigida E., Ezeaku V.I., Ofem K.I. Akwoga J.A. and Ezeaku P.I.

(2020a). Land suitability evaluation for maize production and taxonomic classification of soils overlaying undifferentiated basement complex in Northeast Nigeria. *Nigerian Journal of Soil Science*, 30 (1): 42-52

Kefas P.K., Ali S., Ofem K.I. and Umeugokwe C.P. (2020b). Genesis and classification of soils along a topo sequence in the Teaching and Research Farm of Taraba State University, Jalingo, Nigeria. *Global Journal of Agricultural Science*, 19: 33-43. https://dx.doi.org/10.4314/gjass.v19i1.5

Kefas P.K., Shobayo A.B., Ofem K.I., Akwoga J.A., Asadu C.L.A. and Ezeaku P.I. (2021). Influence of forms of Fe and Mn oxides on the physical and chemical properties of soils formed over mica-schist in a northern Guinea Savanna, Nigeria. *Nigerian Journal of Soil Science*, 31 (1): 25-35

Kefas P. K., Ofem K. I., Hammanjoda A. and Garjila Y. A. (2023). Characterization and classification of three major soils at the College of Agriculture, Jalingo, Taraba State, Nigeria. *Agro-Science*, 22 (1), 10-16. DOI: https://dx.doi.org/10.4314/as.v22i1.2 Agro

NIMET (2009). Climate Review for Jalingo. Nigerian Meteorological Agency, Abuja. Nigeria.

Obalum S. E., Nwite J.C., Watanabe Y., Igwe C.A. and Wakatsuki T. (2012). Comparative topsoil characterization of sawah rice fields in selected inland valleys around Bida, north-central Nigeria: physicochemical properties and fertility status. *Tropical Agricultural Development*, 56 (2), 39-48. https://doi.org/10.11248/jsta.56.39

Obi, M. E., and Ogunkunle, A. O. (2023). Soil health and agricultural sustainability: Challenges and opportunities. *Sustainability*, 15(1), 95: 34 - 43

Ofomata, G. E. K. (1975). Morphostructural subdivisions of Nigeria. In Geology of Nigeria (ed. C. A. Kogbe), 72–78. Rockview (Nigeria) Limited.

Ogezi, A. O. (2002). Geology and mineral resources of Taraba State, Northeastern Nigeria: a reconnaissance report. Technical Report submitted to the National Water Resources Institute, Kaduna, Nigeria. Pp. 202

Ojeniyi, S. O. (2000). Effect of goat manure on soil phosphorus and crop performance in the southern guinea savanna zone of Nigeria. *Applied Tropical Agriculture*, 5, 11-13.

Shobayo, O. D., Jimoh, A. A., and Ademola, S. A. (2019). The fundamentals of pedology and soil survey. In Ecology and restoration of degraded ecosystems. Academic Press. Pp 3-45.

Smith, S. V., Parsons, A. J., Thornes, J. B., Wainwright, J., and Oades, J. M. (2020). How geomorphology controls soil properties: a theory of stratification. *Geoderma*, 365, 114238.

Udo E.J., Ibia T.O., Ogunwale J.A., Ano A.O. and Esu I.E. (2009). Manual of Soil, Plant and Water Analysis. Sibon Books Ltd., Lagos, Nigeria. Pp. 102

SUITABILITY EVALUATION OF SOILS OF AWE FLOOD PLAIN FOR SUGARCANE PRODUCTION IN NASARAWA STATE, NIGERIA

[1]Azagaku E.D*., [2]Usman J., [1]Usman I.N., and [1]Michael A.P
1.Department of Crop Production Technology, College of Agriculture, Science and Technology, Lafia, Nasarawa State, Nigeria
2.Department of Soil Science and Land Resource Management, Federal University, Wukari, Taraba State, Nigeria
Corresponding author email:Azagakuemmanueldominic@gmail.com

ABSTRACT
The morphological, physical, chemical properties and suitability ratings of the soils were examined to suit the requirements of sugarcane production. To achieve these objectives, A reconnaissance survey was carried out in the area. Three profile pits were sunk in each of the topographic positions (Jangwa and Gidan Tindin), giving a total of 6 profile pits. Soil samples were collected from identified soil horizons into polythene bags carefully labelled and taken to the laboratory for physical and chemical analysis such as particle size distribution, pH, organic carbon, CEC, EB, TN, available P, ECEC, base saturation, particle size distribution, pH, organic carbon, CEC, exchangeable bases (Ca, Mg, K and Na), total nitrogen and available P using standard laboratory procedures. Suitability evaluation of the soils was carried out using the guidelines of the frame work for land evaluation using the limitation method. The results shows that the soils were deep (101 cm – 170 cm) and well drained. The soils were weakly acidic and slightly alkaline (PH 5.10 – 7.15). The percentage sand fraction ranged from 44.8% to 83.1%; silt 5.4% to 9.4% and clay 9.4% to 46.7%. They had low to moderate organic carbon (0.41% to 3.52%); total N (0.04% to 0.11%); available P (1.64 mg kg^{-1} to 3.72 mg kg^{-1}), total exchangeable bases (2.85cmol kg^{-1} to 7.97 cmol kg^{-1}), CEC (4.10 cmol kg^{-1} to 7.98 cmol kg^{-1}), base saturation (65% to 97.5%) and Fe^{2+} (1.10 µmol $l^{-1}$to 2.11 µmol l^{-1}). Soils of the three flood levels were rated highly suitable ($S_{1)}$ because of the soils ability to retain water during the growth period with the favourable physical and chemical characteristics. In conclusion, the soils in the study area can used for sugarcane production with nutrient supplements such as organic or inorganic fertilizers.
Keywords: Soil, Awe, Nasarawa, flood plain and Sugarcane.

INTRODUCTION

Nasarawa State is an agrarian state with enormous agricultural potentials. The state is located in the Southern Guinea Savannah vegetation zone which supports virtually all crops. Areas around the eastern part of the state have major rivers like River Bakin Kogi, River Shankodi, River Ankwe and River Wuse (Asu River group). These rivers provide a wide floodplain that is low-lying, stretching from Jangwato Gidan Tindi where Seasonal floods enrich the soils with nutrients as well as water through surface floods and seepage, from the rivers. This area is widely known for sugarcane production. Sugarcane is one of the major sources of income to farmers who are engaged in small land areas of about 0.4 hectares on the average (Ufot, 2012). Its demand for domestic consumption, ceremonial purpose, economic growth, and export for foreign exchange return is on the increase along with low production and discouraging yield (Ogbu, *et al*., 2019). This could be partly attributed to incessant crop failure in recent times due to low output caused by flood and drought despite the seemingly excellent environmental conditions for sugarcane production. The apparent effects of this observed trend are more significant pressure on the wetland soils,

Generally, farmers need adequate information on soil properties which will significantly help in the management of the soil and its suitability rating for the crop (Idoga and Ogbu, 2012). Parcels of land vary in their suitability for use and adaptable management. For sugarcane production, edaphic factors (soil) and climatic factors like rainfall and temperature are critical for farmers to obtain maximum yield on their farms. Ogunkunle (1993); Olaleye *et al*., (2002) and Oluwatosin (2005) reported that soil fertility is the major limitation to the suitability of Nigerian soils. Therefore, this research is therefore designed to evaluate the suitability of the flood plain soils of Awe for sugarcane production.

MATERIALS AND METHOD

Study Area

The study area is is located in Awe LGA (as shown in figure 1 below), south- eastern block of Nasarawa State stretching from Jangwa in the North East to Gidan Tindin the South. The land area is geomorphologically referred to as Jangwa flood Plains. It lies between latitude 7º 45ʹ and 9º 25ʹ N and longitude 7º32ʹ and 9º 37ʹ E and covers a total area of over 22,000 hectares of Fadama along Rivers Shankodi, Wuse and Ankwe (ASU river group). Two principal air masses influence the climate of the area. The south west maritime wind which originates from the Atlantic Ocean blows across Lafia between April and October and is associated with the wet season while the dry season which starts from November to March is brought about by the north eastern wind locally called harmattan. Wet or rainy season is fairly long and well distributed lasting for about seven months in the year.

Nassarawa State experiences two rainfall peaks, July and September, separated by moderate decrease in August known as August break (Hill, 1979). Annual rainfall in the area is between 1143 mm and 1270 mm. The monthly maximum mean air temperature was highest (36.4 º C) in the period prior to the onset of rains in March/April and lowest (22.9 ºC), during the period of heaviest rainfall in August, Jangwa flood plain is drained by Asu group of rivers and its tributaries. The river which runs north –south forms a dendritic drainage system with its tributaries. The slope of the area is about 0 to 2% and the elevation above mean sea level is about 93 m (Hill, 1979). The study area consists of extensive flood plains dissected by rivers, Bena, Gbagbok rivers, (Jangwa) while Abanbu, Hunki (Gidan Tindi) which drain dendrically into river Katsina-Ala in Benue State. River Wuse forms the major drainage pattern of the area. It rises from the Jos Plateau (River depth) and empties into river Ankwe a tributary of River Benue. The extensive flood plain is bordered to the north by the escarpment of the Jos plateau. The plain continues south wards to River Benue, westwards to the rolling plains of Lafia and eastward to River Maiburugu. There are few isolated lateritic mesas in the area. The Jangwa flood plain has an abrupt boundary with the Namu formation and Benue piedmont which is predominantly made of cretaceous shales (Fagbemi and Akamigbo, 1986).

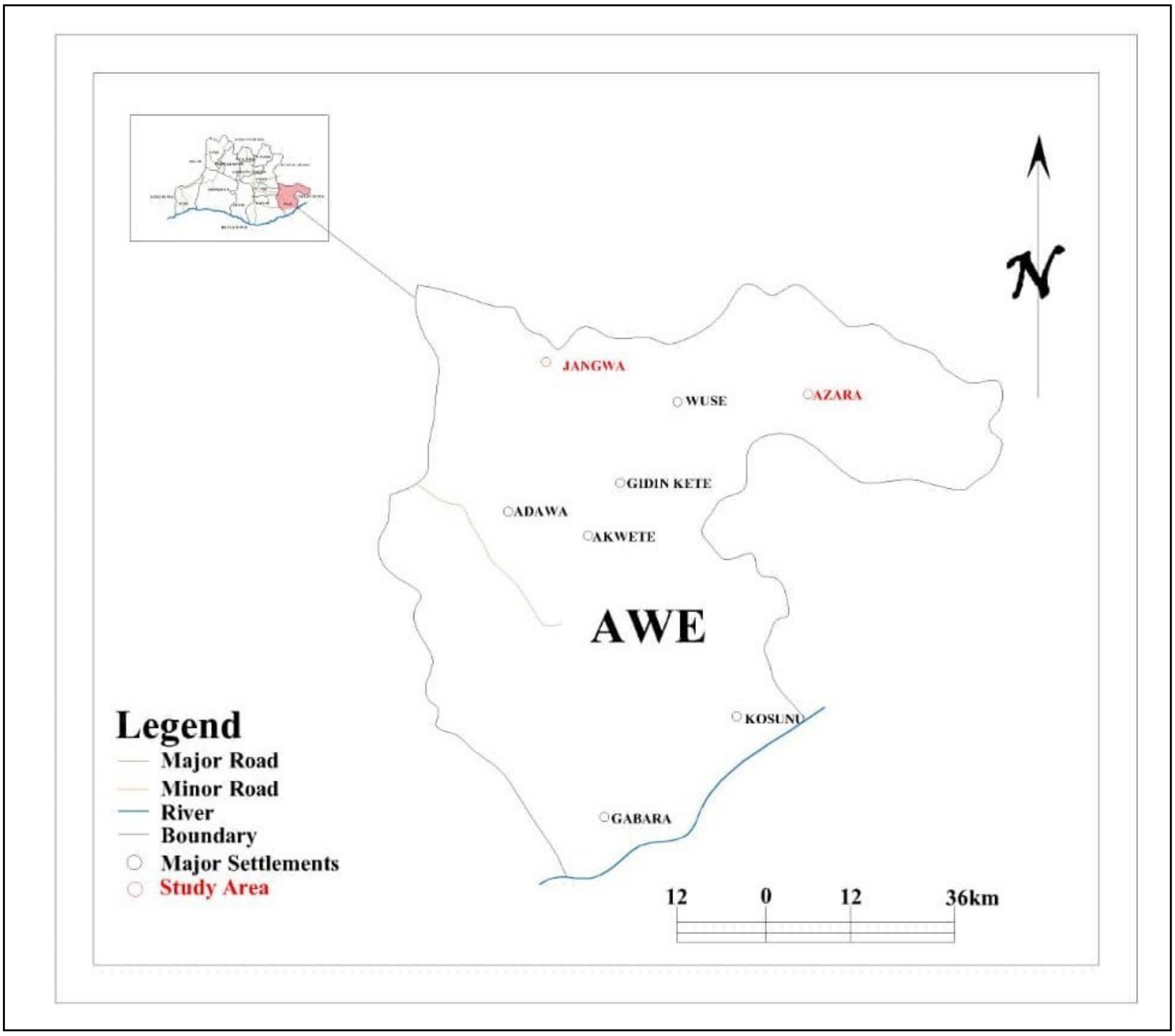

Figure 1: Awe LGA

Treatments and experimental design

The treatments consist of the study area which is divided in to two: Jangwa North and Gidan Tindi (which is Jangwa south), where soil samples were collected using methods profile pits and auger. The experiment was replicated three times. Suitability evaluation of the soils was carried out using the limitation method.

A reconnaissance survey was carried out in the area. Based on the local relief/drainage, three soil units were mapped (as shown in figure 2) out as soils on Levee, soils of the lower slope from the surrounding upland and the soils over toe slope between the lower slope and the levee corresponding to shallow swamp (>0 cm), medium swamp (lower slope) (0-50 cm), and deep swamp (>50 cm).

Data collection and Laboratory Studies

Soil samples were collected from three replicates of each of the treatments and taken to laboratory for physico-chemical analysis. The air dried, crushed and sieved (<2 mm) samples were analysed for particle size distribution, pH, organic carbon, CEC, EB, TN, available P, ECEC and base saturation (table 1and 2) following the procedures described in IITA (2015).

An Auger point investigation was carried out across the slope according to the topographic positions mentioned above. Three profile pits were sunk in each of the topographic positions (Jangwa and Gidan Tindi) as seen in figure 2, giving a total of 6 profile pits. Each profile pit was described according to the guideline for soil profile description and samples collected from identified soil horizons into polythene bags carefully labelled and taken to the laboratory for physical and chemical analysis. The samples were air dried, crushed and sieved (diameter <2 mm sieve). The samples were analysed for particle size distribution, pH, organic carbon, CEC, exchangeable bases (Ca, Mg, K and Na), total nitrogen and available P. PSD was determined by Bouyoucos hydrometer method (Day, 1965). Soil pH was determined by electrometric methods as described by IITA (2015). Walkley- black method as described by Nelson and Sommers (1982) was employed for organic matter content. Total nitrogen was determined using the modified macro-kjeldahl method as described by IITA (2015). Bray-1 method as described by IITA 2015 was used for extractable P.

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Land Evaluation

Suitability evaluation of the soils was carried out using the guidelines of the frame work for land evaluation (FAO, 2007). Climate (annual rainfall and temperature), topography (slope) and soil physical and chemical characteristics (soil depth, texture, drainage, pH, available P, total N, Organic Matter, CEC, BS and soil type) were key factors considered in the evaluation (Fasina and Adeyanju, 2006; Ritungs *et al*., 2007). Using a simple limitation method, the identified soil units were placed in suitability classes by matching their characteristics with the requirements of the crop (Sugarcane). The profile descriptions summarizing the soil characteristics were presented in table 3 and table 4 to give over view of the soil information alongside other land characteristics in order to arrive at aggregate suitability classes. The suitability of each factor for respective soil unit was classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and/or not suitable (N)

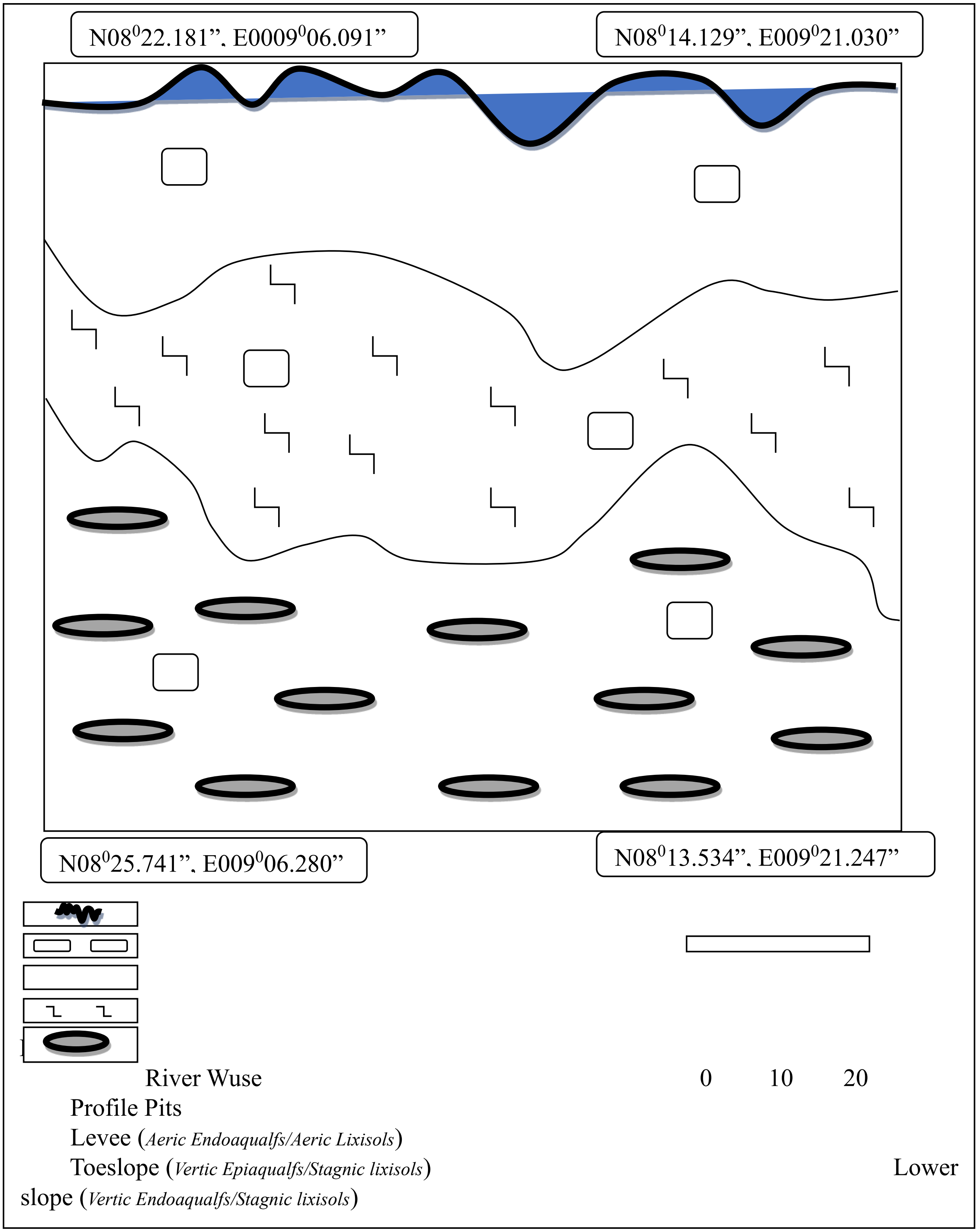

Figure 2: The study area

RESULTS AND DISCUSSIONS

Morphological and Physico-chemical Properties of Soils of the Study Area

The major surface characteristics are gilgai micro-relief and poor drainage as indicated by the presence of mottles at the surface. Soil structure is well developed and soil texture is generally sandy clay loam to clay loam at surface and clay at subsurface. The surface soil is moderate- fine subangular blocky to strong subangular blocky at the subsurface for soil in unit 1. Soils in unit 2 (lower slope flood level) were generally low-lying and nearly flat and covers about 35% of the study area. The texture is generally clay loam to loamy sand to sandy loam at the surface and clay loam to clay at subsurface. In the case of unit 3 (Levee flood level), it is located by the river bank and relatively more elevated and nearly flat. The soils in Jangwa and Gidan Tindi are somewhat poorly drained. Soil texture is sandy clay loam at surface and clay at subsurface. Soil structure is well developed being medium subangular blocky at the surface and at subsurface is strong coarse subangular blocky.

Generally, the soils ranged from low to high clay content. The values of the surface horizons ranged from 8.6% to 34.6%. The relatively high clay content could be due to nature of the underlying geological materials (shales). The Awgu Shales are presumed to have constituted the underlying geology of the area (Idoga, 2005). Clay is the dominant mineral in shale and therefore tends to accumulate when shale weathers (Idoga and Azagaku, 2005). Alluvium is another geologic material in the area, being an inland depression. The fine materials are deposited here probably because of the reduction in the velocity of flow of rivers due to low slope gradient. Sand fraction was most the dominant particle size at surface and subsurface horizons in all the mapping units. The high sand fraction is a feature of most savannah soils due to eluviations and illuviation processes as well as the effect of erosion and lessivage (Igwe and Agbatan, 2007). Soils with high sand fractions are vulnerable to erosion because they can easily be detached where heavy down pour and running water are frequent. The silt fraction was irregular with depth in AP, B, Bt_1, Bt_2, Bt_3, A, AB, B and BC due to the rate of materials brought by flood (flash and river flood). The PH values generally across the study area indicate that the soils were moderately acidic to slightly alkaline in reaction (5.10 – 7.15). This pH levels suitable for sugarcane production as described by Maniyunda *et al.* (2015) that fall within the range of 4.5 – 7.5 is considered highly suitable for sugarcane production. Therefore, the range covered in the study in table 2 is close to these values, hence it is also considered highly suitable for sugarcane production. The pH values decreased with increase in soil depth from surface to subsurface in Jangwa and Gidan Tindi. This decrease with depth may probably be due to the effect of nutrient biocycling (Ogunwale *et al.,* 2002; Idoga and Azagaku 2005) the exchangeable bases increased with increase in soil depth. The percentage organic carbon content in the study area was low to moderate, it ranged from 0.41 to 3.62. The values decreased with depth in all the Pedons due to the concentration of plant roots and plant residues on the topsoil. The low values may be attributed to the "aquic moisture" conditions of the flood plains, which reduce soil temperature and consequently lower the rate of organic matter decomposition (Idoga and Azagaku, 2005; Dengiz, 2010). Total Nitrogen values of the soil ranged from 0.05 to 0.11%. This is rated low at the surface and high in the subsurface (Esu*,* 1991). The phosphorus content of the study area was extremely low with values ranging from 1.64 to 3.72mg/kg. The low values however agree with the views of (Brady and Ray 2014) that the total quantity of phosphorus in most native soil is low, with most of it present in the form quite unavailable to plants. The low available phosphorus may be attributed to low amount of organic carbon of the flood plains. The exchangeable bases (Ca, Mg, K and Na) in the study area were low. The low exchangeable bases may be attributed to the nature of the underlying materials, intensity of weathering, scorching, low activity clay very low organic matter content, surface runoff and the lateral translocation of bases. The CEC values ranged between 4.10 and 7.98cmol/kg^{-1}. The CEC of the soils of the study area was low to medium according to ESU (1991) rating of <6 = low, 6-2 = medium and <12 = high. The low CEC values of the soils could be attributed to the nature of the silicate clay minerals Kaolinite believed to be the dominant clay type as reported by Hassan *et al*. (2011) and Obini,and Adeniyi, (2020). The percentage base saturation values of the soils (65 to 97.5%) were rated moderately high to very high. The distribution of base saturation is irregular in all the units. This could be attributed to the active plant litter decomposition which could incorporate cations from the litter into the soil (Idoga, 2002).

Suitability Status of Soil of the Study Areas for Sugarcane Production

Suitability ratings of both locations of study as it influenced the cultivation of sugarcane are shown in Table 3. The assessment ratings resulting from matching of land qualities and their requirements for sugarcane is presented in table 4, using the FAO (2007) suitability ratings. The annual rainfall for Jangwa and Gidan Tindi was highly suitable (S_1) except where no adequate rainfall during the cropping season during the year they may experience drought where no adequate rainfall (S_3). Mean Temperature for jangwa and Gidan Tindi was high and suitable for sugarcane (S_1) on the basis of texture, Jangwa and Gidan Tindi were highly suitable. The slope <3% of Jangwa and Gidan Tindi were highly suitable (S_2). However, slope of <3% may favour mechanical operations (Fasina and Adeyanju, 2007). The entire Pedons were moderately drain (S_2) for sugarcane production.

On soil reaction (pH), jangwa and Gidan Tindi were highly suitable (S_1). Base saturation was high across both locations; which indicates high fertility in the areas. This could be as a result of the non-acidic condition of the soils. Soils with high base saturation percentage have high pH and are more buffered against acid conditions for plant roots and they also contain greater amount of the essential plant nutrients for use by plants (Agber *et al.,* 2017). Considering nutrient retention ability (CEC) Jangwa and Gidan Tindi were marginally suitable (S_3). Organic carbon content of Jangwa and Gidan Tindi were marginally low (S_2). Total nitrogen was moderately suitable (S_2) in some Pedons of Jangwa and Gidan Tindi and marginally low (S_3) for some Pedons as well. Available P were marginally low (S_2) for Jangwa and Gidan Tindi Ca, K+ and Na2+ were moderately suitable for both locations (S_3). Magnesium were highly suitable (S_1) in Jangwa and Gidan Tindi. All the soil Pedons were highly suitable (S_1) with regards to salinity and sodicity status.

Table 1 Morphological Description of the study area (2015 and 2016)

Depth	Munsell colour (moist)	Mottling	Texture	Structure	Boundary	Inclusions	Consistency	Remarks
Profile 1: Toeslope – Vertic Epiaqualfs/stagnic lixisols								
0 – 32	10YR 2/2		SCL	2msbk	CS	Common fine roots	SSW	
32 – 57	10YR 3/2	10YR 3/1fif	C	2msbk	GS	Common fine roots	VSW	
57 – 96	2.5Y5/2	10YR 5/8cif	C	2msbk	GS	Common fine roots	VSW	
96 – 120	2.5Y 5/3	10YR 6/4cif	C	2msbk	GS	Fine roots	VSW	
120 – 170	10YR 4/4	7.5YR 4/6cid	C	2msbk	GS	Fine roots	SW	
Profile 2: Toeslope – *Vertic Epiaqualfs/stagnic lixisols*								
0 – 35	10YR 2/2		CL	2msbk	CS	Many fine and medium roots	SSW	
35 – 61	10YR 3/3	7.5YR 4/4fif	C	2msbk	GS	Common fine and medium fine roots	VSW	
61 – 94	2.5Y 5/6	7.5YR 6/4cif	C	2msbk	GS	Fine roots	VSW	
94 – 122	2.5Y 5/2	10YR 5/8cid	C	2msbk	GS	Few fine roots	VSW	
122 – 170	2.5Y 5/6	10YR 5/8cid	C	2msbk	GS	Few fine roots	VSW	
Profile 3: lower slope – *Vertic endoqualfs/stagnic lixisols*								
0 – 10	10YR 5/4		LS	2msbk	CS	Common fine root	SSW	
10 – 22	7.5YR 4/4		LS	2msbk	GS	Few fine roots	VSW	
22 – 89	7.5YR 5/6		SL	2msbk	DS	Few fine roots	VSW	
89 – 101	7.5YR 4/6		SCL	2msbk			SW	

Table 1 Continue

profile 4: lower slope – *Vertic endoqualfs/stagnic Lixisols*

Depth	Munsell colour (moist)	Mottling	Texture	Structure	Boundary	Inclusions	Consistency	Remarks
0 – 14	10YR 4/2		SL	3csbk	GS	Common fine roots	SSW	
14 – 25	10YR 5/6		SL	3csbk	GS	Common fine roots	VSW	
25 – 78	7.5YR 4/6		SL	3csbk	GS	Common fine roots	VSW	
78 – 110	10YR 5/8		SL	2msbk	GS	Few fine roots	VSW	
110 – 150	7.5YR 6/4		SCL	2msbk	GS	Few fine roots	VSW	
Profile 5: Levee – *Aeric Endoaqualfs/Aeric Lixisols*								
0 – 22	10YR 4/2		SCL	3csbk	CS	Many fine and medium roots	VSW	
22 – 57	10YR 5/6		SCL	2msbk	DS	Common fine roots	VSW	
57 – 89	10YR 4/3		SCL	2msbk	DS	Common fine roots	VSW	
89 – 101	2.5Y 5/1	10YR 6/3	SCL	2msbk	DS	Few fine roots	VSW	
101 – 150	5YR 3/2		LS	2msbk	DS	Nodules	VSW	
Profile 6: Levee – *Aeric Endoaqusalfs/Aeric Lixisols*								
0 – 22	10YR 2/2		CL	3csbk	CS	Many fine and medium roots	SW	
22 – 53	10YR 5/6	7.5YR4/6	CL	2msbk	CS	Common fine roots	VSW	
53 – 92	10YR 5/6	2.5Y5/6	CL	2msbk	DS	Fine roots	VSW	
92 – 115	10YR 5/2		CL	2msbk	DS	Fine roots	VSW	

Mottling Details:
FIF = Few fine faint, C2D = Few Common medium distinct, M3P = Many coarse prominent, C3P = Common coarse prominent
Texture
S = Sandy, C = Clay, SL = Sandy Loam, SCL = Sandy Clay Loam, SC = Sandy Clay
Structure
3CCR = Strong Coarse Crumb, 2CCOr = Moderate Coarse Crumb, 2MCR = Moderate Medium Crumb, 2MSBK = Moderate Medium Subangular blocky, 2MFBK = Moderate Fine Subangular Blocky, 3 CSBK = Strong Coarse Subangular Blocky, 3MSBK = Strong Medium Subangular Blocky
Consistence
SSW = Slightly Sticky Wet, VSW = Very Sticky Wet, VPW = Very Sticky Wet, SW = Stick Wet, NSW = Non-Sticky Wet, NPW = Non-plastic Wet
Inclusion
C2F = Common Medium Faint, M2D = Many Medium Distinct, F1F= Few Fine Faint, C3D = Common Coarse Distinct
Boundary
DS = Diffuse smooth, GS = Gradual Smooth, CS = Clear Smooth, AS = Abrupt Smooth
Colour
DB = Dark Brown, VDGB = Very Dark Grayisn Brown, LB = Light Brown, SB = Strong Brown, RY = Redishn Yellow, BRB = Dark Redish Brown, RG = Redish Green, DYB = Arkn Yellowish Brown, G = Gray, B = Brown

Table 2: Some Physical and Chemical Properties of the Study Area

Horizon	Depth (cm)	Particle Size dist Sand	Silt	Clay	Texture	pH H2O	Org. C	Total N %	Avail. P Mg/kg	Exchangeable Bases Ca	Mg	K	Na	TEB	CEC	BS %	Fe
		→ (%) ←								→ Cmol /kg ←							
Profile 1: Toeslope *Vertic Epiaqualfs/stagnic lixisols*																	
Ap	0-32	62.0	7.4	30.6	SCL	7.10	3.62	0.06	3.35	1.82	1.34	0.86	0.77	4.79	4.89	72	1.25
B	32-57	48.0	7.6	44.4	C	6.99	1.6	0.07	3.26	2.94	1.86	0.93	0.56	6.29	6.29	78	1.10
Bt_1	57-96	47.0	6.4	46.6	C	6.98	2.54	0.08	2.21	3.67	2.48	0.89	0.03	7.97	7.98	91	1.46
Bt_2	96-120	49.0	7.4	43.6	C	5.86	0.72	0.06	2.42	2.47	1.65	0.42	0.84	5.38	5.49	72	1.45
Bt_3	120-170	47.0	5.4	47.6	C	5.53	2.10	0.04	1.67	1.64	1.34	0.64	0.53	4.15	4.26	65	1.50
Profile 2: Toeslope -*Vertic Epiaqualfs/stagnic lixisols*																	
Ap	0-35	52.1	8.0	30.9	CL	7.15	2.65	0.05	3.56	2.34	1.86	0.95	0.82	5.97	5.98	73	1.60
B	35-61	50.0	7.1	42.7	C	6.58	2.88	0.08	2.25	2.78	2.02	0.41	0.36	5.55	5.67	65	1.76
Bt_1	61-94	44.8	8.4	46.8	C	6.24	1.54	0.06	3.51	3.37	2.62	0.82	0.72	7.53	7.33	91	1.72
Bt_2	94-122	48.0	7.3	44.7	C	5.25	2.72	0.05	2.62	3.43	2.14	1.58	0.42	7.57	7.69	77	1.98
Bt_3	122-170	48.0	6.6	43.4	C	5.14	1.25	0.04	2.42	2.34	2.31	0.32	0.64	4.45	4.74	81	2.01
Profile 3: Lower slope-*Vertic endoqaualfs/stagnic lixisols*																	
A	0-19	86.0	5.4	8.6	LS	6.89	1.65	0.04	3.29	3.68	1.42	0.46	0.55	5.06	7.26	69.9	1.43
AB	10-22	79.0	7.4	13.6	LS	6.85	0.61	0.08	3.61	3.66	2.41	0.35	0.37	6.33	6.98	91.0	1.39
B	22-89	75.0	6.5	18.5	SL	6.75	1.59	0.06	3.72	3.65	1.36	0.36	0.18	5.59	6.57	83.3	1.28
BC	89-101	61.0	8.2	30.8	SCL	6.13	2.52	0.05	2.55	3.15	1.20	0.30	0.24	4.91	6.38	77.2	1.56

Table 2 continues

Horizon	Depth (cm)	Particle Size dist Sand	Silt	Clay	Texture	pH H2O	Org. C	Total N %	Avail. P Mg/kg	Exchangeable Bases Ca	Mg	K	Na	TEB	CEC	BS %	Fe
		→	(%)	←						→				Cmol /kg	←		
Profile 4: Lower slope–*Vertic endoaqualfs/Stagnic Lixisols*																	
Ap	0-14	83.1	7.2	9.7	SL	6.80	2.72	0.05	3.36	3.68	2.34	0.41	0.62	7.05	7.23	97.5	1.48
A	14-25	80.3	7.0	12.7	SL	6.72	2.61	0.08	2.28	3.67	0.95	0.39	0.37	5.38	6.94	77.5	1.52
AB	25-78	76.0	9.2	14.8	SL	6.70	1.59	0.07	3.21	3.05	1.68	0.38	0.16	5.27	6.67	79.0	1.76
	78-110	77.0	10.2	12.8	SL	6.30	0.72	0.11	2.75	3.15	1.25	0.32	0.11	4.83	6.36	75.9	1.98
Bt_3	110-130	70.4	8.2	21.4	SCL	5.26	1.42	0.06	2.68	1.35	1.32	0.28	0.17	3.21	4.10	78.2	2.11
Profile 5: Levee -*Aeric Endoaqualfs/Aeric Lixisols*																	
Ap	0-22	60	6.4	33.6	SCL	5.43	2.06	0.05	3.12	1.87	0.56	0.37	0.60	3.40	5.02	84.5	1.58
Bt_1	22-57	58	9.4	32.6	SCL	5.35	1.56	0.07	2.98	2.56	0.53	0.35	0.38	4.02	4.93	81.5	1.69
Bt_2	57-89	62	7.4	30.6	SCL	5.14	1.52	0.08	3.26	2.14	1.34	0.31	0.34	4.13	4.34	95.1	1.90
Bt_3	89-101	60	8.5	31.6	SCL	5.10	0.41	0.06	1.87	2.11	1.20	0.30	0.21	3.82	4.22	90.5	2.06
Bt_3	110-130	82.6	8.2	9.4	LS	5.25	1.42	0.05	2.36	2.15	1.12	0.28	0.22	3.77	4.10	91.9	2.11
Profile 6: Levee –*Aeric Endoaqualfs/Aeric Lixisols*																	
Ap	0-22	59.0	6.4	34.6	CL	5.40	1.53	0.07	3.27	2.67	1.40	0.37	0.25	4.69	5.62	93.4	1.36
Bt_1	22-53	54.0	9.2	36.8	CL	5.35	1.53	0.08	2.50	1.56	0.68	0.35	0.38	2.97	5.22	90.3	1.48
Bt_2	53-92	58.0	7.4	34.6	CL	5.14	1.44	0.05	2.15	2.14	1.06	0.30	0.31	3.81	4.33	87.9	1.64
Bt_3	92-115	53.2	8.6	38.2	CL	5.12	1.34	0.04	1.64	2.13	0.23	0.29	0.20	2.85	4.15	68.6	1.92

Table 3: Suitability Requirement for Sugarcane

Site characteristics			Rating			
	Climate regime	**Unit**	**Highly suitable S1**	**Moderately suitable S2**	**Marginally suitable S3**	**Not suitable N**
	Mean temperature growing season	^{0}C	30 – 34	26 – 29 35 – 38	25 – 20 39 – 40	<20 >40
	Mean minimum temperature growing season	^{0}C	10 – 20	21 – 30	9 – 5	<5
	Mean RH (%)	Growing season	>0 – 85	60 – 70 85 – 90	60 – 50	<50
		Ripening season	55 – 76	75 – 90	>55, >90	
Land quality	**Land characteristics**					
Oxygen availability to roots	Soil drainage	Class	Well drained	Moderating drained	Poorly drained	Very poorly drained
	Depth of water	M	>1.0	1.0 – 0.5	<0.5	
Nutrient availability	Texture	Class	L, CL, Sil, SiCL, SC, SCL	C (m/k), SL	CL (ss)	
	pH	1:2.5	<4.0 <4.0	0 – 8.0 8.1 – 9.0	6.0 -6.9 9.1 – 9.5	4.0 – 5.9 >9.5
Rooting conditions	Effective soil depth	Cm	>100	100 - 75	>5 - 50	<50
Erosion hazard	Slope	%	<3	3 – 5	5-8	>8

Source: *Naida (1999)*

NB: Clay (m/k) = mixed kaolinite : Clay (ss) = shrink – swell clays

Texture: l = loam, sil = silty loam, sicl = silty clay, sc = sandy clay, scl = sandy clay loam

Table 4: **Actual Suitability of the flood levels**

Flood Level	Profile	Actual Suitability class
Levee	1,2	S_1
Medium	3,4	S_1
Toeslope	5,6	S_1

4.0 CONCLUSION

The suitability rating of Awe flood plain soils indicated a highly suitable (S1) in all the profiles for sugarcane production. Management practices such as organic matter incorporation, liming to increase soil pH, fertilizer application and time of planting have been recommended for improved sugarcane productivity in the mapping units that are not highly suitable for sugarcane production in the area studied.

REFERENCES

Agber, P.I., Adoyi, A, and Gani A.T. (2017). Suitability Evaluation of soils of Ohimini Area of Benue State, Nigeria for sustainable rainfed arable crop production. *International Journal of Environment Agriculture and Biotechnology (IJEAB)* Vol. 2, November 2017. 2888pp.

Brady, N.C and Ray, R.W. (2014). The nature and properties of soils, 14thedn, Person Education Inc. Publishers, India. 976pp.

Day. P.R. (1965). Particle fraction and particle size analysis. In: C.A. Black(ed), Methods of Soil Analysis, Agron.9.ASA, Madison, Wisconsin,USA.Pp547577.

Dengiz O (2010) Morphology, Physico-chemical and Classification of soils on terraces of the Tigris River in the South–East Anatola region of Turkey. Journal of Agric. Science; 16, 205-212.

Esu, I.E. (1991). Detailed soil survey of NIHORT farm Bakaure, Kano State, Nigeria Institute of Agricultural Reseach. ABU Zaria, Nigeria.Pp.126-138.

Fagbemi, A. and F.O.R, Akamigbo, (1986). Soils of Benue State and their capabilities. *Proceedings of the 14th Annual Conference of the Soil Science Society of Nigeria*, Pp 6 – 23.

FAO, (1983). Land Evaluation for rainfed agriculture. Guideline Soil Bull. 52 FAO Rome.37pp.

Fasina, A.S and Adeyanju B.A., (2006). Suitability classification of some granitic soils of humid West Nig. For rainfed maize, cassava and swamp sugarcane production. Nigerian Journal of Soil Science 16: 1-9

Fasina, A.S., Shittu, S.O., Omotoso, S.O, and Adnikinju, A. P. (2007). Properties, classification and suitability evaluation of some selected cocoa soils of South – Western Nigeria. *American Eurasin Journal of Agricultural and Environmental Science*. 2(3);312 -317.

Hassan, A. M., Raji., D. A., Malgwi, W.B. and Agbanin, J. O. (2011): The basaltic soils of Plateau State, Nigeria: Properties, classification and management practices In: M. k. A. Adebaye, A. Odofin, J. Osunde, A. O. Baba, A. and Ojeniyi, S. O. (eds). Soil resources management, global climate change and food security. *Proceedings of the 35th Annual Conference of Soil Science Society of Nigeria,* Minna, Nigeria, March 7th to 11th, 2011.

Idoga, S. (2002). Characterization and effect of harmattan dust on the soils of the lower Benue valley, Nigeria. (Unpublished) Ph.D

Thesis, University of Agriculture Makurdi, 130pp.

Idoga, S. and Azagaku, E.D. (2005). Characterization and classification of soils of Janta area of Plateau State, *Nigeria Journal of Soil Science*, Vol. 15:116 – 122.

Idoga, S. and Ogbu, O.J. (2012). Agricultural potentials of the Andibillo Plateau State, *Nigeria Journal of Soil Science* Vol. 22(2):53 – 30.

Igwe C.A and Agbatah A. (2007) Clay and silt dispersion in relation to some physicochemical properties of derived savanna soils undertwo tillage management practices in southeastern Nigeria. *Soil and Plant science.* Vol. 58 (1): 17-26.

IITA, (2015). Selected Methods for Soil and Plant Analysis. Manual Series N0.3, IITA Ibadan, Nigeria. 126pp.

Lawal, B.A., Odofin, A.J., Adeboye, M. and Ezenwa, M.I.S. (2012).Evaluation of Selected Fadama Soils in Katcha Local Government area of Niger State for Arable Cropping. *Nigeria Journal of Soil Science*, vol. 22(2): 104-112.

Obini N and Adeniyi A.R (2020). Characteristics of geotechnical behaviour of soil aggregates around Lafia, area, North central Nigeria. *Nigerian Mining and Geosciences Society.* Vol. 5622-27.

Ogbu O. J, S. Idoga, Abagyeh S. O, and **J. Usman** (2019). Land Suitability Evaluation of the Wetland Soils of Obukiyo, Oju LGA of Benue State, Nigeria for Sugarcane (*Oryza sativa*) Production. *Nigeria Journal of Soil Science.* 29 (2). Pp 7-17

Ogunkunle A.O. (1993). Topographic location, soil characteristics and classification in three bio-geological locations in Mid-Western Nigeria; *Malay. J. Trop. Geog*. 19, 22-32

Olaleye, A.O., Ogunkule, O.A., Sahorant, K.I., Osiname, O.A. and Ayanloja, S.A. (2002). Suitability Evaluation of selected Wetland Soils in Nigeria for Rainfall Sugarcane Cultivation. *Tropocultural* pp. 97-103.

Oluwatosin, G.A. (2005). Soils and Management domain for land use planning in South western Nigeria. *Moor Journal of Agricultural Research* 9:1-14 (Nigeria)

Ufot, U. O. (2012). Soils and the Environment for Colleges and Universities. Shadow Pub. Ltd, Owerri, Nigeria. Pp1635

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CHARACTERIZATION, CLASSIFICATION AND SUITABILITY ASSESSMENT OF SOILS ALONG A TRANSECT FOR RAIN FED RICE CULTIVATION IN NIMO, ANAMBRA STATE, NIGERIA

[1]Ajoagu, G.M., [2]Onwudiwe, O.E. and [1]Unagwu, B.O.
[1]University of Nigeria, Nsukka, Enugu State, Nigeria
[2]Federal College of Education (T), Asaba, Delta State, Nigeria
Corresponding Authors: ekynet09@gmail.com

ABSTRACT
A good number of communities in Anambra State has been identified as rice growing communities. Despite these numbers of rice growing communities, the rice production in Anambra state is a far from what is expected when compared to other rice producing states in Nigeria. The present study was carried out to characterize, classify and evaluate the suitability of soils along a transect in Nimo, Anambra State for rice cultivation. Three slope positions (upper, middle and lower slopes) were identified along the transect using a free survey method while a profile pit was dug on each slope position. The pits were described insitu following FAO guidelines and soil samples were collected from the identified generic horizon for laboratory analyses. The soils were strongly to slightly acid with low CEC, total nitrogen, organic matter and exchangeable bases. The soils were classified as Grossarenic Kandiudults at the upper slope and Typic Kandiudults at the middle and lower slopes. The current and potential aggregate suitability evaluation indicated that the soils were currently not suitable for rice production but have the potential of being moderately suitable if managed properly. The major limitations identified were drainage, wetness, CEC, calcium and available phosphorus.
Keywords: characterization, transect, classification, suitability, evaluation

Introduction

Soil plays a pivotal role in the agricultural ecosystem. Sustainability of soils hinges largely on the knowledge of its potential maximal utility and effective maintenance of soil's invaluable natural resources. As soils differ in properties due to differences in parent materials (Law-Ogbomo and Nwachokor, 2010), soil characterization and evaluation is very vital to sustainable crop production (Okonkwo and Nsor, 2015). Sustainability in agricultural production is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 2007). Ande (2011) noted that soil suitability evaluation involves characterizing the soils of a given area for specific land use types. Land evaluation is not only expedient but crucial because often, soil classification, soil maps, and the accompanying legends do not meet the needs of farmers and other land users (Ogunkunle, 2016).

Soil characterization and evaluation help in identifying limiting factors associated with a parcel of land for a particular crop production and enable decision-makers to develop a crop management system for sustainably land productivity (Halder, 2013). Soil characterization provides information on the morphological, physical, and chemical properties of soils as well as insights into their behavioural patterns (Basavaraju et al., 2005). This is essential for utilizing and maximizing soil properties (Kumar et al., 2013). Hence, periodic assessment of soils and their suitability for defined uses and management practices is inevitable. Soil information can be used for a more realistic land use recommendation (Nsor et al., 2014), thus, promotes suitable use and proper management of soil natural resources.

Rice is one of the fastest-growing food commodities in Nigeria with a likelihood of continued growth; its increase in demand is associated with the rapid population growth, urbanization and consumer's preference for rice as convenience food (Akande, 2003; Obianefo et al., 2019; USDA, 2014). Rice production in Anambra State, Nigeria, has seen significant growth over the years (Obianefo et al., 2022). However, the increment is marginal as most of the naturally endowed areas are left untapped due to paltry or no information on soil properties. To increase rice production, suitable areas and ecological conditions must be identified (Heumann et al. 2011). Such important tasks of increasing rice production can be addressed through spatial analyses of soil characteristics and land use suitability. Characterization, classification, and suitability evaluation of soils will not only establish a relationship between soil properties and the landscape parameters but also provide preliminary information on the soil nutrient status, potentials and constraints for a particular use. Therefore, this study tends to characterize, classify, and evaluate the suitability of soils along a transect in Nimo for rain fed rice cultivation.

Materials and Method

Description of the study area

Nimo in Njikoka Local Government Area, Anambra State Nigeria lies within latitudes 6° 8' 0'' N and 6° 14' 0'' N and longitudes 6° 56' 0'' E and 7° 2' 0'' E. The area is characterized by two seasonal climatic conditions: rainy and dry season with most rain falling from March to October; and a short break in either July ending or August known as August break. The dry season extends from November to February with harmattan occurring between the months of December and January. The mean annual rainfall is above 1450 mm. It has an average temperature of 27°C with daily minimum and maximum temperatures in ranges of 22°C to 24°C and 30°C to 34°C, respectively. The relative humidity ranges from 75 to 95% (Hydrometeorological Department, Awka, 2022). The native vegetation of area was originally rainforest characterized by very tall, big trees with thick undergrowth and numerous climbers (Ezeigwe, 2015). However, due to human interferences, the vegetation now consists of bush regrowth, arable crop farms and tree crops. Agriculture, hunting and cottage industries are predominant means of livelihood in the area (Orji-Uzor and Obasi, 2012). The major crops along the selected toposequences include: cassava (Manihot spp); cocoyam (Colocasia esculentus); yam (Discorea spp); maize (Zea mays), plantain (Musa spp.), oil palm (Elaeis guinensis) and mango (Mangifera indica). The soils of the area are developed on sandstone parent material (Ezeigwe, 2015).

Field studies

A sloping portion of an arable land, adjoining River Oshoku, was selected for the study. The slope was partitioned based on changing slope pattern and designated as upper, middle and lower slopes. In each segment, a representative profile of dimension 2 × 1.5 × 2 m was dug and described according to Food and Agriculture Organization (FAO) guidelines for soil profile descriptions (FAO, 2014). Soil samples (core and auger samples) were collected from generic horizons for laboratory analysis.

Soil analyses

The soil samples were air dried, crushed and sieved using a 2 mm sieve size. Particle size distribution was determined by Bouycous hydrometer method using sodium hydroxide as a dispersant (Gee and

Or, 2002). Silt clay ratio was obtained by dividing the value of silt with that of clay. Bulk density was determined using core method after oven drying the soil samples to a constant weight at temperature 105ºC for 24 hours (Grossman and Reinsch, 2002). Saturated hydraulic conductivity was measured by core method as described by Klute and Dirksen (1986). Pore size distribution was determined using water retention data as follows: macroporosity as water drained at 60 cm tension/volume of bulk soil: microposity as water retain at 60 cm tension /volume of bulk soils and total porosity from the sum of macroporosity and microporosity (Brady and Weil, 2002).

Soil pH was determined both in water and 0.1N potassium chloride solution at the soil/liquid ratio of 1:2.5 using Beckman Zerometic pH meter (Van Reeuwijk, 1992). Organic carbon content was determined by the dichromate wet oxidation method (Jackson, 1973) and multiplied by 1.724 to obtain organic matter. Total nitrogen was determined by the Kjeldahl digestion, distillation and titration procedure as described by Bremner (1965). Available phosphorus was determined using Bray II method as described by Olsen and Sommers (1982). Cation Exchange Capacity was determined using the ammonium acetate method (Chapman, 1965). Exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were extracted using 1N ammonium acetate; calcium and magnesium was determined by titration method (Chapman, 1965) while sodium and potassium was determine using flame photometer as described by Rhoades (1982). Exchangeable hydrogen and aluminium were determined by titrimetric method using potassium chloride extract (Mclean, 1965). Exchangeable Acidity was calculated by summing the values of exchangeable aluminium and hydrogen. Base Saturation was calculated as thus in equation (1):

$$\mathrm{PBS} = \frac{\mathrm{TEB}}{\mathrm{ECEC}} * \frac{100}{1} \qquad \ldots\ldots 1$$

where TEB = total exchangeable bases and ECEC = effective cation exchange capacity which was obtained by summation of total exchangeable bases and total exchangeable acidity.

Land Evaluation Procedure

The suitability of the soils for rice production was assessed using the parametric linear additive model as stated in Ezeaku and Tyav (2013):

$$\mathrm{LI} = A + \frac{B}{100} + \frac{\mathrm{C}}{100} + \frac{\mathrm{D}}{100} + \cdots \frac{\mathrm{F}}{100}, \qquad \ldots\ldots 2$$

where LI is the Land Suitability Index (%), A is the overall lowest characteristics ratings (%) and B, C, D….. F are the ratings for each property (%). The value of the land suitability index was used to determine the aggregate suitability class. The detailed land and soil requirements for rice is presented in the Table 1 below.

Table 1: Land/Crop requirements for rain-fed rice cultivation

Land qualities	Land Characteristics	Unit	S_1	S_2	S_3	N_1	N_2
			(100-85)	(84-60)	(59-40)	(39-20)	(19-0)
Climate (c)	Annual Rainfall	Mm	> 1400	1200-1400	950-1100	850-900	< 850
Soil physical characteristics (s)	Soil Depth	Cm	> 20	10-20	5-10	< 5	any
	Clay	%	45-25	25-15	15-5	<5	any
	Texture	-	Loam	Clay loam	Clay	Sandy clay	any
Wetness (w)	Drainage	-	VPD	PD	MD	MWD	WD
	F.D	Months	> 4	3-4	2-3	< 2	any
	G.W.T	Cm	0- 15	15-30	30-60	> 60	Any
Fertility status (f)							
	pH(H_2O)	-	5.5-7.5	5.2-5.5	≤ 5.2, ≥ 8.2	≤ 5.2, ≥ 8.2	Any
	Total Nitrogen	g kg^{-1}	> 0.2	0.1-0.2	0.05-0.1	< 0.05	Any
	Organic carbon	g kg^{-1}	5-6	3-4	1-2	<1	Any
	Available Phosphorus	mg kg^{-1}	> 20	15-20	10-15	< 10	Any
	Exchangeable Ca	cmolkg^{-1}	10-15	5-10	1-5	< 1; > 15	Any
	Exchangeable Mg	cmolkg^{-1}	2-5	1-2	< 1	< 1; > 5	Any
	Exchangeable K	cmolkg^{-1}	> 0.2	0.1-0.2	< 0.1	< 0.1	Any
	CEC (Soil)	cmolkg^{-1}	> 16	10-16	5-10	< 5	Any

Key: F. D: Flooding Duration, G. W. T: Ground Water Table; VPD: Very poorly drained; PD: Poorly drained; MD: Moderately drained; MWD: Moderately well drained WD: Well drained; CEC: Cation exchange capacity Ca: Calcium; Mg: Magnesium K: Potassium; S1: highly suitable, S2: moderately suitable: S3: marginally suitable, N1: currently not suitable, N2: permanently not suitable

Adapted from Sys (1985)

Results and Discussion

Soil morphological properties

The soils were very deep greater than 150 cm (SSS 1999) (Table 2). Soil colour ranged from dark reddish brown (10R 3/3); reddish brown (10R 4/3) and red (10R 6/6) for the upper, middle and lower slopes for the surface soils while the subsurface soils ranged from reddish brown (10R 4/4) and red (10R 4/6 and 10R 4/8), respectively. The soils were dominated by reddish colour which could be attributed to high iron content of the parent material and the oxidation state of the soils (Esu, 2010; Nsor, 2017). Soils of the upper slope ranged from sand in the surface to sandy loamy and loamy sand in subsurface soils. Middle slope soils were sand at the surface soils and sandy loan at subsurface soils. Lower slope soils were sandy loan at both surface and subsurface soils. The surface soils were weak single grained granular structure underlain by weakly developed medium sub angular blocky structures at the upper slope soils. At the middle and lower slopes, the structure were fine massive granular structure at the surface underlain by moderately developed medium sub angular blocky structure. The weak to moderate developed sub angular blocky might be attributed to the degree of soil formation in profiles (Abubakar et al., 2019).

The soils were loose to friable (moist) and non-sticky to slightly sticky (wet) in the Ap horizons and very friable to friable (moist) and not sticky to slightly sticky (wet) in the sub horizons. Roots varied from very fine to coarse and few to very many in size and relative abundance respectively. Ants and pores were observed in sub horizons. The presence of the roots, ants and pores were indications of considerable number of biological activities in the soils. Pottery was observed in the 'B1' horizon, which suggested evidence of human settlement in the past (Esu, 2010). Gravels were present at the subsurface soils of the lower slope. Generally, horizon differentiation between Ap horizons and the B horizons was quite clear across the profiles, which might be due to melanization from humification of organic matter content added to the Ap horizons as form of manure (Esu, 2010). In B horizons, differentiation ranged from gradual and smooth in the middle and lower slopes to diffuse smooth in the upper slope HD: horizon designation; T: texture; Hb: horizon boundary; RB; reddish brown; R: red; DRB: dark reddish brown; LS: loam sand; S: sand; SL; Sandy loam; f: fine; ma: massive, g: granular; vf: very fine; m: medium; mod: moderate, ab: angular blocky; sab: sub angular blocky; fr: friable; vfr: very friable; fi: firm; ns: not sticky; ss: slightly sticky; s: sticky; p: perfect; F: few; ; M: many; cs: clear smooth; ds: diffuse smooth; cw: clear wavey; -: absent

.

Table 2: Morphological properties of soils

Depth (cm)	HD	Colour	T	Structure	Consistency moist	Consistency wet	Roots	Hb	Other features
				Upper slope					
0-30	Ap	10R 3/3 (DRB)	S	w sg g	l	ns	M vf	Cs	-
30-116	B_1	10R 4/4 (RB)	SL	w m sab	vfr	ns	F vf	Ds	-
116-200	B_2	10R 4/8 (R)	LS	w m sab	vfr	ss	-	-	-
				Middle slope					
0-27	Ap	10R 4/3 (RB)	S	f ma g	vfr	ns	M vf; F f	Cw	-
27-114	B_1	10R 4/6 (R)	SL	mod m sab	fr	ss	VF f	Gs	Very few medium pores, very few pottery
114-200	B_2	10R 4/6 (R)	SL	mod m sab	vfr	ns	-	-	-
				Lower slope					
0-40	Ap	10R 4/6 (R)	SL	f ma g	fr	ss	M f	Cs	-
40-125	B_1	10R 4/8 (R)	SL	mod m sab	fr	ss	F f	Gs	very few gravel
125-200	B_2	10R 4/8 (R)	SL	mod m sab	fr	ss	-	-	very few gravel, many ants

Soil physical properties

The particle size distribution data for the soils is presented in Table 3. Sand dominated the particle size fraction of the fine earth (<2mm) portion of the soils. The sand content varied from 802 to 903 g kg^{-1} in the Ap horizons while the values for the sand content in the underlying horizon were between 742 and 882 g $kg^{-1.}$ Clay content ranged from 65 to 265 gkg^{-1} in the Ap horizons and 85 to 205 gkg^{-1}in sub horizons, respectively. The silt content was 33 gkg^{-1} in Ap horizon and varied between 33 and 39 gkg^{-1} in the sub horizons. Generally, sand content of the surface horizons was slightly higher than the sub horizons. Clay fraction was next to sand in abundance with an increasing pattern of distribution down the profiles and slope. The higher clay content often observed in subsurface horizons of many soils may be ascribed to illuviation and pedoturbation processes (Malgwi et al., 2000). This confirms the presence of either kandic or argillic B horizons in the profiles. The texture of the soils varied between sand, sandy loam and loam sand.

The silt clay ration ranged from 0.20 to 0.51 in surface soils and 0.16 to 0.39 in the subsurface soils. Silt clay ratios were relatively higher in the surface soils and decreased with depth suggesting that subsurface soils were more weathered than the surface soils (Fasina et al., 2015). The values of bulk densities for upper, middle and lower slopes ranged from 1.61 to 1.74 g cm^{-3}; 1.63 to 1.74 g $cm^{-3}$and 1.64 and 1.82 g cm^{-3}, respectively with increasing trend down the profiles due to compaction caused by the overlying horizons. Generally, the soils have high bulk density which might to attributed to the sandy nature of the siols (Nsor, 2017). The values of the saturated conductivity varied between 11. 80 and 69.72 cm hr^{-1}. The upper slope soils had the highest values of ksat relative to other slope positions due its moisture content. This is in line with the findings of Antiono et al. (2001) and Bagaireaello and Lovino (2003). They reported high ksat on the upper slope due to higher water content and smaller pores. The high bulk density could be attributed to the sandy nature of the soil. The macro, micro and total porosity of soils varied from 5.13 to 5.70%, 34.29 to 39.08% and 39.68 to 44.46%, respectively

Table 3: Physical properties of soils

Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	Bd (MgM^{-3})	Ksat (cm hr^{-1})	Map (%)	Mip (%)	Tp (%)
Upper slope										
0-30	902	33	65	S	0.51	1.61	68.01	5.62	38.74	44.36
30-116	882	33	85	LS	0.39	1.65	69.72	5.58	36.40	41.98
116-200	862	33	105	LS	0.31	1.74	65.45	5.39	34.29	39.68
Mean	882	33	85	S	0.40	1.67	67.73	5.52	36.48	42.01
Middle slope										
0-27	903	33	65	S	0.51	1.63	33.43	5.70	38.14	43.84
27-114	742	53	205	SL	0.29	1.68	11.80	5.58	37.09	42.67
114-200	762	33	205	SL	0.16	1.74	17.33	5.49	34.26	39.75
Mean	803	39	158	SL	0.32	1.68	20.85	5.59	36.50	42.09
Lower slope										
0-40	802	33	165	SL	0.20	1.65	23.61	5.38	39.08	44.46
40-125	782	33	185	SL	0.18	1.82	31.59	5.23	37.06	42.29
125-200	762	33	205	SL	0.16	1.82	17.02	5.13	34.62	39.75
Mean	782	33	185	SL	0.18	1.76	24.07	5.25	36.92	42.17

TC: textural class; S: sand; SL: sandy loam; LS: loam sand; SCR: silt clay ratio; Bd: bulk density; Ksat: saturated hydraulic conductivity; Map: macroporosity; Mip: microporosity; Tp: total porosity

Soil chemical properties

The soils were strongly to slightly acid with pH in H_2O and KCl ranging from 4.80 to 5.60 and 4.40 to 5.00, respectively as shown in Table 4. This might be attributed to continuous cultivation, application of commercial fertilizers and leaching of exchangeable bases (Brady and Weil, 2002; Havlin et al., 2006). The organic matter values for surface horizons were 3.45 to 8.96, 3.65 to 6.72, and 2.76 to 8.89, g kg^{-1} for upper, middle and lower slope soils respectively. The soil OM content decreased with depth and were rated low irrespective of soil depth and slope positions. The low values of OM inferred that the studied site have been under continuous or intensive cultivation. This is because high agricultural activities deplete soil organic matter content (Fedaku et al., 2018). The OM decreased down the profiles, which may be linked to decrease in microbial pedoturbation and zero tillage activities with depth (Nsor, 2017). The total nitrogen values varied from 0.30 to 0.80; 0.20 to 0.70 and 0.10 to 0.40 g kg^{-1} for soils of upper, middle and lower slopes, respectively. Total N was low and decreased down the slope due to losses through runoff, low organic matter, high N mineralization and crop removal (Njoku, 2012; Uzoho et al., 2014). The available phosphorus varied from 11.90, 5.60 and 0.93 mg kg^{-1} in the Ap horizon to 1.87, 1.87 and 4.66 mg kg^{-1}, respectively in the underlying horizon. The low level of available P may be due to low apatite content of the soil forming materials. Amhakhian and Osemuota (2012) opined that tropical soils are generally low in available P due to low apatite content of the soil forming materials.

The trend in dominance of the exchangeable bases at the colloid is $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. Exchangeable calcium (0.20 to 1.00 cmol kg^{-1}), magnesium (0.20 to 0.40 cmol kg^{-1}), sodium (0.05 to 0.09 cmol kg^{-1}) and potassium (0.08 to 0.92 cmol kg^{-1}) were considered to be low. This might be attributed partly to the dominance of 1:1 clay mineral and partly to the leaching loss of nutrients (Orji Uzor and Obasi, 2012; Chikere-Njoku, 2015). Total exchangeable bases ranged from 0.61 to 2.01 cmol kg^{-1} at the surface horizons and 0.53 to 2.04 cmol kg^{-1} at the subsurface soils. The values of cation exchange capacity (CEC) in the surface horizons were 4.00, 4.80, and 3.20 cmol kg^{-1} for upper, middle and lower slope in the Ap horizon while 4.00 to 8.80, 4.80 to 8.80 and 5.60 to 6.00 cmol kg^{-1} were the values at the subsurface horizons, respectively. Low CEC values were reported to be an indication of dominance of sesquioxide and

Table 4: Chemical properties of soils

Depth (cm)	pH (H_2O)	pH (KCl)	OM (g kg^{-1})	TN (g kg^{-1})	Av. P (mg kg^{-1})	H^+ (cmol kg^{-1})	Al^{3+}	EA	Ca^{2+}	Mg^{2+}	Na^+	K^+	TEB	CEC	BS (%)
Upper slope															
0-30	5.30	4.90	8.96	0.80	11.90	0.40	0.80	1.20	0.60	0.40	0.09	0.92	2.01	4.00	62.62
30-116	5.00	4.60	4.14	0.40	5.60	0.40	1.20	1.60	0.80	0.20	0.07	0.43	1.30	4.00	44.83
116-200	4.90	4.70	3.45	0.30	1.87	0.80	1.60	2.40	1.00	0.40	0.07	0.55	1.41	4.80	39.83
Mean	5.07	4.73	5.52	0.50	6.46	0.53	1.20	1.73	0.80	0.33	0.08	0.63	1.57	4.20	49.40
Middle slope															
0-27	5.30	5.00	6.72	0.70	5.60	0.80	0.20	1.00	0.20	0.20	0.08	0.13	0.61	4.80	37.89
27-114	4.80	4.40	6.55	0.40	1.87	2.80	0.40	3.20	0.40	0.40	0.09	0.55	2.04	6.40	38.93
114-200	5.10	4.60	3.62	0.20	4.66	1.00	0.80	1.80	1.00	0.40	0.09	0.09	0.78	8.80	30.23
Mean	5.07	4.67	5.63	0.43	4.04	1.53	0.47	2.00	0.53	0.33	0.09	0.27	1.14	6.67	35.68
Lower slope															
0-40	5.00	4.60	8.89	0.40	0.93	0.80	1.20	2.00	0.40	0.40	0.04	0.09	0.93	3.20	31.74
40-125	5.60	4.70	4.48	0.20	4.66	0.20	1.60	1.80	0.40	0.20	0.06	0.09	0.75	5.60	29.41
125-200	4.90	4.70	2.76	0.10	3.73	0.80	2.00	2.80	0.20	0.20	0.05	0.08	0.53	6.00	15.94
Mean	5.17	4.67	5.37	0.23	3.11	0.60	1.60	2.20	0.33	0.27	0.05	0.09	0.74	4.93	25.69

OM: organic matter; TN: total nitrogen; Av. P available phosphorus; H^+: exchangeable hydrogen; Al^{3+}: exchangeable aluminum; Ca^{2+}: exchangeable calcium; Mg^{2+}: exchangeable magnesium; Na^+: exchangeable sodium; K^+: exchangeable potassium; EA: exchangeable acidity; TEB: total exchangeable bases; CEC: cation exchange capacity; BS: base saturation;

kaolinitic clays in the fine earth fractions (Tan, 2000). The increase in CEC values with depth in the profiles was as a result of increase in clay content (Abubukar et al., 2019) as it had similar trend with the clay content. The percentage base saturation (BS) varied from 39.83 to 62.62%; 30 to 38.93% and 15.94 to 31.74% in the upper, middle and lower slope soils respectively. The higher BS values at the surface horizons and upper slope might to be due to lower rate of leaching.

Soil classification

The soils of all the slope positions were classified as Order Ultisols as they had kandic horizons and base saturations <50% throughout the entire horizons. An udic moisture regime was inferred for all the soils as they are not dry in any part for more than 90 cumulative days in a normal and this placed the soils at Sub order Udults (Table 5). The presence of kandic horizon with no densic, lithic, paralitic or petrolithic contacts with 150cm of mineral soils and a clay increase of 3% or more in the fine earth fractions qualified the soils as Great group Kandiudults (Soil Survey Staff, 2014). At the Sub group level, the soils of the upper slope were as Grossarenic Kandiudults as they had sandy skeletal particle-size throughout the layers extending from the mineral soil surface to the top of the kandic horizon at the depth of 100 cm and more. Whereas the soils on the middle and lower slopes qualified as Typic Kandiudults (Soil Survey Staff, 2014).

According to FAO's World Resource Base (WRB), all the soils were correlated with Acrisols as they had agric horizons, CEC values of <24 and exchangeable bases of <50% within the upper 100 cm depth (FAO, 2014) (table 4). The soils of the upper and lower slopes were further classified as Arenic Acrisols while the lower slope soil was were further correlated as Loamic Acrisols owing to the presence of sandy and loamy sand textures respectively in a layer ≥30 cm thick within <100 cm (FAO, 2014) respectively.

Table 5: Soil Classification

	USDA SOIL TAXONOMY				WRB
	Order	Sub order	Great group	Subgroup	
Upper slope	Utisols s	Udults	Kandiudults	Grossarenic Kandiudults	Arenic Acrisols
Middle slope	Ultisols	Udults	Kandiudults	Typic Kandiudults	Arenic Acrisols
Lower slope	Ultisols	Udults	Kandiudults	Typic Kandiudults	Loamic Acrisols

Land suitability assessment

The study showed that the climate data: rainfall and temperature were ideal for rice production scoring 95% (Table 6). Soil texture was highly suitable scoring 85% whereas clay was marginally (upper and middle slopes) to moderately suitable (lower slope) 50 to 70%. Soil chemical characteristics such as total nitrogen and organic matter were rated highly suitable (95%) for all the pedons. The pH of the soils was moderately suitable (70%) for the upper and middle slopes but marginally suitable (50%) for the lower slope. CEC and calcium were not suitable (35%) in all the pedons. Exchangeable magnesium was moderately suitable scoring 70%. Exchangeable potassium was highly suitable (95%) in the upper slope, moderately suitable (70%) in the middle slopes and marginally suitable (50%) in the lower slope. Available phosphorus rated from not suitable (35%) in middle and lower slopes to marginally suitable (50%) in the upper slope. wetness were rated not suitable (25%) for rice production in all the slope positions.

Aggregate suitability evaluation: current and potential indicated that the soils of the slope positions were currently not suitable and moderately suitable for rice production respectively. The major limitation was drainage, wetness, CEC, calcium and available phosphorus. The wetness and drainage limitations can be overcome through irrigation and mulching to conserve enough moisture in the soils. Soil management strategies such as spreading of crop residue on the soils after harvesting, inclusion of grasses and legumes during fallow should be practiced so as to boost the fertility of the soils. The pH of the soils can be raised by liming. This will also increase the available P, supply Ca and Mg, and eliminate any toxic substances like iron, aluminum and manganese ions. Periodic soil tests are also recommended to ascertain pH levels at a time in order to avoid over-liming

Table 6: Land suitability assessment for rain fed rice production

Land qualities	Upper slope	Middle slope	Lower slope
Climate			
Annual rainfall (mm)	S1(95)	S1(95)	S1(95)
Temperature (°C)	S1(95)	S1(95)	S1(95)
Physical characteristics			
Depth (cm)	S1(95)	S1(95)	S1(95)
Clay (%)	S3 (50)	S3 (50)	S2 (70)
Texture	S1(85)	S1(85)	S1(85)
Wetness			
Drainage	N1(25)	N1 (25)	N1 (25)
Flooding duration	N1(25)	N1 (25)	N1(25)
Ground water table	N1(25)	N1 (25)	N1 (25)
Fertility Status			
pH	S2 (70)	S2 (70)	S3 (50)
Total N	S1(95)	S1(95)	S1(95)
Organic C	S1(95)	S1(95)	S1(95)
Available P	S3 (50)	N1 (35)	N1 (35)
Exchangeable K	S1 (95)	S2 (70)	S3 (50)
Exchangeable Ca	N1 (35)	N1 (35)	N1 (35)
Exchangeable Mg	S2 (70)	S2 (70)	S2 (70)
CEC	N1 (35)	N1 (35)	N1 (35)
Aggregate Suitability (current)	N1 (35.67)	N1 (35.67)	N1 (35.67)

Aggregate Suitability (potential)	S3 (50. 33)	S3 (50. 33)	S3 (50.33)

S1: highly suitable, S2: moderately suitable: S3: marginally suitable, N1: currently not suitable, N2: permanently not suitable

Conclusion

The soils of the study area were strongly to slightly acid with low CEC, total nitrogen, organic matter and exchangeable bases. The soils were classified as Grossarenic Kandiudalfs at the upper slope and Typic Kandiudults at the middle and lower slopes. The soils were currently not suitable for rice production but have potentials to be moderately suitable if properly managed. Hence, there is the need to continually monitor the drainage, wetness and fertility status of the soils for effective optimization of its potentials for rice production. Management practices such as irrigation, cover cropping, mulching and organic manuring should be adopted so as to provide and conserve moisture in the soils as well as enhance the fertility.

References

Amhakhian, S. O. and Osemwota, I. O. (2012). Physical and chemical properties of soils in Kogi State, Guinea savanna zone of Nigeria. *Nigeria Journal of Soil Science,* 22(1), 44-52

Ande, O. T. (2011). Soil suitability evaluation and management for cassava production in the derived Savanna Area of Southwestern Nigeria. *International Journal of Soil Science*, 6(2), 142.

Antonio, C.D.A., Angulo-Jaramilo, R., deSouza, E.S., Netto A.M., Cameiro C.J.G. and Montenegro, A.A.A. (2001). Determinants of hydraulic conductivity and sorptivity of soils using a disk infitrometer. *Br. Journal of Agriculture and Environmental Engineering*, 1802-1899

Bagiaraello, V. and Lovino, M. (2003). Field testing parameter sensitivity of the two-term infiltration equation using differentiated linearization. *Soil Science Society of America Journal,* 2, 358-367

Basavaraju, D., Naidu, M. V. S., Ramavatharam, N. and RAA, K. G. (2005). Characterization, classification and evaluation of soils in Chandragiri mandai of Chittoor district, Andhra Pradesh. *Journal of Agropedology*, *15*(1), 55-62

Brady, N.C. and Weil, R.R. (2006). Elements of the nature and properties of soils. Prentice Hall Inc. New York, USA. 95p

Brady, N.C. and Weil, R.R. (2002). The nature and properties of soils. 4th Ed. Prentice Hall Inc. New Jersey, U.S.A.

Bremner, J.M. (1965). Total nitrogen in C.A. Black (Eds.). Methods of soil analysis. Agronomy. No 9. Part II. American society of Agronomy, Maidson, Wisconsin. USA. 1149-1178

Chapman, H.D (1965). Cation exchange capacity In: C.A. Black, L.E Ensminger and F.E. Clark (Eds.). Methods of soil analysis. Agronom 9. American Society of Agronomy, Maidson, Wisconsin. USA. 891-901

Chikere-Njoku, C. (2015). Characterization and classification of soils along a toposequence for agronomic use in Oba idemili South L.G.A. of Anambra State, Southern Nigeria. *FUTO Journal Serie,* 1(2), 103-110

Esu I.E. (2010). Soil characterization, classification and survey. HEBN Publishers, Plc, Ibadan, Nigeria. 73-99

Ezeaku, P.I and Tyav C. (2013). Fuzzy and parametric methods for land evaluation along Kastina-Ala flood plains in Central Region of Nigeria: Application to rice production.

Elixir International Journal, 61, 173033-173039
Ezeigwe, P.C. (2015). Investigation of the characteristics of the soils behind the proposed governor's lodge, Ekwueme Square Awka and the environmental hazards prevalent in the area. *Journal of Natural Science Research*, 5(20), 43-51
FAO (2007). Land evaluation: Towards a revised framework. Land and water discussion paper no. 6. Food and Agriculture Organization of the United Nations, Rome, Italy. 108p. http://www.fao.org/nr/lman/docs/lman_070601_en.pdf
FAO (2014). World reference base for soil resources. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/a-i3794e.pdf
Fasina, A.S., Raji, A., Oluwatosin, G.A., Omoju, O.J. and Oluwadare, D.A. (2015). Properties, genesis, classification, capability and sustainable management of soils from South-Western Nigeria. *International Journal of Soil Science*, 10, 142-152
Fekadu, A., Kibebew, K.A, Bobe, B.A. and Asmare, M.B. (2018). Characterization and classification of soils of Yikalo Subwatershed in Lay Gayint District, Northwestern Highlands of Ethiopia Endalkachew. *Eurasian Journal of Soil Science,* 7(2), 151-166
Gee, G.W. and Or, D. (2002). Particle size analysis. In: Dane, J.H., Topp, G.C. (Eds). Methods of soil analysis. Part 4, Physical Methods. *Soil Science Society of America Book series*; No 5, ASA and SSSA Madison WI. 255-295
Grossman, R.B. and Reinsch, J.G. (2002). Bulk Density and linear extensibility in methods of soil analysis part 4. Physical Methods. Book Series. No. 5. ASA and SSA Madison, WI. 201-228
Halder, J.C. (2013). Land suitability assessment for crop cultivation by using remote sensing and GIS. *Journal of Geography and Geology*, 5(30), 65-74.
Havlin, J.L., Beaton, J.D., Tisdale, S. and Nelson, W.L. (2006). Soil fertility and fertilizers. An introduction to nutrient management. 7th Ed. Prentice Hall of India private limited, New Delhi. 110001.633p
Heumann, B.W., Walsh, S.J. and McDaniel, P.M. (2011) Assessing the application of a geographic presence-only model for land suitability mapping. *Ecological Inform,* 6(5), 257–269. https://doi.org/10.1016/j.ecoinf.2011.04.004
Hydrometeorological Department (2018). Anambra State Ministry of Environment, Awka
Jackson, M.L. (1973). Soil chemical analysis. Prentice Hall, New Delhi. 489p
Klute, A. and Dirksen, C. (1986). Hydraulic conductivity and diffusivity: Laboratory methods. In Klute, A. (Eds). Methods of soil analysis part 1: *Physical and mineralogical methods.* 2nd edition. Agronomy 9, America Society of Agronomy, Madison, WI. 199-224
Kumar, R.S., Kumar, Y.S. and Srinivas, P. (2013). Characterization, classification and evaluation of Chilli growing soils of Khammam District, Andhra Pradesh. *International Journal of Innovative Resources and Development,* 2(9), 26-33.
Law-Ogbomo, K.E. and Nwachokor, M. A. (2010). Variability in selected soil physic-chemical properties of five soils formed on different parent materials in southeastern

Nigeria. *Res. J. Agric. Biol. Sci*, *6*(1), 14-19

Malgwi, W.B., Ojanuga, A.G., Chude, V.O., Kparmwang, T. and Raji, B.A. (2000) Morphological and Physical Properties of Some Soil at Samaru, Zaria, Nigeria. Nigeria *Journal of Soil Research,* 1, 58 - 64

McLean, E.O. (1965). Aluminum. Pp 978-998. In: C.A. Black (Eds.). *Methods of soil analysis.* Agronomy. No 9. Part II. American society of Agronomy, Maidson, Wisconsin. USA

Munsell Soil Colour Chart. (2009). Munsell soil colour charts (revised ed.) Baltimore.

Njoku, J.D (2012). Application of geographical information system technology in soil fertility variation analysis in Southeastern Nigeria. *International Journal of Science and Technology,* 1, 47 - 59

Nsor, M.E. (2017). Pedogenesis, classification and management implications of soils derived from Nanka sands of false bedded sandstones lithology in Orumba North L.G.A, Southeastern, Nigeria. Proceeding of the 41st Annual Conference of Soil Science Society of Nigeria held 13-17th March, 2017 at ATBU, Bauchi, Nigeria. 195-204

Nsor, M.E., Otu, E J., Okeafor, M.O. and Lifu, M.I. (2014). Physico-chemical evaluation and site suitability assessment of selected flood plain soils along river cross for arable cropping. *Journal of the science in agriculture, food technology and environment*, 13, 19 -31

Obianefo, C. A., Ezeano, I. C., Isibor, C. A. and Ahaneku, C. E. (2023). Technology Gap Efficiency of Small-Scale Rice Processors in Anambra State, Nigeria. *Sustainability*, *15*(6), 4840

Obianefo, C. A., Okoroji, N. O., Obiekwe, N. J., Osuafor, O. O. and Shah, Z. A. (2022). Economics of good agronomic practices adoption by rice farmers in value chain development programme, Anambra State, Nigeria. *African Journal of Food, Agriculture, Nutrition and Development*, 22(8), 21308-21330

Ogunkunle, A.O. (2016). Management of Nigerian soil resources: An imperative for sustainable development. University Lecture, University of Ibadan. University Press, Ibadan. 88p

Okonkwor, E I. and Nsor, M.E. (2015). Land suitability evaluation of wetland soils of Adani, Enugu State, Nigeria for swamp rice cultivation. *Journal of sustainable agriculture and the environment,* 16(1), 121-138

Olsen, S.R. and Sommers, L.E. (1982). Phosphorous In: *Method of soil analysis.* Page, A.L., Miller, R.H. and Keeney, D.R. (Eds). Madison, WI. American Society of Agronomy: 1572p

Orji Uzor, E.N. and Obasi, S.N. (2012). Properties and classification of erosion prone soils of Ukpo, Nnewi South L.G.A, Anambra State, Nigeria. *International Journal of Agricultural Sciences and Rural Development,* 15(2), 1079 - 1084

Rhoades J.D. (1982). Cation exchange capacity. In Page A L. (Eds.). *Methods of soil analysis* part II. 2nd edition Agronomy Monogor.9.ASA, Madison, WI. 149-157

Soil Survey Staff (2014). Keys to soil taxonomy: 14th Edition, United States Department of Agriculture/Natural Resources Conservation Service, USA. 161-195

Sys, C., Van Ranst, E., Debaveye, I. J. and Beernaert, F. (1993). Land evaluation. part III: crop requirements. General Administration for Development

Cooperation, Agricultural Publication No. 7, Brussels-Belgium

Uzoho, B.U., Ekpe I.I., Ahukaemere, C.M., Ndukwu, B.N., Okoli N.H., Osis F.A and Chris-Emenyeonu, C.M. (2014). Nitrogen status of soils of selected land uses of cropping systems in the humid tropical rainforest, Southeastern Nigeria. *Advances in life Sciences and Technology,* 25, 24-33

Van Reeuwijk, L.P. (1992). Procedures for soil analysis. 3rd edition. International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands. 34p

CLASSIFICATION AND SUITABILITY ASSESSMENT OF SELECTED SOIL UNITS IN FEDERAL UNIVERSITY WUKARI FOR RAINFED CULTIVATION OF CASSAVA (*MANIHOT ESCULENTA*)

Awwal Y.A.* **and David J.E.**
Federal University Wukari, Wukari, Taraba State
Corresponding author email:awalyasin@fuwukari.edu.ng

ABSTRACT
This study assessed selected soil units within Federal University Wukari to classify and evaluate their suitability for rainfed cassava (Manihot esculenta) cultivation. Three pedons were excavated across representative land units, and morphological, physical, and chemical properties were analyzed. Soils were classified using USDA Soil Taxonomy and correlated with the FAO World Reference Base (WRB). Suitability evaluation followed the FAO Land Suitability Evaluation framework, employing a parametric approach. Results showed that soils were sandy loam to sandy clay loam in texture, with an argillic horizon and increasing clay content in the subsurface, indicating eluviation-illuviation processes. Soil pH ranged from 5.05 to 6.25, while organic carbon (mean: 10.9 g kg^{-1}) and available phosphorus (mean: 10.9 mg kg^{-1}) were low to moderate. Soils were classified as Typic Haplustalf and Typic Paleustalf (USDA), corresponding to Haplic Lixisols (FAO). Suitability assessment placed all pedons in the moderately suitable class (S2-cf), with constraints in climate (rainfall) and fertility (low organic carbon and phosphorus). However, fertility enhancements, particularly organic matter amendments and phosphorus supplementation, could improve suitability to S1, raising potential cassava yields from 10–20 t ha^{-1} to 20–30 t ha^{-1}. Sustainable soil management strategies are recommended to optimize productivity in the study area.
Keywords: *Soil classification, Land suitability, Cassava cultivation, FAO framework, Soil fertility management.*

Introduction

Cassava (*Manihot esculenta Crantz*) is a vital staple crop that contributes to food security and economic growth especially for nations in the tropical and subtropical regions (Ferraro *et al.*, 2016). In 2021, global cassava production exceeded 300 million tonnes, with Nigeria accounting for approximately 20% as the largest producer (Onyediako and Adiele, 2022). The adaptability of cassava to diverse soil and climatic conditions makes it indispensable in regions with marginal soils and erratic rainfall patterns (Ikuemonisan *et al.*, 2020). However, optimizing cassava productivity remains challenging, particularly in areas with poor soil quality and suboptimal land use practices (Zulkarnain *et al.*, 2021).

In Nigeria, average cassava yields fall significantly below the genetic potential of 25–40 tonnes per hectare under optimal conditions (International Institute of Tropical Agriculture [IITA], 2022). This shortfall is primarily due to poor soil fertility, drainage issues, excessive acidity, and nutrient deficiencies, alongside pests, diseases, and weed infestations (Sánchez *et al.*, 2014; Zulkarnain *et al.*, 2021). Historically, efforts to improve cassava productivity focused on expanding the area under cultivation rather than enhancing yield per hectare. For example, in a bid to increase cassava output due to its growing importance, the area under production in Africa was grown from 5.6 million hectares per year in the 1960s to 10 million hectares by the 1990s (Nweke, 2001). This form of expansion is still present to this day. However, the lack of empirical suitability studies has perpetuated low yields and profitability, emphasising the need for suitability evaluations before expansion.

Various methods have been used to assess cassava's spatial suitability in different areas. Some studies utilized GIS and multi-criteria decision-making techniques (e.g., Zemba *et al.*, 2017; Purnamasari *et al.*, 2018; Nungula *et al.*, 2024), and others applied fuzzy methodologies (e.g., Atijosan *et al.*, 2021). While these approaches provide valuable insights, the FAO Land Suitability Evaluation (LSE) framework stands out for its simplicity and robustness (FAO, 2016). This framework classifies land units into suitability classes, from highly suitable (S1) to not suitable (N), based on soil and climatic requirements.

The FAO LSE framework offers significant advantages, including ease of application, reliance on widely available data, and consistency across regions. For instance, Awwal and Maniyunda (2023) used the FAO framework to evaluate maize, rice and cowpea suitability in Giwa LGA, while Fatihu *et al.* (2020) applied it to determine maize suitability in northwestern Nigeria. Okorocha *et al.* (2023) demonstrated its utility for cassava, classifying land in Bayelsa based on key soil attributes like drainage and fertility. Although the FAO LSE Framework has been widely adopted for other crops, its application in a bid to improve cassava suitability in the study area remains limited.

Wukari in Taraba State, Nigeria, features diverse soil types shaped by geological formations and climatic influences. These soils significantly affect agricultural potential. Understanding their alignment with cassava's growth needs is crucial for optimizing productivity while minimizing environmental degradation (Senjobi, 2007). The aim of this study is to utilize the FAO LSE framework in the assessment of cassava suitability in Wukari, integrating soil classification under the USDA system correlated with the FAO World Reference Base (WRB).

Materials and Method

Study Area

Wukari Local Government Area (L.G.A.) in Taraba State is an agricultural center known for cultivation of several crops including yam and sweet potato. With an average elevation of 155 m above sea level, the area has a tropical climate characterized by both dry and wet seasons (Angye *et al.*, 2024). The annual precipitation average at 886.1 mm yr^{-1}, the annual average relative humidity is 44.9%, the minimum and maximum temperature is 13.3°C and 40.8°C respectively, averaging at 27.7°C.

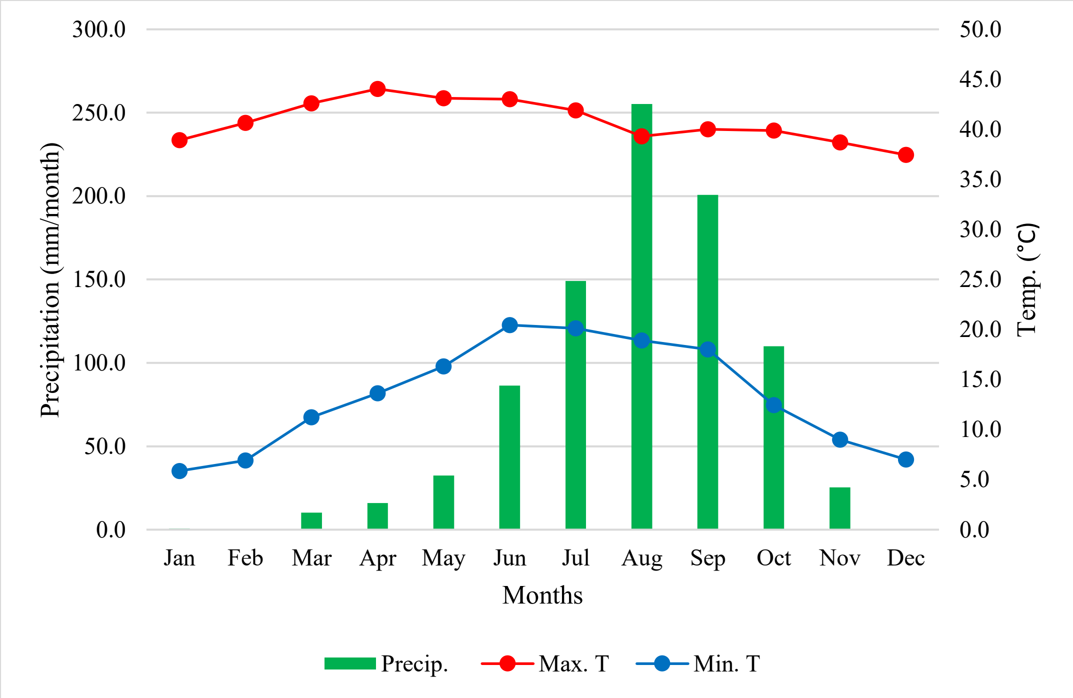

Figure 1: Showing Mean Monthly Precipitation, Maximum and Minimum Temperatures of the Study Area from 1992 to 2022

The soils in Wukari L.G.A. are mainly derived and dominated by underlying sedimentary rocks, which are found in different formations across the region (National Bureau of Statistics [NBS], 2009). Wukari L.G.A. is drained by several rivers and streams that flow into the Benue River, including River Donga, River Katsina-Ala, River Kam, and River Benue at Ibi. These rivers provide water for domestic, agricultural, and industrial purposes in the area and also serve as transportation routes for people and goods, especially during the rainy season (Ezekiel *et al.*, 2023).

Reconnaissance survey and profile description

A reconnaissance survey was conducted to identify three land units under agricultural use in Wukari based on subtle geomorphic characteristics, including microrelief variations, and soil surface conditions. At representative sites of each land unit, a pedon was excavated, and the genetic horizons were identified and described. In the field, morphological properties were recorded following the USDA Soil Survey Manual (Soil Science Division Staff, 2017). Observed features included depth, horizon thickness, colour, structure, texture, consistence, horizon boundary, roots, pores, and other distinguishing characteristics. Additionally, soil samples were collected from genetic horizons, labelled, processed, and used for laboratory analyses of selected soil properties.

Laboratory Analyses

Particle size distribution was determined using the Bouyoucos hydrometer method, while bulk density was measured using the core sampler method, both following standard protocols described by Gee and Or (2002). Soil pH was measured with a pH meter in a 1:2.5 soil-to-water. Organic carbon was analyzed using the dichromate wet combustion method outlined by Nelson and Sommers (1996), while total nitrogen was assessed through the Kjeldahl digestion method according to Bremner and Mulvaney (1982). Available phosphorus was determined using the Bray II extraction method described by Olsen and Sommers (1982). Exchangeable acidity and exchangeable bases were measured through KCl extraction and ammonium acetate leaching methods, respectively (Thomas, 1982), from which the base saturation percentage was calculated using the effective cation exchange capacity.

Soil Classification
Soil classification was carried out according to the USDA Soil Taxonomy (Soil Survey Staff, 2022) and correlated to the FAO World Reference Base for Soil Resources (IUSS Working Group, 2022).

Suitability Evaluation
To assess soil suitability for rainfed cassava production, the parametric approach of land suitability evaluation was employed. Climatic factors such as rainfall, length of dry season, and temperature; topographical factors like slope; wetness indicators including drainage; and soil physical and fertility characteristics were considered (Table 1). Suitability was determined by matching land qualities with crop requirements (FAO, 1976; Sys *et al.*, 1993), and an index of productivity (IP) was calculated using the equation,

$$Index\ of\ Productivity\ (IP) = A \times \sqrt{\prod_{i=4}^{4} \frac{S_i}{100}}$$

Where A was the most limiting climatic variable, while S_i refers to other land quality indicator used in this study. This approach allowed for actual and potential suitability ratings, with the latter considering inherent limitations that are traditionally corrected, like fertility as non-limiting (Udoh *et al.*, 2012). The IP was then used to classify the soil units as either S1 (highly), S2 (moderately), S3 (marginally) or N1 (currently not) suitable, with values that correspond to <74, 74 – 50, 49 – 25, and 24 – 14 respectively, as per Udoh *et al.* (2012).

Table 1: Land Use Requirements for Cassava

S/N	Land quality criteria	Suitability Classes				
		S1 (100)	S2 (75)	S3 (50)	N1 (25)	N2 (15)
A.	**Climate (c)**					
	Annual rainfall (mm yr^{-1})	1000-1800	600-1000	500-600	400-500	<400
	Length of dry season (months)	3-5	5-6	6-7		>7
	Mean annual temp. (ºC)	20-30	>30	16-12		<12
B.	**Soil Physical Properties (s)**					
	Soil depth (cm)	>100	75-100	50-75	<50	
	Texture	L, SCL, SL, SiC, SiCL, CL, SiL, SC	LFS, LS, FS	LFS, LS, FS	Si	S, C
C.	**Topography (t)**					
	Slope (%)	0-8	8-16	16-30	30-50	>50
D.	**Wetness (w)**					
	Drainage	Well	Moderate	Poor	Very poor	Non-drain
E.	**Fertility (f)**					
	Organic carbon (g kg^{-1})	8-15	5-7	3-6	1-2	<1
	pH	5.5-7.5	5.0-5.5 7.5-8.0	4.0-4.9 8.0-8.5	4.0-8.0	<4.0, >8.0
	Total N (g kg^{-1})	>1.5	1.0-1.5	0.8-1.0	0.4-0.8	<0.4
	Available P (mg kg^{-1})	>22	13-22	7-13	3-7	<3
	Base saturation (%)	>35	20-35	10-19	<10	

Keys: L – loam, SCL - sandy clay loam, SL - sandy loam, SiC - silty clay, SiCL - silty clay loam, CL - clay loam, SiL - silty loam, SC - sandy clay, LFS - loamy fine sand, LS – loamy sand, FS - fine sand, C - clay, Si - silt; CEC - cation exchange capacity.
Source: Modified from Sys *et al.* (1993)

Results and Discussion

Morphological and Physical Properties of the Studied Pedons

The depth and differentiation of soil horizons across the pedons indicate varying degrees of pedogenic development. The Ap horizons are generally shallow in Pedon 2, with a depth of 14 cm, compared to 20 to 22 cm in Pedons 2 and 3 (Table 2). This suggests a slightly more developed surface layer in the latter Pedons, attributable to prolonged surface stabilization or higher organic matter accumulation (Aiser and Guggenberger, 2003). Colour transitions between horizons corroborate the degree of soil development, with the shift from reddish hues in the Ap horizons (2.5YR 6/4) to lighter colours in the Bt horizons (5YR 7/8 in Bt3 of Pedon 1), revealing changes in organic matter content and oxidation conditions (Table 2) (Rowe, 2005).

There was a preponderance of sand sized particles in the Ap horizons (83.9 – 61.9%) indicative of soils with high permeability but low water retention capacity (Weil and Brady, 2017). This is a trademark of soils developed on sedimentary basement complexes as postulated by Esu (2010). In contrast, Bt horizons exhibited a marked increase in clay content, particularly in Pedon 1, where clay content reached a maximum of 30.0% in Bt2. Such variations in texture indicates effective eluviation of finer particles from the surface and their subsequent deposition in the subsurface horizons (Awwal, 2021).

Structural development varied significantly among the pedons and horizons. Ap horizons predominantly exhibited weak granular structures, indicative of lower compaction and frequent pedoturbation (Alamanisa and Chouliara, 2018). Bt horizons showed more developed subangular blocky structures, particularly in Pedon 2 (1msbk in Bt1), which is expected to enhance water retention and root penetration at depth. Bulk density increased with depth across all pedons, consistent with compaction and reduced organic matter content in the subsurface (Awwal and Maniyunda, 2023). The lower bulk density in Ap horizons, such as 1.21 Mg m^{-3} in Pedon 1, favours root growth and water infiltration, while higher bulk densities in Bt horizons, such as 1.45 Mg m^{-3} in Bt2 of Pedon 3 are typical, but not high enough to restrict root elongation and soil aeration (Hillel, 2007)

Table 2: Soil Morphological Properties

Horizon	Depth (cm)	Colour (moist)	Sand	Silt	Clay	Texture Class	BD Mg m^{-3}	Structure Class	Other features
				(%)					
Pedon 1: (7° 50' 37.70" N, 9° 45' 51.10" E)									
Ap	0-20	2.5YR 6/4	80.2	7.4	12.4	SL	1.21	1fg	Common medium roots
Bt1	21-46	5YR 5/8	67.9	10.0	22.1	SCL	1.42	1msbk	Common fine roots
Bt2	47-80	2.5YR 6/8	62.9	7.1	30.0	SCL	1.45	1fsbk	Common medium roots
Bt3	81-120	5YR 7/8	68.8	6.1	25.1	SCL	1.43	2cp	Common medium roots
Pedon 2: (7° 50' 44.57" N, 9° 46' 7.18" E)									
Ap	0-14	7.5YR 6/4	83.9	5.1	11.0	SL	1.31	1fg	Common fine roots
Bt1	15-54	7.5YR 6/8	61.9	8.1	30.0	SCL	1.43	1msbk	Few fine roots
BC	55-110	7.5YR 8/6	75.4	6.4	18.2	SL	1.45	1mcr	Few medium roots
Pedon 3: (7° 50' 47.43" N, 9° 46' 16.16" E)									
Ap	0-22	2.5YR 4/3	82.6	7.4	10.0	SL	1.33	0fg	Common medium roots
Bt1	23-50	2.5YR 6/4	73.4	5.4	21.2	SCL	1.44	1fg	Few fine roots
Bt2	51-90	2.5YR 6/8	67.6	8.4	24.0	SL	1.45	2mcr	Few medium roots
BC	91-130	2.5YR 8/8	78.0	7.0	15.0	SL	1.44	3cp	Common medium roots

Soil Classification

Based on the USDA Soil Taxonomy, the presence of an argillic horizon characterized by significant clay accumulation compared to the surface horizon and high base saturation (>35%) as depicted in Figure 3a and 3b, all three pedons classify under the Alfisols order. At the sub-order level, the region's semi-arid conditions and moderate soil moisture regime, inferred from the morphological features such as the 2.5YR and 7.5YR hues, classify as Ustic, placing the pedons under Ustalfs.

The absence of a petrocalcic horizon, natric horizon, or other significant limiting subsurface features qualifies Pedons 1 and 3 as a Haplustalf, while evidence of extended weathering, with thick and well-developed Bt horizons extending deeper than in Pedons 1 and 3, characterize Pedon 2 as Paleustalfs. Furthermore, due to a lack of atypical characteristics, all pedons classify as Typic at the subgroup level. These correspond to Haplic Lixisols in the FAO World Reference Base, evidenced by the presence of an argic layer, high base saturation (>50%), high CEC-clay (Figure 3c), and the absence of stagnic or gleyic features. A summary of pedon classification is shown in Table 3

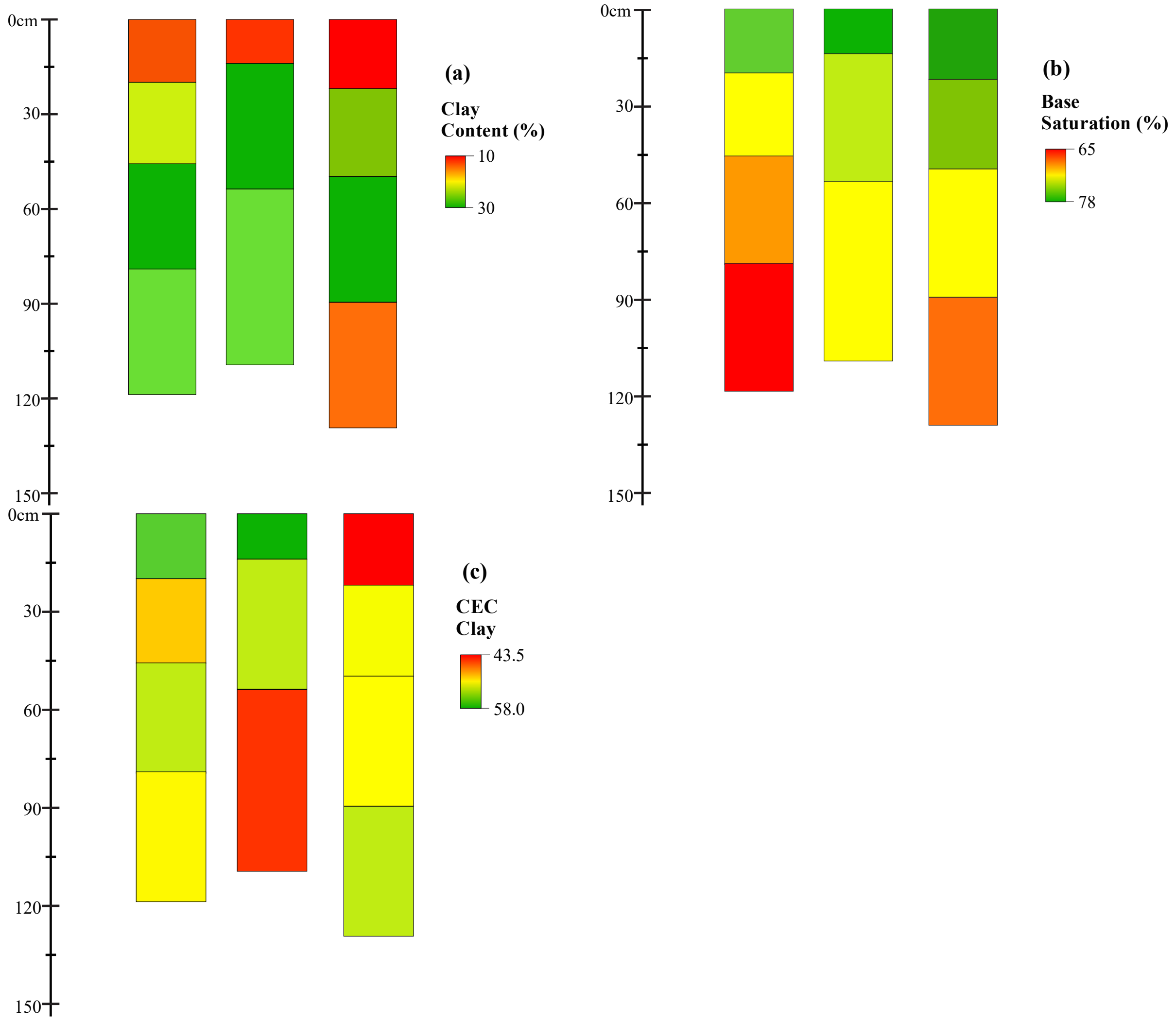

Figure 3: Vertical Distribution of (a) Clay Content (b) Base Saturation (c) CEC Clay values across Studied Pedons

Table 3: Summary of Pedon Classification According to USDA and WRB Taxonomy

Pedon	USDA Soil Taxonomy				WRB (FAO)
	Order	Suborder	Great Group	Subgroup	
Pedon 1	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalf	Haplic Lixisol
Pedon 2	Alfisols	Ustalfs	Paleustalfs	Typic Paleustalf	Haplic Lixisol
Pedon 3	Alfisols	Ustalfs	Haplustalfs	Typic Haplustalf	Haplic Lixisol

Cassava Suitability Classification

Climatic Suitability

The climatic requirements of cassava showed varying levels of suitability in the study area. With an annual rainfall of 886.1 mm yr^{-1}, precipitation was classified as S2 in all soil units, indicating moderate suitability (Table 4). However, cassava's deep-rooting system and efficient water-use strategies allow it to thrive under such conditions, reducing the risk of water stress (Maniyunda and Ya'u, 2023). The length of the dry season was rated as highly suitable (S1), as cassava can tolerate extended dry periods. Additionally, the mean annual temperature of 27.7°C was optimal for cassava growth and also classified as S1. These findings suggest that while rainfall may be slightly limiting, the overall climatic conditions remain favourable for cassava cultivation.

Soil Physical Property Suitability

The slopes of all pedons were rated S1, signifying that the topography is highly suitable for cassava production. Gentle slopes enhance water infiltration, reduce the risk of erosion, and facilitate mechanized farming practices (Magdić *et al.*, 2022), all of which are favorable for root crop production. This land quality does not require further intervention. Similarly, the drainage condition across all pedons was rated as S1, indicating well-drained soils conducive to cassava growth, since proper drainage reduces the risk of waterlogging, which can compromise root health and productivity (Alves *et al.*, 2024)

Table 4: Summary of Land Suitability Criteria for the Pedons

Land Suitability Criteria		Pedon 1	Pedon 2	Pedon 3
A.	**Climate (c)**			
	Annual rainfall (mm yr^{-1})	886.1	886.1	886.1
	Length of dry season (months)	5	5	5
	Mean annual temp. (°C)	27.7	27.7	27.7
B.	**Soil Physical Properties (s)**			
	Soil depth (cm)	>120	>110	>130
	Texture	SCL	SCL	SCL
C.	**Topography (t)**			
	Slope (%)	0-1	0-1	0-1
D.	**Wetness (w)**			
	Drainage	Well-drained	Well-drained	Well-drained
E.	**Fertility (f)**			
	Organic carbon (g kg^{-1})	10.9	14.4	13.7
	pH	5.05	5.23	5.6
	Total N (g kg^{-1})	1.21	1.31	1.17
	Available P (mg kg^{-1})	11.32	10.15	11.22
	BSECEC (%)	85.4	87.4	88.2

The soil texture in all pedons ranged from laomy sand to sandy loam which provide optimal aeration, water retention, and root penetration, and were hence rated S1. Additionally, soil depth in all pedons exceeded 100 cm further supporting unrestricted root development and nutrient uptake (Nungula *et al.*, 2024). These characteristics demonstrate that the physical properties of the soil are highly suitable for cassava cultivation without the need for physical amendments.

Soil fertility Suitability

Soil fertility posed significant limitations to cassava suitability across the pedons. Organic carbon (OC) levels in Pedon 1 were critically low (N1), while Pedons 2 and 3 were classified as S3. The deficiency in OC can limit soil microbial activity, nutrient availability, and overall soil health (Blanco-Canqui *et al.*, 2013). Similarly, available phosphorus was rated S3 in all pedons, highlighting a moderate constraint for cassava, as phosphorus is essential for root development and crop productivity (Weil and Brady, 2017). Conversely, total nitrogen and soil pH were rated S1, suggesting that these parameters are not limiting factors for cassava cultivation in the area.

Suitability Classification

The integrated suitability index (IP) was employed to arrive at the final suitability classes for the three studied soil units. An

IP of 53.03 was gotten for all three Pedons, which was considered moderately suitable, with constraints in climate and fertility. However, with fertility improvements, the potential suitability of all pedons could be elevated to S1, with an IP of 75. This improvement can be achieved through organic matter incorporation to boost soil OC and available P content. Based on the FAO (1976) yield estimates, cassava productivity could vary between 10 – 20 t ha^{-1}, with a potential to reach 20 – 30 t ha^{-1} in the study area

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Figure 5: Suitability Scores for Land Quality Indicators

Land Suitability Criteria	Soil Unit 1	Soil Unit 2	Soil Unit 3
A. Climate			
Annual rainfall	S2 (75)	S2 (75)	S2 (75)
Length of dry season	S1 (100)	S1 (100)	S1 (100)
Mean annual temp.	S1 (100)	S1 (100)	S1 (100)
B. Soil Physical Properties			
Depth	S1 (100)	S1 (100)	S1 (100)
Texture Class	S1 (100)	S1 (100)	S1 (100)
C. Topography			
Slope (%)	S1 (100)	S1 (100)	S1 (100)
D. Wetness			
Drainage Class	S1 (100)	S1 (100)	S1 (100)
E. Fertility			
OC	S1 (100)	S1 (100)	S1 (100)
pH	S2 (75)	S2 (75)	S1 (100)
Total N.	S1 (100)	S1 (100)	S1 (100)
Avail. P	S3 (50)	S3 (50)	S3 (50)
BS	S1 (100)	S1 (100)	S1 (100)
IP (Actual)	53.03	53.03	53.03
Current Suitability Class	**S2-cf**	**S2-cf**	**S2-cf**
IP (Potential)	75	75	75
Potential Suitability Class	**S1**	**S1**	**S1**

Conclusion

The studied pedons exhibited distinct pedogenic development, with well-structured argillic horizons and textural differentiation indicative of eluviation-illuviation processes. Soil classification aligned with USDA Typic Haplustalfs and Typic Paleustalfs, corresponding to FAO Haplic Lixisols. Cassava suitability analysis showed that climatic conditions were largely favorable, with slight limitation in rainfall (S2). Soil physical properties, including slope, drainage, and depth, were highly suitable (S1) for cassava growth. However, soil fertility posed a major limitation, with low OC (N1) and avail. P (S3) levels. The integrated suitability index placed the pedons in the moderately suitable class (S2-cf), but targeted fertility improvements, particularly organic matter incorporation and phosphorus supplementation, could elevate the potential suitability to S1, boosting cassava yields from 10–20 t ha^{-1} to 20–30 t ha^{-1}. Thus, site-specific soil fertility management remains critical for optimizing cassava productivity in the study area.

References

Aiser K.K. and Uggenberger G.G. (2003). Mineral surfaces and soil organic matter. *European Journal of Soil*

Science, 54, 219–236 pp. DOI: 10.1046/j.1365-2389.2003.00544.x

Alamanisa N., Chouliara I (2018). Improvement to Loose Soils. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS),* 43(1), 190-210pp.

Alves A.F., de Freitas C.P.O., Alencar A.J., Zanon J., Streck N.A., Cardoso P.S., Tardetti F.A. (2024). Water excess and its effect on cassava growth and yield. *Revista Ceres, Viçosa*, v. 71, e71016. DOI: 10.1590/0034-737X2024710016

Angye G.F., Ezekiel B., Bwasi A.Y., Oruonye E.D., Magaji M.M., Albert R.K. (2024). Effects of Climate Variability on Maize Yield in Wukari Local Government Area of Taraba State, Nigeria. *African Journal of Agriculture and Food Science*, 7(4): 288- 307. DOI: 10.52589/AJAFSQUR886VL

Atijosan A., Ewang E., Badru R., Taofeek A. (2021). Land Suitability Evaluation for Cassava Production Using Integral Value Ranked Fuzzy AHP and GIS Techniques. *International Journal of Hybrid Information Technology* Vol. 14(No.1 (2021)):45-62. DOI: 10.21742/ijhit.2021.14.1.03

Awwal Y.A. and Maniyunda L.M. (2023). Toposequence effect on soil properties and suitability rating for selected crops in Northern Guinea Savanna, Nigeria. *Journal of Agriculture and Environment*. Vol. 19(2): 215-235pp.

Awwal, Y.A. (2021). Influence of toposequence on soil properties, genesis, suitability and degradation at Hayin Gada, Zaria Nigeria. MSc. Thesis. Ahmadu Bello University, Zaria, Nigeria.

Blanco-Canqui H., Shapiro C.A., Wortmann C.S., Drijber R.A., Mamo M., Shaver T.M., and Ferguson R.B. (2013). Soil organic carbon: The value to soil properties. *Journal of Soil and Water Conservation* 68(5):129A-134A. DOI: 10.2489/jswc.68.5.129A

Bremner J.M. and Mulvaney C.S. (1982). Nitrogen-Total. In: Methods of soil analysis. Part 2. Chemical and microbiological properties, Page, A.L. Miller, R.H and Keeny D.R. Eds. American Society of Agronomy, Soil Science Sciety of America, Madison, Winsconsin, 595-624.

Esu I.E. (2010). *Soil characterization, classification and survey*. HEBN Publishers, Plc, Ibadan, Nigeria, 232pp.

Ezekiel B.B., Adelalu T.G., Christopher J.N., Alhassan T. (2023). Assessment of agro allied chemical pollution on surface water quality of River Lamurde and mayo-gwoi, Jalingo, Taraba state, Nigeria. *Advances in Environmental and Engineering Research*, *4*(1), 1-21.

FAO (1976). *A framework for land evaluation*. Soils Bulletin 32. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2016). Land suitability classifications. A framework for land evaluation. Natural Resources Management and Environment Department. Retrieved from www.fao.org/docrep/x5310e/x5310e04.htm.

Fatihu S., Maniyunda L. M. and Awwal Y.A. (2020). Assessment of Soil Properties under different Land Uses and their Suitability for Maize (*Zea mays*) Production in Hunkuyi, Northern Guinea Savanna, Nigeria. *Dutse Journal of Agriculture and Food Security (DUJAFS)*, 7(1): 9-21 pp.

Ferraro V., Piccirillo, C., Tomlins K. and Pintado M. E. (2016). Cassava (Manihot esculenta Crantz) and yam (Dioscorea spp.) crops and their derived foodstuffs: safety, security and nutritional value. *Critical reviews in food science and nutrition*, *56*(16), 2714-2727.

Gee, G.W., Or, D., (2002). Particle-size analysis. In: Dane, J.H., Topp, G.C. (Eds.), *Methods of Soil Analysis.* Part 4. Physical Methods. SSSA, Inc., Madison, WI, pp. 255-294pp.

Hillel D. (2007). *Soil in the environment: Crucible of terrestrial life*. Elsevier.

Ikuemonisan E.S., Mafimisebi T.E., Ajibefun I., Adenegan K. (2020). Cassava production in Nigeria: trends, instability and decomposition analysis (1970–2018). *Heliyon*, *6*(10).

International Institute of Tropical Agriculture [IITA] (2022). Annual Report. Ibadan, Nigeria. Available online at www.iita.org/annual-reports

IUSS Working Group WRB. (2022). *World Reference Base for Soil Resources: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps* (4th ed.). International Union of Soil Sciences (IUSS).

Magdić I., Safner T., Rubinić V., Rutić F., Husnjak S., Filipović V. (2022). Effect of slope position on soil properties and soil moisture regime ofStagnosol in the vineyard. *Journal of Hydrology and Hydromechanics*, 70(1), 1–6. https://doi.org/10.2478/johh-2021-0037

Maniyunda, L. M. and Ya'u, S. L. (2023). Evaluation of Land Suitability for Rice (*Oryza sativa* L.) and Cassava (*Manihot esculenta Crantz*) Production on Selected Soils across Niger State, Nigeria. *Nigerian Journal of Soil and Environmental Research*, 22: 2023 59 – 70.

National Bureau of Statistics NBS (2009). Geological Survey of Nigeria. National Bureau of Statistics and Landuse Planning Publication 2009.

Nelson D.W. and Sommers L.E. (1996). *Total Carbon, Organic Carbon, and Organic Matter. In: Black, C.A., Ed., Methods of Soil Analysis. Part 3*. Chemical Methods, Soil Science of America and American Society of Agronomy, Madison, 961-1010.

Nungula E.Z., Massawe B.J., Chappa L.R., Nhunda D.M., Seleiman M.F., Ali N. and Gitari H.I. (2024) Multicriteria land suitability assessment for cassava and bean production using integration of GIS and AHP. *Cogent Food & Agriculture*, 10:1, 2333316, DOI: 10.1080/23311932.2024.2333316

Nweke, Felix, I., Spencer, Dunstan, S. and Lynam, John, K. (2001). *The Cassava Transformation: Africa's best kept secret*. Michigan State University Press, East Lansing.

Okorocha O.M., Onweremadu E.U., Ahukaemere C.M., Aririguzo B.N. and Onyechere A.U. (2023). Current and Potential Soil Suitability for Cassava for Sustainable Production in Varying Soils of Bayelsa State Nigeria. *International Journal of Research and Innovation in Applied Science* VIII(VII):48-57. DOI: https://doi.org/10.51584/IJRIAS.2023.8705

Olsen S.R. and Sommers L.E. (1982). Phosphorus. *In: Page A.L., Miller R.H. and Keeney D.R. (eds.), Methods of Soil Analysis Part 2 (pp. 403-434).* Agron. Monogr. No. 9. Madison WI: ASA and SSSA

Onyediako, P. O. and Adiele, J. G. (2022). Enhanced Cassava Production for Food Security and Economic Development in Nigeria: A review. *Nigerian Agricultural Journal*, 53(3), 204-211pp.

Purnamasari R.A., Ahamed T., Noguchi R. (2018). Land suitability assessment for cassava production in Indonesia using GIS, remote sensing and multi-criteria analysis. *Asia-Pacific Journal of Regional Science* 3(5):1-32pp. DOI: 10.1007/s41685-018-0079-z

Rowe W. F. (2005). Forensic applications. In D. Hillel (Ed.), *Encyclopedia of soils in the environment* Vol. 2, 67–72 pp. Elsevier. DOI: 10.1016/B0-12-348530-4/00495-1

Sánchez, T., Vilchez, S., Ocampo, J., Fuentes, L., and Rumayor, R. (2014). The role of soil properties on cassava yield in rainfed and irrigated systems. *Soil Science and Plant Nutrition*, 60(1), 27-39pp.

Senjobi, B. A. (2007). Comparative assessment of the effect of land use and land type on soil degradation and productivity in Ogun State, Nigeria. 161pp. Unpublished Ph.D. Thesis submitted to the Department of Agronomy, University of Ibadan, Nigeria.

Soil Survey Division Staff (2017). Keys to Soil Taxonomy. Twelfth Edition, United States Department of Agriculture (USDA). Agric. Handbook. No 436. U.S. Gov. Print., Office. Washington, DC. 346 pp.

Soil Survey Staff. (2022). *Keys to Soil Taxonomy* (13th ed.). United States Department of Agriculture, Natural Resources Conservation Service.

Sys C., Van Ranst E., Debaveye I. J. and Beernaert F. (1993). *Land evaluation. Part III: Crop requirements*. General Administration for Development Cooperation, Agricultural Publication-No. 7, Brussels, Belgium. Pp. 199.

Thomas G.W. (1982). Exchangeable cations. *In: Page A.L., Miller R.H. and Keeney D.R. (eds.), Methods of Soil Analysis* Part 2 (2nd ed., 159-165pp.). Agron. Monogr. No. 9. Madison WI: ASA and SSSA

Udoh, B.T. and Ogunkunle, A.O. (2012). Land Suitability Evaluation for Maize (*Zea mays*) Cultivated in a Humid Tropical Area of South Eastern Nigeria. *Nigerian Journal of Soil Science,* 22(1): 1 – 10pp.

Weil R.R., and Brady N.C. (2017). *The Nature and Properties of Soils*. 15th Edition. Pearson Education Publisher. ISBN: 978-0133254488

Zemba A.A., Kefas J. and Hamza A. (2017). Land suitability analysis for decision-making in cassava (*Manihot spp*.) Cultivation in southern part of Adamawa state, Nigeria. *Global Journal of Agricultural Sciences*, 16(2017): 1-10pp. DOI: 10.4314/gjass.v16i1.1

Zulkarnain Z., Zakaria W. A., Haryono D., Murniati K. (2021). Economic efficiency and risk of cassava farming in Lampung province. *International Journal of Financial, Accounting, and Management*, 3(2), 129-148. DOI: 10.35912/ijfam.v3i2.433

INFLUENCE OF *JATROPHA CURCAS* ON QUALITY RECLAMATION OF DEGRADED SUDAN SAVANNAH ALFISOLS

[1]Aminu, Y., [1]Danturai, S.A., [2,3]Sani, A., [3]Abdullahi, R., [1,4]Abubakar, M.B., [1]Kafinga, M.H., [2]Adam, I.A, [2]Aliyu, R.W., [2]Amin, M.A., [2]Hayatu, B.S., [2]Lamido, A.K and [2,5]Auwal, M

[1]Department of Forestry and Wild Life Management, Aliko Dangote University of Science and Technology, Wudil, PMB 3244, Kano State, Nigeria

[2]Soil Science Department, Aliko Dangote University of Science and Technology, Wudil, PMB 3244, Kano State, Nigeria.

[3]Department of Crop Science, Umaru Musa Yar'adua University Katsina, PMB 2218 Katsina State, Nigeria

[4]Department of Agroforestry and Environment, Hajee Muhammad Danish, Science and Technology University, Dinajpur, PMB 5200, Bangladesh

[5]Institute of Soil and Water Resources and Environmental Science, Zhejiang Provincial Key Laboratory of Agricultural Resources and Environment, Zhejiang University, Hangzhou 310058, China

Corresponding author email:abdulrikegam25@gmail.com

ABSTRACT

A nursery experiment was conducted at the Department of Forestry and Wild Life Management, Aliko Dangote University of Science and Technology, Wudil to assess the influence of Jatropha curcas plant on quality restoration of degraded alfisols. The experiment was arranged in a completely randomized design (CRD) with 3 replications and control. Pre and post Jatropha planting soil samples were analyzed for soil physicochemical quality properties in Jatropha seeds and cuttings with and without organic amendment used for the experiment. Findings indicated that at pre and post Jatropha planting periods, the pH of the soils were within the range of 6.77-7.02 and their texture were sandy loam and loamy sand. The results also revealed that seed without organic amendment (SF) recorded high reclamation potential in chemical soil quality parameters; with an increase in nitrogen content N (>90%) and exchangeable magnesium, Mg (71%) while seed with organic amendment (SO) also recorded high organic carbon content increase OC (>90%) and cation exchange capacity CEC (64%) at post Jatropha planting period compared with pre-planting period. Moreover, cuttings with organic amendment (CO) recorded the highest reclamation percentage change in phosphorous, potassium, exchangeable sodium and calcium (>90%) in that order compared with other treatments at post Jatropha planting period. For soil physical quality indices however, SO, recorded a decrease of 19% for bulk density BD and 27% increase in aggregate stability MWD values respectively, whereas CO recorded the highest percentage rise in soil porosity of 77% compared with other treatments in that order at the expiration period of the experiment. Statistically, both physical and chemical soil quality parameters showed significant variation (P<0.05) with Jatropha plant, where SO and CO in major soil quality parameters; OC, N, P, K, MWD and CEC significantly recorded highest values in comparison with other treatments at post Jatropha planting period. Overall, the research findings have shown that Jatropha curcas have the ability to reclaim degraded marginal soils quality and improve them effectively particularly if grown in cuttings and amended with organic amendments.

Keywords: *Jatropha curcas*, reclamation, marginal land, soil quality, organic carbon

1.0 Introduction

The environmental impacts of anthropogenic activities are increasing at an alarming rate and severe climatic changes are taking place globally. This, in turn, contributes to an increase in the trend of the average daily air temperature and deterioration of the water regime of soils (Biliavskyi and Biliavska, 2019). Batjes (2001) reported that degraded soils in Africa account to about 494 million hectares and about 65% of them are degraded because of soil chemical and physical erosions.

Nigerian soils are geologically old, highly weathered, leached and with very low nutrient and water holding capacities. Consequently, the soils decline in quality and fertility due to loss of soil chemical properties (Bello and Akinrinde, 2005). Conversely, the soils of Northern Nigerian Savanna are predominantly Alfisols, Inceptisols, Oxisols and Ultisols. The latter especially, are characterized by low activity clays (Salako *et al.,* 2001), small amount of organic matter content and high sand proportion in the surface layers which make them physically fragile and susceptible to degradation. Hence, the soils need huge amount of external inputs and other related management practices such as inorganic and organic fertilizers to replenish their poor or less nutrients concentration, and reclaim their quality and productivity. However, application of these management practices are strenuous, labor intensive and economic demanding particularly on buying inorganic fertilizers. Subsequently, the need for simpler, less intensive and cheap sources of providing the required nutrients to improve the marginal soils quality like *Jatropha curcas* (henceforth referred as Jatropha)

Jatropha is a drought-tolerant shrub belonging to Euphorbiaceae family and is widely distributed in tropical and subtropical regions (Wurdack *et al.,* 2005). The shrub has the ability to thrive on marginal lands under climate and soil conditions that are unsuitable for food crop production and it has the potential of restoring marginal and degraded soils, increase their quality and fertility by re-anchoring the soils with its substantial roots that reduce the possibility of erosion (Agbogidi et al., 2013).

Several studies have indicated that plantation of Jatropha served as a nutrient pump for the rehabilitation of degraded lands and enhances the quality, fertility and productivity of the soils through the shedding of its succulent leaves that are easily decomposed (Divakara et al., 2009; Pandey et al., 2012). In addition, its seedlings are known to have consistent root system architecture, with a prominent vertical taproot and four lateral roots branching at equal angles 90∘ (Reubens et al., 2011).

The contribution of the aforesaid Jatropha attributes in replenishing lost soil nutrients, soil quality, fertility and productivity enhancement with concomitant restoration of environmental quality degradation has made the plant a topic of concern globally in different areas of environmental studies including soil science (Ogunwole *et al.,* 2008; Pandey et al., 2012; Sani et al., 2022).

Studies have shown that the application of manure has positive effects on the physical and chemical properties of soils mainly due to increase in organic matter (Yolanda et al., 2014). The important roles of organic matter include being a rich source of essential plant nutrients (FAO, 2005), that helps in improving moisture holding capacity of the soil, soil structure, soil aeration, water permeability, acts as pH buffer, contains metal-organic matter complexes that help in making available micro nutrients to the plant (Ikeh et al., 2013) and enhances its reclamation ability. In addition, the plant has the potential of improving marginal land physical properties of alfisols such as bulk density, porosity, aggregate stability (Francis et al, 2005; Divakara et al, 2009), OC and other nutrients, increased aggregates turnover, soil structure and soil texture (Ogunwole et al., 2008).

Degraded alfisols are the key potentials of land degradation without any external additional input, and are global environmental problems that threaten the survival of more than 250 million people living in the dry lands of the developing world (FAO, 2011). Furthermore, it has been recognized to be one of the chronic and continuous problems that have been deteriorating natural resources at alarming rate. Hence, there is a need for effective measures to reclaim the degraded soils.

This research may provide useful information to agricultural and environmental industries to incorporate growing of Jatropha plant in their soil fertility and quality improvement with simultaneous environmental pollution management for sustainable crop production particularly on degraded or marginal alfisols.

There are quite number of researches conducted in Northern Nigerian Savannah on Jatropha plant (Shehu et al., 2016; Onwu *et al.*, 2018; Abdullahi *et al*., 2021; Sani *et al*. 2022). However, all these researches concerted their effort on the assessment of fertility and heavy metals concentration in soils planted to Jatropha while investigation on the potential of the plant in restoring the marginal quality of degraded alfisols particularly in Southern Sudan Savanna zone of Kano state was thinly implemented. Therefore, this research is geared towards filling this gap.

Hence, this research is aimed to assess the potentiality of Jatropha curcas on quality reclamation of marginal land soils while the specific objectives are;

i) To test the ability of Jatropha curcas on soil quality improvement of marginal land soils
ii) To determine the higher reclamation potential between seeds and cuttings on the marginal land soils with and without organic amendment.
iii) To assess the soils physical and chemical nutrients at pre and post marginal land soils treatments.

2.0 Materials and methods

2.1 Study area and Experimental site description

The experiment was carried out in the university nursery unit of Forestry and Wild Life Management Department, Aliko Dangote University of Science and Technology, Wudil. The geographical location of the site is between N11˚48’18” latitude and E8˚51’40” longitude, and about 37.5 m above sea level with annual rainfall and temperature ranging from 850 to 870 and 26 and 33ºC respectively. The relative humidity of the region is always low and ranges between, 40 to 51.3% (Olofin *et al.,* 2008)

2.2 Collection, preparation of soil samples and duration of the experiment

Three undisturbed core samples were collected to determine the soil bulk density and porosity from the sampling area as depicted in figure 1 in addition to another 12 degraded and 3 control soils that were used for the nursery experiment. The sampled soils were measured at pre and post Jatropha planting periods with seeds and cuttings in the experimental pots respectively. Furthermore, the experimental soils were thoroughly mixed with the quantity of organic fertilizer (in the case of organic amended treatments) in the ratio of 2:1 and well watered prior to sowing to assess the impact of organic amendment on the performance of Jatropha in soils quality improvement.

The experiment lasted for good three months from March 15 to June 15, 2023 during which the Jatropha plant has attained juvenility of growth capable of reclaiming the soils (Ofelia et al., 2013). The plant was watered twice daily and then reduced to once when the plant exceeded two months of growth, hand weeding was done as well as proper supervision of the experimental site during the whole period of the experiment.

2.4 Experimental treatments

The treatments were Jatropha plant seed free of organic matter amendment (SF) T1, cuttings free of organic matter amendment (CF) T2, seed with organic matter amendment (SO) T3 and cutting with organic matter amendment (CO) T4, tested on a free amended marginal soils and organic amended marginal soils. Whereby T0 is the control.

The experimental pots were labeled according to their composition where each treatment was replicated three times given a total of twelve (12) samples and 3 control soils, all arranged in a completely randomized design (CRD).

2.5 Laboratory analyses

The physical and chemical parameters of the soils were analyzed at pre and post planting Jatropha using standard procedures; Bulk density by core sampler method (Blake and Hartge, 1986), Porosity by the procedure of Rattan (2009). MWD was estimated using the amount of aggregate in each sieve size range which was determined as a fraction of the initial air-dried samples weight. The MWD was calculated as the sum of multiplication of the mean diameter of each size fraction and the proportion of the sample weight occurring in the corresponding size fraction (Van Bavel, 1950). Soil pH and EC were determined using pH and conductivity meter respectively, Cation Exchange Capacity (CEC) was determined using neutral pH_7 in NH_4OAC saturation method as described by Anderson and Ingram (1993), Organic Carbon was determined by the dichromate oxidation method as detailed by Nelson and Sommers (1982) while Mechanical Analysis was by standard hydrometer method as outlined by Gee and Bauder (1986). Total Phosphorus was determined by acid digestion as outlined by Murphy and Relay (1962), Total Nitrogen content was determined using the micro-Kjeldhal technique as described by Bremner (1996) while The exchangeable bases of Na and K were determined using the flame photometer; Mg and Ca were determined using atomic absorption spectrophotometer.

2.6 Statistical analysis

To assess the level of soil quality parameters and their corresponding differences, data mean values of the parameters concentration were subjected to analysis of variance (ANOVA) using R statistical software. The treatment means were separated using Least Significant Difference (LSD) at 5% level of probability. Percentage change in soil parameters was calculated using the formula below.

% change in soil parameters, ð = $\left(\frac{X2-X1}{X1}\right)$ 100 (Abdullahi et al., 2021), where X1 = Soil parameter level at the beginning of study period, X2 = Soil parameter level at the end of the study period and ð= percentage change in soil nutrients

3.0 Results and Discussion

3.1 Experimental soil quality at pre-planting Jatropha period

Table 1 shows the overall mean values of experimental soil properties of the study area before planting Jatropha. The recorded values of pH were neutral (Msanya, 2012; Sani et al., 2021), electrical conductivity, organic carbon, phosphorous, nitrogen, exchangeable cations and cation exchange capacity were of low concentration and belonged to low fertility and quality classes (Esu, 1991; Sani et al., 2022). Moreover, the bulk density of the soil recorded 1.70g/cm^3 which was above the permissible limit of 1 to 1.6 g/cm3 (FAO, 2020) whereas low porosity of 28.08% was recorded due to the high level of compactness in the soil as one of the major characteristics of marginal soils as reported elsewhere (Bello and Akinrinde, 2005) indicating characteristics of degraded soils of marginal quality status that are vulnerable to erosion (Sani et al., 2022) and not compliant with quality standard of agricultural soils.

3.2 Effect of Jatropha on Soil Quality Reclamation

3.2.1 Comparison of Soil pH

Soil pH is an important index of soil quality and affects nutrients movement and their distribution in soil matrix. For instance, at low soil pH condition, the most needed nutrients by crops are not much available for absorption but the undesirable ones become more accessible and can reach level of toxicity (Sani et al., 2020) which can affect the grown crops. The result of the soil pH at post Jatropha planting period was shown in Table 2. The pH range was between 6.32 and 7.02 in all the treatments with significant difference recorded ($P>0.05$) between pre and post Jatropha planting period and the soils treatments (Tables 1and 2).

The pH values of the experimental soils at pre-Jatropha planting period were 6.77, however, at post planting period, the values for all the treatments decreased except for SO treatment; SW(6.32), CF(6.38), SO(7.02), CO(6.34) and O(6.35) respectively. This reduced pH values among the treatments could be attributed to the Jatropha plant roots ability to release exudates in the soil rhizosphere that might have caused the reduction in the pH values observed (Edris, 2015; Daliya, 2020). Conversely, the increased pH values recorded in SO treatment could be ascribed as a result of mineralization of organic matter leading to release of exchangeable cations which might have increased the recorded pH values (Table 2) indicating the impact of Jatropha plant on the pH of the treatments and was confirmed elsewhere (Ano and Agwu, 2005). Nonetheless, despite significant pH variation at pre and post Jatropha planting periods between the soil treatments, the pH range is within the range of compliance limit of qualitative agricultural soils (FAO, 2020).

3.2 Comparison of Electrical Conductivity (EC)

EC is a measure of the ability of a solution to carry an electric current or the concentration of soluble salts in the sample at any specific temperature. The EC values recorded at both pre and post Jatropha planting periods (Table 1) were below 4ds/m, a value considered acceptable for most crops (FAO, 1993). The result also indicated that Jatropha increased EC values with more than 80% in all the treatments (Table 3) despite being low in concentration. Moreover, the differences in the EC concentration between the treatments in both pre and post planting Jatropha periods was significant ($P<0.05$) according to Table 2 with SF recording the lowest values. The plausible reason for this difference could be credited to an increase in particles released from the plant roots and accumulation of exchangeable bases from decomposition of organic matter in the rhizosphere vicinity leading to the decrease and increase in the recorded EC values (Table 1) in the affected treatments and has been reported elsewhere (Habtamu, 2011; Sisay *et al*., 2016).

3.3 Comparison of Organic carbon (OC)

Soil OC is critical for the sustenance of plant growth. It is the carbon stored in soil organic matter content, which is the primary source of quality in soil (Jobbágy and Jackson, 2000). Overall, Accordingly, Table 1 showed an increase of OC in all the treatments with SO and CF at post Jatropha planting period recording the highest and lowest values respectively. In addition, the increase was highly significant ($P<0.05$) as depicted in Table 2. With regards to % increase or fall, the CO and SO treatments recorded the highest values (>100%) compared with other treatments (Table 3). This high % increase in the affected treatments could be due to the fact that, decomposition of additional application of organic matter to the treatments, Jatropha leaves degradation and accumulation of plant roots exudates could have triggered the concentration of the OC (Soulama, 2008; Sisay *et al*. 2016) which were absent in the other treatments

3.4 Comparison of Nutrients (NPK)

N, P, K are the most essential nutrients and indices for soil quality improvement that support plant growth, development and reproduction (Abdullahi *et al*., 2021; Sani et al., 2022). According to Table 1**,** The N, P and K nutrients showed an increasing trend with both seed and cuttings of Jatropha amended with organic matter recording higher values of the nutrients than the former treatments at post Jatropha planting period in comparison with the pre-planting period. Moreover, the difference in the higher values recorded was highly significant ($P<0.05$) as shown in Table 2.

With regards to % rise or fall in the increment of the assessed nutrients by Jatropha, findings indicated that there was a rise of N by about 100%, 79% and 29% in SF, SO and CO treatments

Table 1: Overall mean values of Soil Quality Parameters of the Experimental Soils at both Pre and Post Jatropha planting period

Marginal Soil Properties at Pre-Jatropha planting period		Marginal Soil Properties at Post-Jatropha planting period			
		Experimental Soil Treatments			
Soil Properties	Values	SF	CF	SO	CO
pH (-)	6.77	6.32	6.38	7.02	6.34
EC (dS/m)	0.05	0.09	0.14	0.14	0.15
OC (%)	0.36	0.42	0.38	1.14	0.90
P (mg/kg)	6.33	13.91	8.25	60.3	70.59
N (%)	0.14	0.28	0.14	0.25	0.18
K (cmol/kg)	0.14	0.22	0.18	0.11	0.36
Na (cmol/kg)	0.13	0.23	0.18	0.12	0.34
Ca (cmol/kg)	0.14	0.19	0.16	0.11	0.27
Mg (cmol/kg)	0.14	0.24	0.18	0.13	0.22
CEC (cmol/kg)	4.07	6.54	3.81	6.68	6.18
BD (g/cm^3)	1.7	1.58	1.57	1.38	1.42
PR (%)	28.08	43.78	43.99	4.60	49.81
MWD (-)	0.464	0.144	0.149	0.591	0.498

Note, SF, Jatropha seeds without any organic amendment, CF, Jatropha cuttings without any organic amendment, SO, Jatropha seeds with organic amendment and CO, cuttings with organic amendments, pH is potential hydrogen, EC is electrical conductivity, OC is organic carbon, P is phosphorous, N is nitrogen, K is potassium, Na is sodium, Ca is calcium, Mg is magnesium, CEC is cation exchange capacity, BD is bulk density, PR is porosity and MWD is mean weight diameter, EC, dS/m, decisiemens per meter, %, percentage, Mg/kg is milligram per kilogram, Cmol/kg is centimole per kilogram and g/cm^3 is gram per centi-meter cube

respectively (Table 3) while no values were recorded in CF treatment. The plausible reason for this increase and its variation among the treatments could be attributed to differences in soil microorganisms and their activities induced by the conducive microclimate provided by the Jatropha plant and organic matter accumulation from the applied manure, decayed litter and roots exudates in the rhizosphere leading to differences in the recorded nitrogen concentration in the different treatments (Table 3) and was in conformity with data reported elsewhere (Daliya *et al.,* 2020; Sani et al., 2022).

Similarly, P concentration showed an increasing trend with those treatments amended with organic manure recording higher values than those without (Tables 1 and 2) and control. Furthermore, the differences in the concentration was significant among the treatments ($P<0.05$) as shown in Table 2. In addition, the rise in concentration after post Jatropha planting was more than double of their original concentration at the pre-Jatropha planting period (Tables 1 and 3) except for CF treatment that recorded 30% (Table 3) indicating highest impact of Jatropha on the former treatments than the latter. This difference could not be unconnected with selectivity behavior of the rhizosphere microorganisms in decomposing the organic materials, litter and root exudates that enhance P addition leading to the lower concentration recorded under the latter treatment (Sani et al., 2022).

Contrastingly, K nutrient showed a variable trend with no pattern of increasing or decreasing concentration, with CO treatment at post Jatropha planting period recording the highest values followed by SF and control (Tables 1 and 2) compared to other treatments with high significant difference between them ($P<0.05$). High rise in % increase (Table 3) in terms of quality improvement for all the treatments was recorded except for SO which recorded negative values indicating reduction in K concentration compared with its original values recorded at pre-planting period (Table 1). This reduction in the K concentration could be attributed to previous stated reason above with respect to P concentration (Sani *et al.*, 2022).

3.5 Comparison of Exchangeable Bases (Na, Ca and Mg)

The results of exchangeable Na, Ca and Mg showed variability in the increase trend of their concentration in the experimental treatments (Table 1) in post Jatropha planting period in comparison to pre-planting one with Na and Ca recording highest values in CO while lowest values were recorded in SO and Control, and the difference was statistically significant

Table 2: Showing Statistical differences of the Soil Quality Parameters at Post Jatropha planting period in the study area

Soil Parameters	SF	CF	SO	CO	O
pH	6.32d	6.38b	7.02a	6.34cd	6.35c
EC	0.09b	0.14a	0.14a	0.15a	0.16a
OC	0.42c	0.38d	1.14a	0.90e	0.64b
P	13.91d	8.25e	60.3b	70.59a	23.5c
N	0.28a	0.14d	0.25b	0.18c	0.11e
K	0.22b	0.18c	0.11d	0.36a	0.21b
Na	0.23b	0.18c	0.12d	0.34a	0.19c
Ca	0.19b	0.16c	0.11d	0.27a	0.13d
Mg	0.24a	0.18c	0.13d	0.22b	0.18c
CEC	6.54b	3.81e	6.68a	6.18c	5.66d
BD	1.58a	1.57a	1.38d	1.42e	1.48b
PR	43.78e	43.99d	48.60b	49.81a	48.16c
MWD	0.144e	0.149d	0.591a	0.498b	0.241c

Note, SF, Jatropha seeds without organic amendment, CF, Jatropha cuttings without organic amendment, SO, Jatropha seeds with organic amendment and CO, cuttings with organic amendments, pH is potential hydrogen, EC is electrical conductivity, OC is organic carbon, P is phosphorous, N is nitrogen, K is potassium, Na is sodium, Ca is calcium, Mg is magnesium, CEC is cation exchange capacity, BD is bulk density, PR is porosity and MWD is mean weight diameter.

(P<0.05) as depicted in the Anova table (Table 2). Contrastingly, SF treatment recorded highest concentration of exchangeable Mg compared to other treatments with high statistical difference (P<0.05; Table 2). Moreover, all the exchangeable bases have shown an increase in concentration in the range of 14% to >100% except for SO treatment which recorded negative values indicating reduction in the concentration of the exchangeable bases (Table 3). This is suprising considering reported increase in their concentration in the literature (Habtamu et al., 2011). However, this contradiction could be attributed to the differences in temperature of the soil rhizosphere, nature and population density of the microorganisms of the reported study in literature and that of the current study which were involved in the process of mineralizing the organic matter and Jatropha root released exudates that subsequently pump and increase the concentration of nutrients including the exchangeable bases (Pandey et al., 2012; Sani et al., 2022).

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3.6 Comparison of Cation exchange capacity (CEC)

CEC is an index of soil quality that describes the potential of soil to supply nutrient cations to soil solution for plant uptake (Sonon *et al.,* 2014). The CEC result (Tables 1 and 2) indicated that there was an increase in its concentration in all the treatments at the post Jatropha planning period in comparison with the pre-planting one. SO treatment recorded the highest values compared to other ones while CF and Control recorded the least values, and the differences in the mean values were significant (P<0.05) statistically (Table 2).

The % increase in concentration of CEC from pre and post Jatropha planting period was >50% in all the treatments except for CF that recorded negative values indicating reduction of CEC in that treatment (Table 3). This reduction could be attributed to combined effect of lack of organic matter and type of microorganisms involved in decomposition of the organic matter which increase in CEC concentration leading to the observed recorded negative values

Table 3: Changes in Quality improvement in % at Post Jatropha planting period of some selected Soil Quality parameters

Soil Parameters	SF	CF	SO	CO
pH	-7	-6	4	-6
EC	80	>100	>100	>100
OC	17	6	>100	>100
P	>100	30	>100	>100
N	100	0	79	29
K	57	29	-21	>100
Na	77	38	-8	>100
Ca	36	14	-21	93
Mg	71	29	-7	57
CEC	61	-6	64	52
BD	-7	-8	-19	-16
PR	56	57	73	77
MWD	-69	-68	27	7

Note, SF, Jatropha seeds without any organic amendment, CF, Jatropha cuttings without any organic amendment, SO, Jatropha seeds with organic amendment and CO, cuttings with organic amendments, pH is potential hydrogen, EC is electrical conductivity, OC is organic carbon, P is phosphorous, N is nitrogen, K is potassium, Na is sodium, Ca is calcium, Mg is magnesium, CEC is cation exchange capacity, BD is bulk density, PR is porosity and MWD is mean weight diameter.

Conversely, the nature, selectivity and availability of the microorganisms in the SF treatment which together with the applied organic manure and the release of the Jatropha plant exudates can increase organic matter concentration (Singh et al., 2022) leading to the increase of CEC concentration, could be the possible reason behind the 61% CEC concentration recorded in the SF, SO and CO treatments respectively and has been confirmed elsewhere (Velayutham, 2000).

3.7 Comparison of Soil texture

Soil texture refers to the percentage or relative proportion of sand, silt and clay present in a soil and very critical physical parameter that enhances water permeability, porosity, aeration and water holding capacity (FAO, 2006) with positive impact on plant growth and overall productivity.

Table 4 depicts the result of soil texture of the marginal soils at pre and post Jatropha planting period in SF,CF, SO and CO treatments respectively with increasing and decreasing trend in concentration of the soil texture parameters. Silt and clay particles showed increasing trend from pre-Jatropha planting period and post planting one across all treatments while sand fractions decreased in that order and dominated silt and clay particles indicating the impact of Jatropha plant on the textural particles. The plausible reason for the decreasing and increasing trend of sand, silt and clay fractions respectively could be attributed to lack of any organic or inorganic amendments in the degraded soils at the pre-Jatropha planting period leading to the observed high sand particles recorded when compared to silt and clay in all the treatments which increased overtime at post Jatropha planting period due to additions of organic and inorganic materials released from the decomposition of the released Jatropha plant root exudates and manure additions making the observed increase in the recorded clay and silt fractions (Agbodi *et al.,* 2013; Sani *et al.,* 2022) (Table 4). Moreover, Jatropha plant roots have been reported to anchor soils with its substantial and consistent root system architecture which serves as a nutrient pump that has ability of replenishing soil lost nutrients. Subsequently, leading to the rehabilitation of the degraded soils, improving their structure and enhances their quality, fertility and productivity (Divakara *et al.*, 2009; Pandey et al., 2012).

3.8 Comparison of bulk density (BD), porosity (PR) and mean weight diameter (MWD)

Soil BD is the weight of a dry soil per unit of soil volume and is usually expressed in g/cm3. Furthermore, is an indicator of soil compaction that can affect the rate at which water infiltrates into the soil, the proliferation of plants roots, soil porosity, available water capacity, soil aeration and soil microbial activity. In addition, it changes depending on aggregate stability soil texture, soil structure and organic matter content (FAO, 2020).

Table 4: Overall mean values of Soil Textural Parameters of the Experimental Soils at both Pre and Post Jatropha planting period

Textural Soil Properties at Pre-Jatropha planting period		Textural Soil Properties at Post-Jatropha planting period			
		Experimental Soil Treatments			
Soil Texture Properties	Values	SF	CF	SO	CO
Sand	76.56	64.4	66.4	70.56	74.4
Silt	18.56	26.56	22.56	20.44	18.56
Clay	4.88	9.04	11.04	9.00	7.04
Textural Class	Loamy Sand	Sandy Loam	Sandy Loam	Loamy Sand	Loamy Sand

Note, SF, Jatropha seeds without organic amendment, CF, Jatropha cuttings without organic amendment, SO, Jatropha seeds with organic amendment and CO, cuttings with organic amendments

Mean values of BD recorded at pre-planting period were high and above the recommended threshold values of 1-1.6g/cm^3 (Table 1) advocated by regulatory agencies that do not affect soil processes and plant growth (FAO, 2020). However, at post Jatropha planting period, the BD values decreased in all the treatments; SF, SO, CF and CO respectively indicating the influence of Jatropha in decreasing the soil compactness (Tables 1 and 2) with a statistical significant difference ($P<0.05$) and recorded highest reduction in the treatments amended with organic amendments in comparison to control and those without. This has been confirmed by data reported elsewhere (Kumar *et al.,* 2009; Makkar and Becker 2009; Soumit *et al.,* 2010). Furthermore, many studies have indcate high positive correlation between BD reductions and soils amended with organic manure planted to Jatropha (Pandey et al., 2012; Athira *et al.*, 2019).

Pertaining % increase in terms of soil quality improvement, findings indicated that there was a rise in quality in all the treatments, with manure amended treatments recoding highest % reduction in BD values (Table 3) compared to those without. Furthermore, the negative signs attached to the values indicate reduction in soil compactness which is normal and what is expected of BD values in qualitative soil. The plausible reason for this high BD values reduction in the manure amended treatments is attributable to the combined impact of the decomposed applied manure and the root exudates in the rhizosphere that reduced the soil compactness of the marginal soils after Jatropha planting and has been confirmed elsewhere (Ogunwole, 2008; Pandey et al., 2012; Athira et al., 2019).

Equally, PR values recorded showed increasing trend at post Jatropha planting period in comparison to pre-Jatropha one with treatments amended with organic manure recording higher porosity values and high % increase (Tables 1 and 3) compared to other treatments and control. Moreover, the recorded values were different statistically ($P<0.05$) among the treatments (Table 2). This increase in both porosity and % quality improvement values at post Jatropha planting period could be due to decrease in BD of the soil and high clay and organic matter in the manure amended treatments (Djajadi *et al.* 2011).

The observed average MWD of the marginal soils at pre-Jatropha planting was 0.464 and showed an increasing trend with manure amended treatments (SO and CO) and a decreasing trend with non-amended ones (Control, SF and CF) at post Jatropha planting period as depicted in Tables 1and 2 respectively with significant statistical difference ($P<0.05$) between them (Table 2). Moreover, the % increase in quality improvement was higher and positive in the latter treatments while the reverse was the case with the former ones (Table 3). This shows the impact of organic amendment on improving the MWD of soils (Ogunwole and Ogunleye, 2004; Sani *et al.,* 2022). In contrast, the MWD values recorded in the latter treatments (Table 3) could be attributed to lack of organic amendment in them, as application of organic manure improves soils structure.

4.0 Conclusion

The research presents the potential of Jatropha plant on soil lost quality restoration. The study revealed that over a period of three months, natural biological activities of Jatropha plant such as litter and roots activities and organic manure imparted positively on the soil quality parameters as the soil electrical conductivity, organic matter, total nitrogen, phosphorus and potassium concentrations rose by >90%, particularly in Jatropha grown under cuttings amended with organic manure making the soil more loamy, fertile and qualitative compared to the control soil. Conversely, Na, Ca, Mg, CEC, and PR have risen by >50% in their concentration in the same Jatropha cuttings amended with organic matter. On the other hand, pH and MWD dropped over the study period showing the plants ability to reduce their concentration. In addition, the very little soil properties variation observed in the control soil samples over the study period could be attributed to the soil being left fallow over the period. Farmers will benefit from this findings by planting Jatropha in their marginal lands to restore their lost quality, improve the soils fertility and productivity. Moreover, they can grow their crops alongside the Jatropha plants in a hedgerow intercropping to derive maximum benefits of soil nutrients enrichment for better agricultural yield.

Pertaining recommendations, the duration of the experiment should be extended beyond three months so as to fully assess the overall impact of the plant reclamation potentials on the quality improvement of the degraded soils. Furthermore, Government should create awareness and encourage farmers to key into these research findings and grow more economic trees that matures rapidly between one to three years like Jatropha in their farms particularly in the degraded soils of semiarid lands of Nigeria to provide lost quality of the soils and improve soil nutrient management for sustainable agricultural production.

References

Abdullahi, T. E., Nazri, M. M, Norazila J. O, Veza I, Mohammed, B, Ayo F. O, and Yahaya, H. S. (2021). Soil fertility enrichment potential of *Jatropha curcas:* A case study of Birnin Kebbi, Nigeria, for sustainable agricultural production Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 4, 2021, Pages. 21061 – 21073 Received05March2021;Accepted01April2021.https://www.researchgate.net/publication/355146897.

Agbogidi, OM, Mariere, AE, Ohwo A. (2013). Metal concentration in plant tissues of *Jatropha curcas* L. grown in crude oil contaminated soil. Journal of Bioinnovation2: 137-145.

Anderson J. M. and Ingram I. S. (1993). Tropical Soil Biology and Fertility: A handbook of methods. 2nd edition. C.A.B International Walling-ford UK.

Ano, A.O., and Agwu, J.A. (2005). Effect of animal manures on selected soil chemical properties. Nigerian Journal of Soil Science, 15, 14 – 19.

Athira, M, R Jagadeeswaran and Kumaraperumal, R. (2019). Influence of soil organic matter on bulk density in Coimbatore soils International Journal of Chemical Studies 2019; 7(3): 3520-3523.

Batjes, N. H. (2001). Options for increasing carbon sequestration in West African soils: An exploratory study with special focus on Senegal. Land Degradation and Development, 12, 131–142.http://dx.doi.org/10.1002/(ISSN)1099-145X.

Bello, S.O., and Akinrinde E.A. (2005). Degradation characteristics and management of marginal lands in Nigeria, Africa. Journal of soils and sediments 5(2):125-126. DOI: 10.1065/jss2005.02.003.

Biliavskyi, Yu. V., Biliavska L. H. (2019). Analysis of agro-climatic and soil conditions of the Forest-Steppe of Ukraine for growing agricultural and energy crops pp. 7–17.

Blake, G. & Hartge, K. 1986. Particle density. In Methods of soil analysis. Part 1: Physical and mineralogical methods. A. Klute, ed. *SSSA: Madison, WI, pp. 377–382.*

Bremner, J. M. (1996). Nitrogen-total. In: Sparks DL, editor. Methods of soil analysis. Part 3. Chemical methods. 2nd ed. SSSA Book Series No. 5.

Madison (WI): ASA and SSSA. p. 1085–1121

Daliya P, Ljungqvist O, Brindle ME, i ostali. Guidelines for Guidelines. (2020). Epub ahead of print 2020. DOI: 10.1007/978-3-030-33443-7_3.

Divakara B.N., Upadhyaya H.D., Wani S.P., and Gowda C.L.L. (2009). Biology and genetics improvement of *Jatroph acurcas*L. *Applied energy* Pp 1-11 Doi:10.1016/J.Apenergy.2009.07.013.

Djajadi., Heliyanto B., and Hidayah N. (2011). Changes of physical properties of sandy soil and growth of physic nut (*Jatrophacurcas* l.) due to addition of clay and organic matter, Indonesia Research Institute for Tobacco and Fiber Crops (IToFCRI) agrivita volume 33 no. 3 ISSN : 0126-0537.

Edrisi, SA., Dubey RK., Tripathi V., i ostali. (2015).*Jatrophacurcas* L.: A crucified plant waiting for resurgence. Renew Sustain Energy Rev 2015.; 41: 855–862.

FAO, 1993. Guidelines for land-use planning. FAO Development Series I. FAO, Rome. xv 78

FAO. (2006). Guidelines for soil description. 4th ed edition. Rome, Food and Agriculture Organization of the United Nations.97 pp.

FAO.(2011).Http://www.fao.org/nr/land/sustainable-land-management/farmer-field-school/agro-pastoral-ffsproject-home/ffs/ en/.

FAO. (2020). Soil testing methods – Global Soil Doctors Programme - A farmer-to-farmer training programme. Rome. https://doi.org/10.4060/ca2796en.

Gee, G. W. and Bauder, J. W. (1986). Particle Size analysis. In: A. Klute (ed.). Methods of Soil Analysis. Part 1. Physical and Minerological methods. 2nd ed. American society of Agronomy Madison, WI. pp. 383-416

Habtamu, A. (2011). Land use/land cover change and impact of Jatropha on soil fertility: the case of Mieso and BatiWoreda, Ethiopia.

Ikeh, A. O., Ndaeyo, N. U., Akpan, E. A., Udoh, E. I., & Akata, O. R. (2013). Evaluation of complementary use of organic manure for sustainable water yam production in Uyo, Southeastern Nigeria. American Journal of Research Communication. 1(2), 33-48.

Kumar, S., K. Ashwani, Sh. Satyawati and S. N. Naik. (2009).Interaction of *JatrophaCurcas* Plantation with Ecosystem and land use.

Legendre, B. (2008), *Jatropha curcas* (Tabanani). Note agronomique. Technologies for Ruman development. 8 p.

Makkar, H. P. S., Kumar, V., Becker, K., (2012). Use of detoxified *Jatropha* kernel meal and protein isolate in diets of farm animals: chapter 21. In: Makkar, H.P.S, Biofuel co-products as livestock feed - opportunities and challenges, FAO.

Murphy, J. and Riley, J. P. (1962). A modified single solution for the determination of phosphorus in natural water. Anal. Act, 27:31-36.

Nelson, D. W., and Sommers, L. E. (1996). Total carbon, organic carbon and organic matter. In: Sparks DL, editor. Methods of soil analysis. Part 3. 2nd ed. SSSA Book Series No. 5. Madison (WI): ASA and SSSA. p. 961–1010.

Ofelia, A. v., Sánchez-Sánchez, O., Pérez-Vázquez, A., Joshua S. C., and Frédéric, D. (2013). *Jatropha curcas* L. Root structure and growth in diverse soils, Hindawi Publishing CorporationThe Scientific World Journal Volume 2013, Article ID 827295, 9 pages http://dx.doi.org/10.1155/2013/827295.

Ogunwole, J.O. , Chaudhary, D.R., A. Ghosh , C.K. Daudu., Chikara J., &.Patolia J.S. (2008). Contribution of *Jatropha curcas* to soil quality improvement in a degraded Indian entisol, Acta Agriculturae Scandinavica Section B – Soil and Plant Science, 58:3, 245-251, DOI:10.1080/09064710701628925 .

Ogunwole, J.O., &Ogunleye, P. (2004). Surface soil aggregation, trace and heavy metal enrichment under long-term application of farm yard manure and mineral fertilizers. *Communications in Soil Science & Plant Analysis*, 35(11&12), 15051516.

Olofin, E.A., Nabegu, A.B and Dambazau, A.M (2008). Wudil within Kano region; a geographical synthesis, Wudil. The Department of Geography, Kano University of Science and Technology

Onwu, A. C., Osujieke, N. D., Gani1 A. T., and Ali A., (2018). Influence of Organic Fertilizer (Nomau®) on Soil, Leaf Nutrient Content, Growth and Yield of Physic Nut (*Jatropha curcas*) in Makurdi, North Central, Nigeria, Asian Journal of Soil Science and Plant Nutrition 3(2): 1-11, 2018; Article no.AJSSPN.42090 ISSN: 2456-9682,DOI: 10.9734/AJSSPN/2018/42090.

Pandey, VC. Singh, K., Singh, JS. Kumar, A., Singh,B. and Singh, RP (2012). Jatropha curcas: A potential biofuel plant for sustainable environmental development. Renewable and Sustainable Energy Reviews, 16, 2870-2883

Rattan, R.K. (2009). Fundamentals of Soil Science. *National Agricultural Science Centre Complex, New Delhi, p 91.*

Reubens, B, Achten WMJ, Maes WH, *et al*. (2011). More than biofuel? *Jatroph acurcas* root system symmetry and potential for soil erosion control. Journal of Arid Environments. 2011;75(2):201–205.

Salako, F. K., Hauser, S., Babalola, O., & Tian, G. (2001). Improvement of the physical fertility of a degraded Alfisol with planted and planted natural fallow under humid tropical conditions. Soil use and manage, 17, 41–47.

Sani, A., Abdulkadir, N.A., Almu, H., Adamu, U.K and Mohamed, U.M (2021). Impact of Industrial Effluents on Soil Quality of Sudan Savanna Alfisols in Semi-arid Tropical Zone of Nigeria. British Journal of Environmental Sciences, 9, (2), 54-65

Sani, A., Danturai, S.A., Mohamed, M., Abubakar, M.B., Kafinga, M.H., Aliyu, R.W., Haruna,A.K.,Adam, I.A., Aliyu, J.A., Garba, M.D and Abdullahi, N. (2022) Phytoremediation of Heavy Metals Contaminated Agricultural Soil Planted to Jatropha curcas, International Journal of Energy and Environmental Research,10 (3) 3,14-32

Shehu, B.M., Ogunwole J.O. & Jibrin J.M. (2016). Physical quality of Northern Nigeria Savanna Alfisol: Influence of Jatropha curcas L. and other land use systems, Cogent Food & Agriculture, 2:1, 1205272, DOI: 10.1080/23311932.2016.1205272.

Singh, D., Keta, JN., Muhammad, A., Imonikhe, MA and Anthony, OB (2022). phytoremediation potential of Jatropha curcas and cassia occidentalis on selected heavy metals in the soil. Journal of Agricultural Policy, .5, (1), 33 – 49

Sisay, A., Kissi, E., Regassa , A. (2016). *Jatropha Curcas* L. for Rehabilitation of Degraded Land of Gilgel Gibe Watershed, South Western Ethiopia Journal of Biology, Agriculture and Healthcare www.iiste.orgISSN 2224-3208 (Paper) ISSN 2225-093X (Online) Vol.6, No.19.

Sonon, LS., Kiessel DE., Saha U. (2014). Cation exchange capacity and base saturation. UGA Exten Circ. 1040:1-4.

Soulama, S. (2008). *Jatropha curcas* carbon sequestration potential, University´ de Ouagadougou.

Van Bavel, C.H.M. (1950). Mean-weight diameter of soil aggregates as a statistical index of aggregation. Soil Science Society of America Proceedings, 14, 20 23

Velayutham, V. (2000).Status of land resources in India.Advances in land resources management for 21st century, Soil conservation society of India, New Delhi, 67-83Pp.

Wurdack, K. J., Hoffmann, P. and Chase, M. W. (2005). Molecular phylogenetic analysis of uniovulate euphorbiaceae (euphorbiaceaesensustricto) using plastid RBCL and TRNL-F DNA sequences. Am. J. Bot. 92(8):1397-1420.

Yolanda, M. S., Fidel. P. M., & Francisco, P. G. (2014). Effect of the application of manure of cattle on the properties chemistry of soil in Tizayuca, Hidalgo, Mexico. International Journal of Applied Science and Technology, 4 (3), 67-72.

WETLAND MAPPING AROUND MALETE AND ENVIRONS, KWARA STATE, SOUTHERN GUINEA SAVANNA ZONE, NIGERIA

[1]Alabi, K. O., [2]Adika, A. O.; [3]Mashood, T. O. & [4]Afe, A. I.
[1,2,3&4]*Department of Crop Production, Faculty of Agriculture,*
Kwara State University, Malete, P.M.B. 1530, Ilorin, Kwara State, Nigeria
Corresponding author email:alabioyebisi@gmail.com

ABSTRACT
Wetlands are ecologically significant landscape that plays a crucial role in maintaining biodiversity, supporting ecosystem services, and mitigating environmental challenges. This project focuses on wetland mapping in the Malete region and its environmental implications. The project employs a combination of remote sensing technologies, Geographic Information Systems (GIS), and field surveys to accurately delineate wetland boundaries covering an area of about (4,000 Hectares) and characterize their attributes within Malete area of Kwara State. By analysing successful wetland mapping projects with the use of Analytical Hierarchy Procedure-Multi Criteria Evaluation (AHP-MCE) with the Expert Choice software and ArcGIS raster calculator, the study draws lessons based on weighting and integration of slope, elevation and drainage density, which all have strong influence on the existence of wetlands. Resultant wetland map indicates that extremely low suitable areas are located in the northeastern by western parts of the study area. These areas cover approximately 7.21% of the total study area, which is about 187.8 ha. The second zone is the "medium suitable zones" which are scattered across the north central, north, and parts of the northeastern and northwestern regions of the study area. These areas account for a significant portion, approximately 59.25%, of the study area, covering approximately 1543.3 ha. The third zone is the "high suitable zones" which are predominantly located in the southwestern, northwestern, and southeastern regions of the study area. These regions have the most favourable conditions for wetland development or preservation. The high suitable zones cover approximately 33.53%, which is about 873.3 ha. It shows that the southwestern, northwestern, and southeastern regions are the most suitable for wetland. Such areas can be suitable for wetland agriculture.
Keywords: Wetlands, Mapping, Remote Sensing, GIS, Suitable zones,

Introduction

According to Knight *et al*. (2001), wetland ecosystem services include providing habitat for species, reducing flood damage, and moderating climate change (Pattison-Williams and McLeod 2018). Wetland has dramatically decreased over the past century as a result of fast global land cover change and pollution (Zedler and Kercher, 2005). Anthropogenic factors such as urbanization, road and building construction, clearing of vegetation for farmland and firewood, water consumption, pollution, and the introduction of invasive species are among those that are considered to be the main threats to wetlands (Ekumah *et al*.,2020; Sun *et al.,* 2020).

The importance of the services that wetlands offer is largely recognized in industrialized nations. Therefore, attempts have been made to save them through restoration and conservation (Niu et al., 2012; Uuemaa et al., 2018). The implementation of restoration efforts, on the other hand, has proven to be far more difficult in developing nations due to the urgent need for housing, greater food production, and other essentials.

Malete, located in Kwara State, Nigeria, is a region known for its rich biodiversity and abundance of wetland ecosystems. Wetlands play a vital role in supporting diverse plant and animal species, regulating water flow, and providing numerous ecosystem services. Due to their ecological significance, it is crucial to accurately map and monitor these wetlands to ensure their effective management and conservation.

The process of wetland mapping involves the systematic identification, delineation, and classification of wetland areas within a specific geographic region. The information gathered through mapping initiatives serves as a foundation for informed decision-making, land-use planning, and conservation efforts. In the case of Malete, wetland mapping will provide valuable insights into the extent, distribution, and ecological characteristics of wetlands within the region. Accurate wetland mapping in Malete requires the utilization of various data sources and techniques.

Remote sensing, including satellite imagery and aerial photography, can provide detailed information on wetland extent and land cover patterns. Ground-truthing, which involves on-site verification and data collection, is another essential component to validate the remote sensing results and ensure accuracy.

Additionally, geographical information systems (GIS) technology facilitates data integration, analysis, and visualization, enabling efficient wetland mapping processes. The importance of wetland mapping in Malete extends beyond conservation efforts. It also serves as a valuable tool for land-use planning, disaster risk reduction, and sustainable development. With the increasing pressures of urbanization, agricultural expansion, and climate change, a comprehensive understanding of the wetland resources in Malete becomes imperative to ensure their long-term protection and sustainable use.

Research has been on the determination of availability of wetland present in Malete, Moro Local Government Area, Kwara State. To this end, the justification for this study cannot be overemphasized. More so, each wetland has specific properties or qualities which affect wildlife and ecosystem directly. Wetlands plays a crucial role in conservation and management of natural resources in the region therefore, a good knowledge of wetland mapping is needed for understanding of their significance in various environmental settings. Furthermore, the information gathered from this study will enable land users and developers of the study area to make proper decisions also indicates that knowledge of the wetland mapping is important for use efficiency. The main objective is to map and delineate potential wetland site within Malete Area of Kwara State.

Materials and Methods

Description of Study Area

The survey was carried out in Malete and its environs situated in Moro Local Government area (LGA) of Kwara State (Figure 1). The study area lies within latitude 8°41’40′N to 8°43’20′N and longitudes 4°25’50′E to 4°30’0′E. It comprises of Malete, KWASU Campus, and the adjoining communities covering an area of about (4,000 Hectares) of land has its headquarters in the town of Bode Sa’adu. Towns and villages that make up Moro LGA include Lanwa, Ejidongari, Olooru, Ipaye, Malete, Aaro, Ige, and Odun-Ade. The current estimated population of Moro LGA is put at 213,448 at 2023 census and 108,792 at the 2006 census inhabitants with the majority of the area’s dwellers being members of the Igbomina sub-group of the Yoruba ethnic affiliation. Moro LGA is part of the Ilorin Emirate and also a part of the Kwara North senatorial district which covers a total area of 3,272 square Kilometres.

Climate

The climate of Malete is characterized by distinct wet and dry seasons with a mean daily temperature ranged between 25°C and 29.5°C, with the month of March having an average high of 30°C. In addition, the annual mean rainfall is about 1,150mm, exhibiting a double maximal pattern between April and October of every year. The wet season is between April and October while dry season starts November and ends in March (Alabi et al., 2017).

Relief and Drainage

Malete consists of Precambrian basement complex rock. The soils of Malete are made up of loamy soil with medium and low fertility. Because of the high seasonal rainfall coupled with the high temperature, there is tendency for lateritic soil to constitute the major soil types in Malete due to the leaching of minerals nutrients of the soil (Ajibade and Ojelola, 2004).

Field Survey

A free-soil survey was conducted in the area. Soil samples were randomly picked. The coordinates were taken and interpreted using study was from Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model obtained from website of Global land cover facility, University of Maryland.

Sources of Data

Digital Elevation Model (DEM) of different spatial resolutions are freely distributed in various portals. Shuttle Radar Topographic Mission (SRTM) 90 m DEM-http://srtm.csi.cgiar.org/ Shuttle Radar Topographic Mission (SRTM) 90 m DEMhttps://earthexplorer.usgs.gov/
ASTER 30m DEM-https://search.earthdata.nasa.gov/SRTM (USGS EROS Archive, 2018).

Digital elevation model was essentially used for this study. DEM was downloaded from global land cover facility website using Global mapper 17 software. From the digital elevation model data, drainage network was extracted. The drainage network was exported as shape file into the ArcGIS software. Also, the DEM was exported into the ArcGIS software version 10.3. On the ArcGIS software, spatial analysis tool was used to extract spatial map for elevation and slope. This spatial tool was also used to generate a drainage density map for the study area. The drainage density map was then converted into a raster image for easy reclassification. After generation of spatial data, reclassification of elevation, slope and drainage density data was performed using ArcGIS spatial analyst reclassification tool (Garba, 2024).

Analytical Hierarchy Procedure-Multi Criteria Evaluation

The Analytical Hierarchy Procedure-Multi Criteria Evaluation (AHP-MCE) serves as a decision-weighting technique that facilitates the assessment of consistency and the establishment of priorities among various criteria and alternatives. This method streamlines the process of evaluating preference ratings for decision criteria through pairwise comparisons (Bunruamkaew, 2012). In the present study, the application of AHP-MCE for weight determination was executed using the Exper Choice software. To validate the consistency of the weight assignment process, a consistency ratio was computed. The procedure involved allocating weights to distinct thematic classes, followed by the integration of each hierarchical layer. By leveraging the ArcGIS raster calculator, the weighted thematic layers encompassing slope, drainage density, and elevation were aggregated to generate a comprehensive wetland suitability map. Subsequently, a manual classification of this wetland map was carried out.

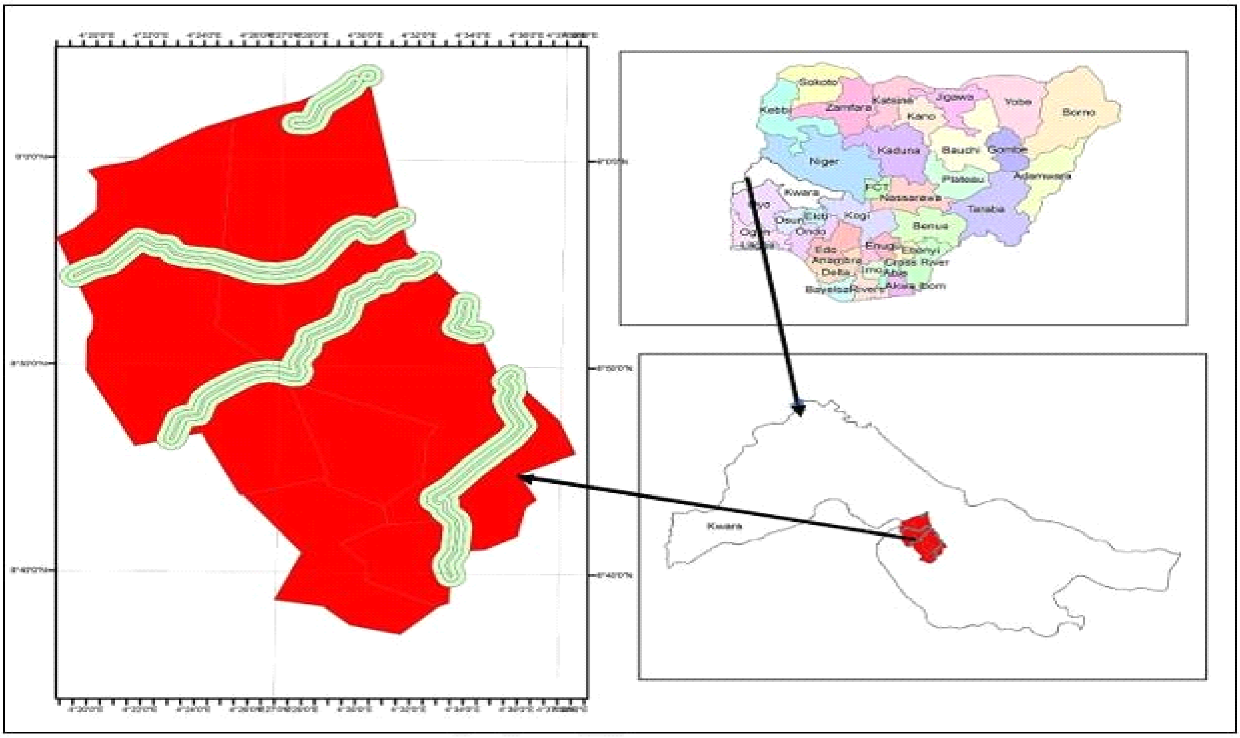

Figure 1: Map of Kwara State showing the Study Area in Moro LGA
Source: (Atlas 1981)

Results

Elevation

Wetlands are significantly impacted by elevation. Since water is subject to gravity, it often flows from highland to lowland areas. Elevation for the study area ranges from 279 m to 377m. It has a mean of 333.17m and a standard deviation of 17.740m (Figure 2). Elevation for the study area was manually classified into five classes (Table 1).

Table 1: Elevation influence on wetland suitability of study area.

Elevation Ranges	Class	Weight	%cover	Area(ha)
270 -307	Very low	42	8.4	279
307 – 323	Low	32	19.8	660
323 – 338	Moderate	13	31.1	1036
338 – 353	High	8	29.8	992
353 – 377	Very High	5	10.9	363

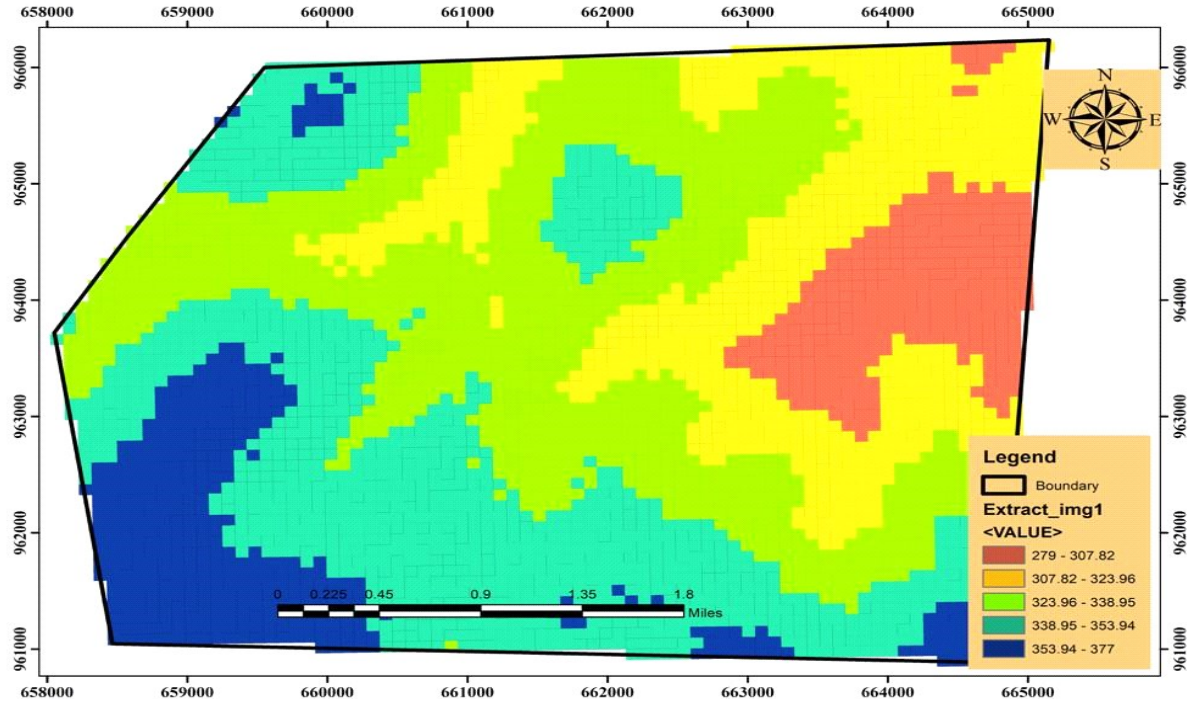

Figure 2: Elevation Map for the Study Area

Slope

Slope plays a significant role in determining the suitability of an area for wetland formation. The influence of slope on wetlands is primarily related to the movement and retention of water. Slope for the study area have been identified to have a minimum of 0% and a maximum of 4.00%, mean of 1.51% and a standard deviation of 0.63 (Figure 3), here are some key points to consider regarding the influence of slope on wetland suitability: Water accumulation, Water drainage, Runoff/Erosion, Hydrological connectivity and soil moisture. It's important to note that 17.81% of the study area has a gentle slope which makes it suitable for the formation of wetland, while 82.19% is a flat/relatively flat land (Table 2) .

Table 2: Influence of slope on wetland suitability

Range	Class	Weight	% cover	Area covered (ha)
0- 2.1degree	Flat land	35	82.19	2539.2
2.1- 4.0degree	Gentle slope	65	17.81	550.16

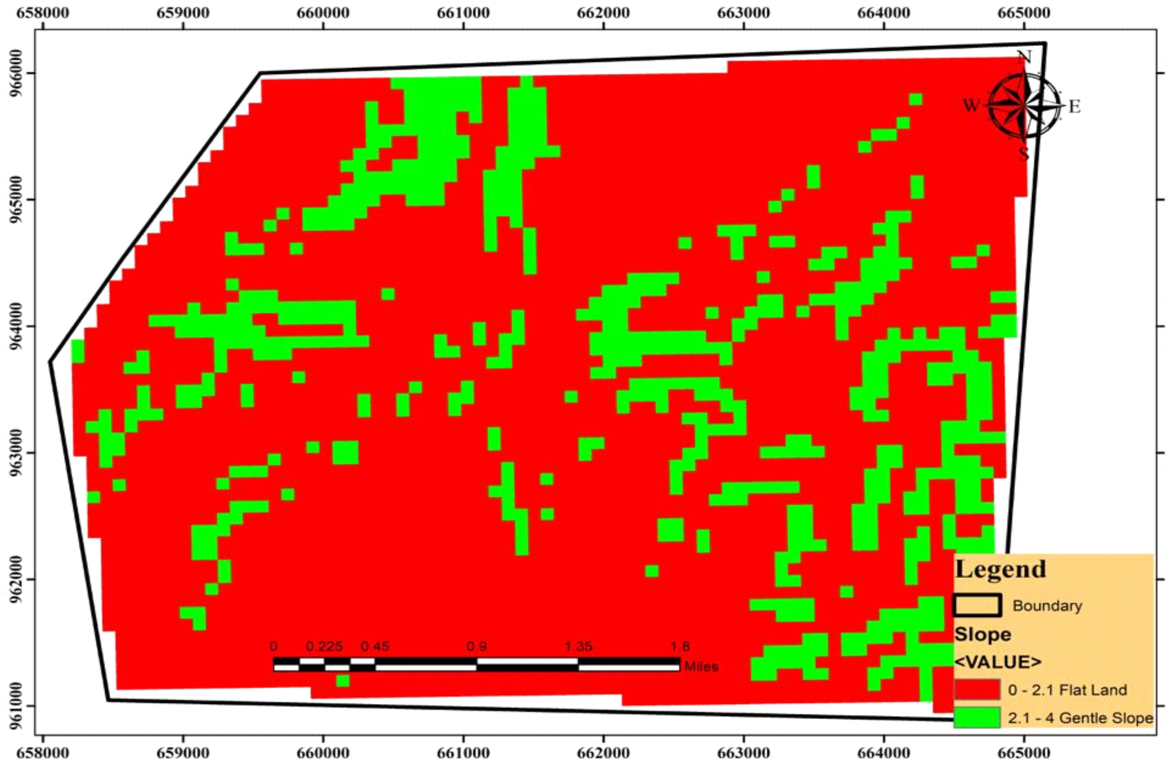

Figure 3: Slope Map of Study Area

Drainage

A contour plot was depicting number of drainages per unit area (drainage density) was produce using ArcGIS software Kernel density algorithm. Drainage density had a minimum of 0, a maximum of 2.16, a mean of 0.56 and a standard deviation of 0.52 (Figure 4). Drainage density was classified manually into five classes (Table 3). Class with high drainage density had the highest weighting while classes with low drainage density had the lowest weighting.

Table 3: Drainage Density classes for the Study Area

S/N	Class Range	Weight	%Cover	Area cover(ha)
1.	0 - 0.431	7	40.91	1123,1
2.	0.431 - 0.862	13	21.90	601.2
3.	0.862 - 1.293	10	23.59	647.6
4.	1.293 - 1.724	30	8.89	244.3
5.	1.724 – 2.155	40	5.42	149.0

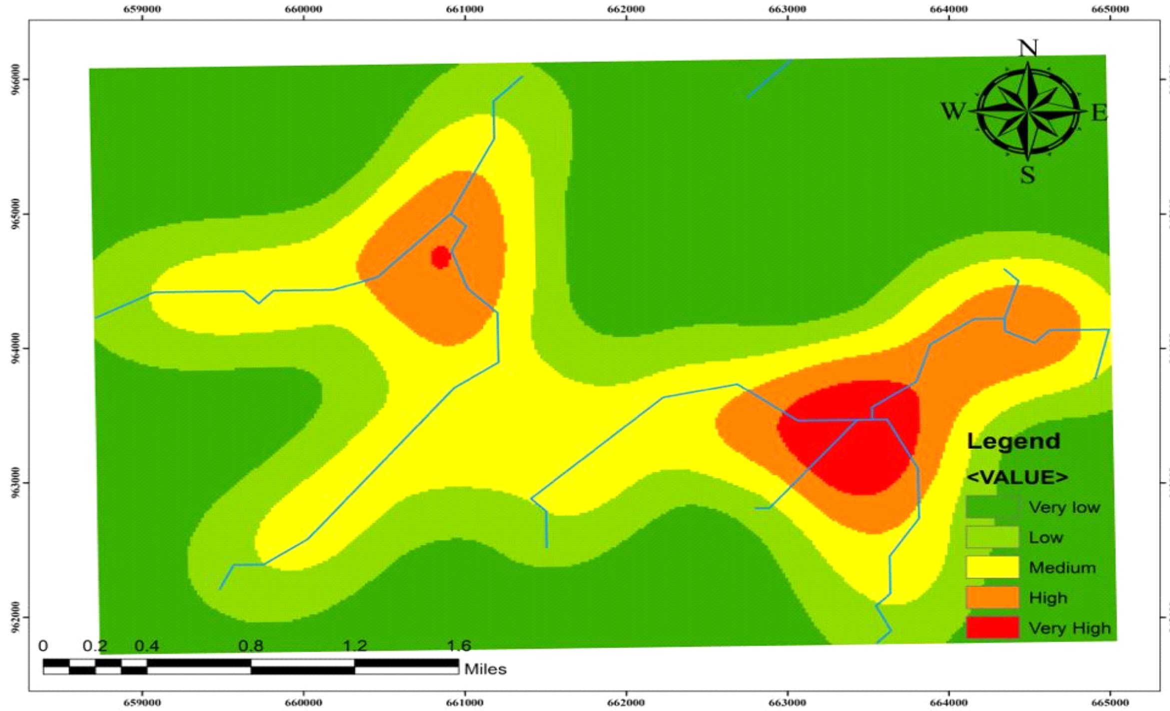

Figure 4: Drainage Map of Study Area

Wetland Suitability

The wetland suitability map provides valuable information about the distribution of suitable areas for wetland development or preservation within the study area. It shows that the southwestern, northwestern, and southeastern regions are the most suitable, while the northeastern by western regions have extremely low suitability. The medium suitable zones are scattered across the north central, north, and parts of the northeastern and northwestern regions (Figure 5). These findings can assist in decision-making related to wetland conservation, development, and land-use planning in the study area.

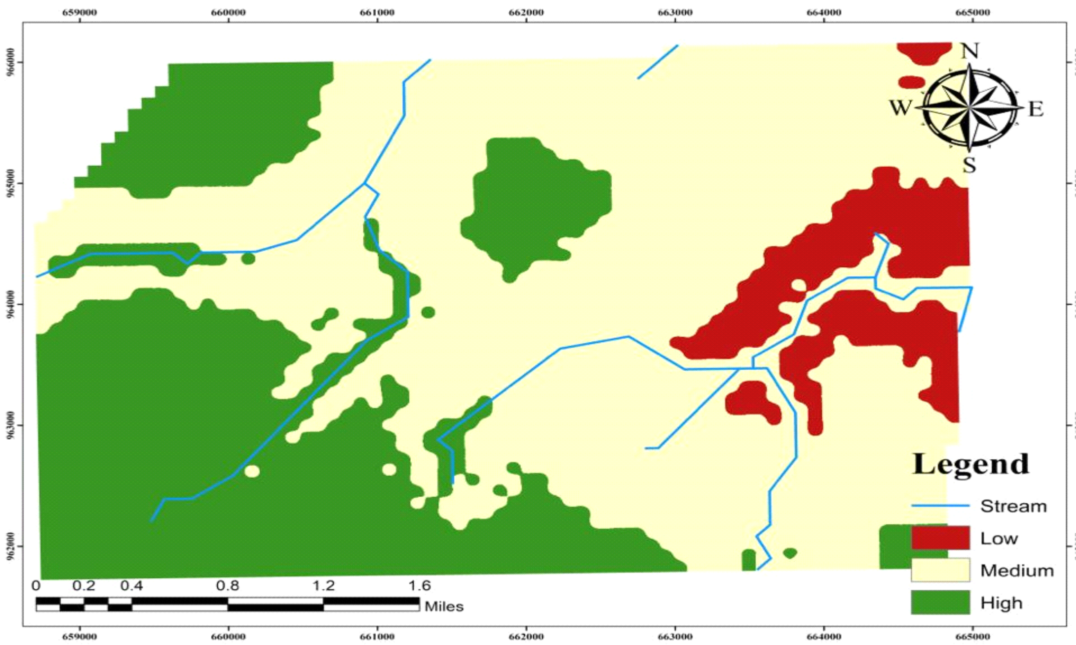

Figure 5: Wetland suitability Map of Study Area

Discussion

Summarily, GIS investigation for wetland mapping involves reclassification and weighting of Elevation, slope and drainage density thematic maps for the study area. Weighting was carried out using multi criteria evaluation technique. The efficiency of this weighting method was improved by keeping the consistency ratio as low as possible. A map was created to determine suitable wetland areas in a study area. This analysis took into account factors such as elevation, slope, and drainage. The findings show that different parts of the study area have varying levels of suitability for wetland development or preservation. This agreed with the findings of Ekumah et al., 2020; Garba and Andongma, 2015. The map has been divided into three zones based on the analysis results. The first zone is the "extremely low suitable areas" which are mainly concentrated in the northeastern and northeastern by western parts of the study area. These areas cover approximately 7.21% of the total study area, which is about 187.8 hectares. The second zone is the "medium suitable zones" which are scattered across the north central, north, and parts of the northeastern and northwestern regions of the study area. These areas account for a significant portion, approximately 59.25%, of the study area, covering approximately 1543.3 hectares. The third zone is the "high suitable zones" which are predominantly located in the southwestern, northwestern, and southeastern regions of the study area. These regions have the most favourable conditions for wetland development or preservation. The high suitable zones cover approximately 33.53% of the total study area, which is about 873.3 hectares. The findings of this study agreed with the work of Garba and Andongma, 2015.

Conclusion and Recommendations

Conclusion

The delineation of “extremely low suitable areas,” primarily concentrated in the north-eastern by western parts of the study area, emphasizes the need for heightened conservation efforts in these vulnerable regions. Spanning approximately 7.21% of the total study area. The identification of “medium suitable zones,” scattered across various regions, underscores the potential for wetland development in these areas. This classification, accounting for about 59.25% of the study area, serves as a valuable guide for decision-makers to plan and manage these zones with thoughtful strategies that harmonize human activities with wetland preservation. The significance of the “high suitable zones” in the south western, north western, and south eastern regions cannot be overstated. Encompassing roughly 33.53% of the total study area, these zones present prime opportunities for wetland conservation and development. The favourable conditions in these regions warrant focused efforts to enhance and maintain the health of wetland ecosystems, thereby benefiting both the environment and local communities.

The outcomes of this study contribute to the overarching goals of biodiversity conservation, water resource management, and environmental resilience. The mapping’s ability to highlight areas demanding immediate intervention, areas with potential for development, and areas primed for preservation underscores its role in achieving a balanced coexistence between human activities and the natural world.

Recommendations

The outcomes of this study contribute to the overarching goals of biodiversity conservation, water resource management, and environmental resilience. The mapping’s ability to highlight areas demanding immediate intervention, areas with potential for development, and areas primed for preservation underscores its role in achieving a balanced coexistence between human activities and the natural

world. Therefore, the following are recommended;

High Suitable Zones should be preserved with good monitoring and Management practices while Restoration Projects are advised or recommended for Medium Suitable Zones and adequate land conservation practices priorities should be given to Low suitable areas. Climate Change Adaptation strategies should also be advocated in the study area.

References

Ajibade, L. T., and Ojelola, T. O. (2004). Remote Sensing and GIS Approach to Groundwater Exploration in Basement Complex Terrain: A Case Study of Malete, North Central Nigeria. *Journal of Mining and Geology*, 40(1), 21-28.

Alabi, K.O., Wahab A.A., Lawal O. O., Aderolu I. A., and B.A. Senjobi (2017). Characterization and classification of soils of Kwara State University Teaching and Research farm, Malete, Nigeria. *Journal of Science, Technology, Mathematics and Education*, 13 (2): 100 – 106.

Atlas, R.M. (1981). Microbial Degradation of Petroleum Hydrocarbons: An Environmental Perspective. Microbiological Reviews, 45, 180-209.

Bunruamkaew, K. (2012). Web-based GIS and multi-criteria decision analysis (MCDA) for watershed management. *Computers & Geosciences*, 42, 87-98

Ekumah, B., Gasparatos, A., & Bardekjian, A. (2020). Wetland protection and climate change mitigation: A global analysis of policy coherence. Land Use Policy, 95, 104620.

Garba, I; and Andongma, W.I. (2015). Wetland Mapping around Bakori and environs, Katsina State, North-Western, Nigeria. Katsina Journal of Natural and Applied Sciences. 4(2):96-105.

Knight, R. L., Payne, V. W., Haines, A. M., and Smith, L. M. (2001). Wetland ecosystems and wetland attributes. In R. P. Brooks & D. E. Samuel (Eds.), Hydrology and Management of Forested Wetlands (pp. 7-32). Springer.

Niu, Z., Lv, Y., Liu, C., and Song, K. (2012). Assessing wetland restoration success in the Yellow River Delta, China using Landsat TM imagery. *Ecological Engineering*, 44, 221-230.

Pattison-Williams, J. K., and McLeod, K. L. (2018). Ecosystem services in urban wetlands: A literature review and case study of wetland management in the Melbourne region. *Ecosystem Services,* 30, 47-61.

Sun, R., Zhou, W., Xu, Q., Qian, H., and Wu, J. (2020). Wetland loss and ecosystem services in China: A meta-analysis. *Science of the Total Environment*, 721, 137551.

Uuemaa, E., Antrop, M., Roosaare, J., Marja, R., Mander, Ü., and Ahas, R. (2018). Landscape metrics and indices: An overview of their use in landscape research. Living Reviews in Landscape Research, 12(1), 1-32.

USGS EROS Archive (2018). Digital Elevation-Shuttle Radar Topography Mission (SRTM) 1 Arc Second Global /U.S. Geological Survey. www.usgs.gov. https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1

Zedler, J. B., and Kercher, S. (2005). Wetland resources: Status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources*, 30, 39-74.

SECTION TWO

Organic Agriculture and Aforestory, Soil Health, Food System And Food Security "B"

NODULATION PATTERN AND TISSUE N, P, K CONCENTRATION OF COWPEA (*VIGNA UNGUICULATA (L*) WALP) VARIETIES AS INFLUENCE BY INTEGRATED NUTRIENT MANAGEMENT IN MAIZE/PUMPKIN/COWPEA RELAY CROPPING IN SAMARU

Agah, B.U. and Abam, P.O
[1]*National Agricultural Extension and Research Liaison Service, Ahmadu Bello University Zaria*
[2]*Department of Crop and Soil Science, Faculty of Agriculture and Forestry, University of Portharcourt*
Corresponding author email:bonyagah@gmail.com

ABSTRACT
Field experiments were conducted during the 2019, 2020 and 2022 wet seasons at the Teaching and Research field of the Institute for Agricultural Research Samaru, Zaria, to assess nodulation Pattern and Tissue N, P, K Concentration of Cowpea (Vigna unguiculata (L) Walp) Varieties as Influence by Integrated Nutrient Management in Samaru, Northern Guinea Savanah of Nigeria. Treatments consists of three levels of poultry manure (0, 3 and 6 tha^{-1}), two genotypes of cowpea (SAMPEA 11 (Determinate) and SAMPEA 14 (indeterminate) and two (2) time of top dressing of N fertilizer (double split and triple split application). The treatments were laid out in randomized complete block design with split plot arrangement replicated four times. Result indicates that cowpea nodule number and nodule dry weight were significantly increased with increased application of poultry manure with higher average number of nodules reported with the application of 6 t ha^{-1} of poultry manure; representing 40 % and 30 % increase over the control and 3 t ha^{-1} respectively. Whereas, application of nitrogen in double split result in higher nodule number (16) compared to triple split application (14). Similarly, varietal difference also occurred with regard to cowpea nodulation whereby SAMPEA 11 produced significantly highest number and mass of nodules. Result further showed that increasing poultry manure from 0 – 6 t ha^{-1} result in 2.6, 16 and 13 per cent increase in N, P and K concentration in cowpea tissues. However split application of nitrogen had no effects on the tissue nutrient concentration across all the years whereas, in 2019 and 2020 cropping season, application of nitrogen in triple splits significantly gave the highest concentration of K in 2019 (0.15 cmol kg^{-1}) and 2020 (0.15 cmol kg^{-1}) respectively. This research suggests the need to apply 6 t ha^{-1} of poultry manure and triple split application of 45 kg N ha^{-1} for enhance cowpea nodulation and improved tissue NPK concentration.

Key words: cowpea, split nitrogen application, tissue nutrient concentration, nodulation

Introduction

Improving fertility level of arable land using organic and inorganic fertilizer**s** to meet the increased demand **for** food globally has been a yearlong strategy over decades. However, these strategies have in recent years been criticized base**d** on environmental and economic concern**s**. Use of inorganic and organic fertilizer**s** has been adjudged to be very expensive and remain**s** a major source of pollution to agricultural soils (Zahran, 1999). Despite these negative antecedences, there have been a continuous rise in global demands and consumption of inorganic fertilizer**s** particularly nitrogen. An increase from 8 to 17 kg **N** ha^{-1} from 1973 to 1988 was reported by FAO (1990).This increasing trend could be due partly to the inefficient handling of nitrogen fertilizer resulting in higher losses via leaching and volatilization. Hence, the need for complementary use of organic and inorganic fertilizer for maintenance of soil organic matter content and long term soil productivity and ground water quality is **being** advocated (Premanandarajah and Prapagar, 2015).

Cowpea (*Vigna unguiculata (L.) walp*) is a popular leguminous crop in Africa which is known as 'beans' in Nigeria and 'niebe' in the Francophone countries (Ishiyaku *et al.*, 2010) and **plays** a significant nutritional and ecological role. Nutritionally, it contributes a very important and inexpensive source of protein and providing more than 23-25% of the plant protein in human diets (Singh *et al*., 2007). Ecologically, it can be used as a nitrogen fixer and as green manure (Yusuf, 2008) via cowpea nodules and rhizobium symbiosis. Total cowpea nitrogen input at the range of 23 to 300 kg $ha^{-1}yr^{-1}$ has been reported (Wani *et al*. 1995). The significance of legumes root nodules and rhizobium symbiosis lies in their ability to increase plant protein levels, reduce depletion of soil nitrogen reserves (Zahra, 1999) by providing well over half of the biological source of fixed nitrogen (Tate, 1995). Yield increases of crops planted after harvesting of legumes are often equivalent to those expected from application of 30 to 80 kg ha^{-1} of nitrogen (Wani *et al*. 1995). However, sustaining the gains from legumes-rhizobium symbiosis **requires advanced** strategies such as development or selection of superior legumes varieties, improvements in agronomic practices and increased efficiency of root nodule nitrogen fixing process via better management of the symbiotic relationship between plant root nodules and rhizobium.

Cowpea (*Vigna unguiculata*) has been proven to be suitable companion crop for multiple cropping without compromising its yield and those of the companion crops. Intercropping is a form of ecological intensification that is potentially sustainable when two or more crops are grown at the same time or in sequence. This approach **allows** for the prudent and targeted use of inputs such as fertilizers which help to improve soil quality and moisture whilst minimizing the environmental impact that its excessive use can cause (Fasoyiro and Taiwo, 2012).

Like most annual crops, the processes involved in cowpea growth are very complex and vitally influenced by environmental factors which are themselves complex and interdependent (Yellamanda and Sankara 2013). Nutrients management is a major environmental factor that is needed for sustainable cowpea production. Hence, balance**d** application of organic and inorganic nutrients has become important particularly in the inherently poor fertility status of Northern Guinea Savannah alfisols which are characteristically sandy in texture. Inorganic fertilizer has often been used as a base option in addressing soil nutrient deficiencies in Nigeria. However several negativities have characterized the use of inorganic fertilizer as comprehensively reviewed by Premanandarajah, and Prapagar, (2015). Alternative approach such as the use of poultry manure has particularly been utilized by cowpea growers in the Northern Guinea Savanna zone. The use of poultry manure has been reported to increase the number of nodules and yield of cowpea and also improved the chemical properties of soils with values ranging from **0.320, 6.8 and 0.04 per cent** for nitrogen, phosphorus and potassium, respectively, in South Eastern Nigeria ultisols (Madukwe *et al*. 2010).

On one hand, the ideal rate of nitrogen application to maize and pumpkin that could sustain the productivity of relay cowpea in the Northern Guinea Savannah of Nigeria is still not known. Hence, information generated from this trial will provide a guide on integrated nutrient management option for enhancing the nodulation pattern and yield of cowpea varieties that will ultimately enhance their biological nitrogen fixing efficiency while promoting higher tissue nutrient concentration. The significant of cowpea tissue nutrient concentration as a result of higher symbiotic relationship between root nodules and rhizobium lies in the fact that more total nutrients will be fix**ed** in the plant tissue (biomass) for subsequent incorporation into the soil via nodules and biomass decay.

Materials and methods

Experimental Site

The experiment was sited at the Teaching and Research field of the Institute for Agricultural Research Samaru (**L**atitude 11°11´008´N and **L**ongitude 7°36´52.1´´E) in the Northern Guinea agro-ecological zone during the 2019, 2020 and 2022 wet seasons. The zone is characterized by a monomodal rainfall pattern. Samaru has a mean annual rainfall of about 1011±161mm concentrated almost entirely in the five months (May/June to September/October) of the cropping season (Oluwasemire and Alabi, 2004). Samaru soils are classified as Typic Haplustalf according to the USDA soil taxonomy (Ogunwole *et al*., 2001) and Acrisols according to FAO-UNESCO legend (1994). The soil is low in inherent fertility: organic matter, cation exchange capacity and dominated by low activity clays (Odunze, 2003).

Treatments

Treatments consist of three levels of poultry manure (0, 3 and 6 t ha^{-1}), two genotypes of cowpea (SAMPEA 11 (Determinate) and SAMPEA 14 (indeterminate) and two (2) time of top dressing N fertilizer (double split and triple split application). At two weeks after sowing pumpkin and maize, fifty per cent (ie 22.5 kg N ha^{-1}) was applied to all the plots whereas at 4 weeks after sowing maize and pumpkin, the remaining fifty per cent (ie 22.5 kg N ha^{-1}) was applied to plots receiving double split doses nitrogen application whereas, for plot receiving triple splits, the 22.5 kg N ha^{-1} was further splits in two equal doses of 11.25 kg N ha^{-1} and applied at 4 and 6 weeks after sowing maize and pumpkin. Nitrogen was supplied in this trial in form of urea. The sum total of amount of N-fertilizer used for this trial was 50% (or 45 kg N ha^{-1}) of recommended dosage (90 kg N ha^{-1}) for early maturing maize. Pumpkin (*Curcurbita maxima L*) and maize were sown two weeks after land preparation and poultry manure application. The residues of harvested pumpkin were incorporated during earthing-up at 10 WAS, thereafter cowpea was then relayed into the maize. Upon harvest of cowpea, its residues were weighed and incorporated into the soil on the basis of treatments, and soil sampled for physical and chemical analyses.

Field Layout and Experimental Design

In 2019, the experimental area was ploughed, harrowed twice and ridged 0.75m apart. The experiment was laid out in randomized complete block design (RCBD) with split plot arrangement in four replications. The field was demarcated into four blocks (replication) with each block containing 12 plots. Each gross plots size was 18 m^2 (6 m by 3 m) , and thus representing eight (8) rows while the net plots size was 9 m^2 (3 m x 3 m) representing the four (4) inner rows. One metre (1 m) was allowed between main plots while the distance between one replication and the next was two meter (2 m) apart. Similarly, one plot equivalent was demarcated outside the plot area for the establishment of sole crops of maize (*Zea may*), squash pumpkin (*Curcurbit maxima*) and cowpea (*Vigna unguiculata L*) which received all requisite recommended cultural practices for optimum production of these three crops.

Varietal Characteristics

Cowpea varieties SAMPEA 14 (Semi-determinate, medium maturing, erect, multiple disease resistance especially Fusarium wilt, Drought tolerance as well as striga and Alectra resistance) and SAMPEA 11 (Indeterminate, late maturing, spreading, nematode resistance, aphid resistance, good seed quality and field tolerance to major pest) were used. The cowpea seeds used as propagules in each year were treated with Apron star (20% w/w thiamethoxam, 20 % w/w metalaxy-M and 2% w/w difenoconazole (0.1 kg a.i ha^{-1}) at the product rate of 10 g to 2 kg of seed as described by NAERLS (2012) as a protection against soil borne pests, diseases and bird attack before and after germination. Three seeds each of cowpea varieties were sown at spacing of 0.75m x 0.30 m later thinned to two plants per stands at 2 WAS.

Cultural Practices

In the three years of the experiment, basal application of 20 kg ha^{-1} each of K as Muriate of Potash (60% K_2O) and P as Single Superphosphate (18% P_2O_5) was done immediately after land preparation to all plots irrespective of treatments. Poultry manure was weighed and applied as per treatment and worked into the soil two (2) weeks prior to sowing pumpkin seeds in each year. Glyphosate at a rate of 4.0 Lha^{-1} at 1.4 kg a.i.ha^{-1} was sprayed two weeks before land preparation to control weed. **S**upplementary hoe weeding was done at 6 WAS or as the need arises.

Observations and Measurements

Nodulation: The significant of legumes in the cropping system is their ability to fix atmospheric nitrogen in association with rhizobium present in their root nodules. Hence, nodule number and dry weight were assessed. This measurement was taken at 8 WAS of cowpea; which correspond with the period of maximum biological nitrogen fixation. Destructive sampling was carried out on three (3) plants per plot. The plants were carefully uprooted from moist soils, being mindful not to dislodge adhering nodules, washed gently under gushing tap water to clear adhering soil particles thereafter the nodules were carefully detached, packed in labeled envelopes, and oven dried at 70°C till constant weight was attained, the average weights were then recorded **for each plot**.

Nodule number per plant: Nodule number was obtained by physically counting and recording the mean number of nodules **on each** plant per plot.

Nodule weight: The dried nodules were then collected and weighed on a sensitive digital scale (SB 16001 Mettler Toledo) and the average weight recorded as nodule weight per plant.

Plant Sample Collection and Analysis

At harvest, plant sample was collected for estimation of nitrogen, phosphorus and potassium concentration using standard laboratory techniques as described by IITA, (1993).

Statistical analysis

Individual analysis of variance was performed for each character in each year. Combined analysis was also carried out for those characters having homogeneous error variance for the three years. The analysis of variance at this stage was performed using the General Linear Model (GLM) procedure of SAS; (SAS Inst., 2000) package because of its high sensitivity. The effects of the various treatment and their interactions were compared using standard error of difference.

Result and Discussion

Characteristics of the Experimental Soil and Poultry Waste (2019, 2020 and 2022)

The results of some of the physical and chemical properties of the soil used in the experiment before the establishment of the trials in 2019, 2020, and 2022 are as shown in Table 1. The results showed that the texture of the soil in the three years was sandy-loam. The soil reaction was slightly acidic in 2019 (6.40), 2020 (5.67) and 2022 (6.23) but did not pose any limitation to maize, pumpkin and cowpea production. Organic carbon and total N were both low in the soil in all the years. However, test values of available P **were** relatively higher in 2022 (9.99) than 2019 (5.66) and 2020 (8.33). There was gradual increase—in organic carbon with relatively higher values reported in 2020 (1.28 %) than 2019 and 2022 (1.21 %). Exchangeable cations (Ca, Mg, and K) were also low with slightly higher values reported in 2022 than 2019 and 2020. The relatively low level of nutrients particularly nitrogen could be due to the high level of leaching of soluble nutrients which has been found to be more **prevalent** with sandy soils. This agreed with the work conducted by Premanandarajah and Prapagar (2015) who reported that sandy soils were more susceptible to leaching due to their large pore sizes and weak structure that tend to limit their potential to retain nutrients. The overall result of the physical and chemical properties of the experimental site depicts typical characteristics of alfisols of the Northern Guinea Savannah of Nigeria as reviewed by Odunze, (2003). The progressive increase in available P content of the soil could be as a result of the total P released by the poultry manure used in the experiment. Previous findings by Madukwe *et al* (2015) indicates **that the** application of poultry may block the pore spaces in sandy soil thereby minimizing leaching while increasing the soil water holding capacity thus promoting retention of dissolve**d** nutrients in soil solution. Similarly, the organic carbon content was below the critical values of 2% reported by Onofiok (2002)

Similarly, results of the chemical composition of the poultry manure **as shown in (Table 2)** showed relatively higher proportions of N, P, K **as well as Mg and Ca.** Manure pH was relatively high in 2019, than 2020 and 2022 with a corresponding higher concentration of organic carbon. The high organic carbon content may be as a result of the high organic matter content of the absorbent materials (wood shadings) used in collecting the poultry manure

Table 1: Physical and chemical properties of the soil of the experimental site in 2019, 2020and 2022

	Level in soil		
Soil Properties	2019	2020	2022
Sand (%)	51.00	48.00	49.35
Silt (%)	34.00	40.00	37.00
Clay (%)	15.00	12.00	13.65
Textural class	Sandy-loam	Sandy-loam	Sandy-loam
pH 1:2.5 water	6.40	5.67	6.23
Organic Carbon (%)	0.83	1.28	1.21
Total Nitrogen (%)	0.06	0.16	0.10
Available P (mg kg^{-1})	5.66	8.33	9.99
Exchangeable Ca^{2+}(Cmol/kg)	0.60	2.33	3.86
Exchangeable Mg^{2+} (Cmol/kg)	0.16	0.25	0.52
Exchangeable K^{+}(Cmol/kg)	0.28	0.16	0.23
Exchangeable acidity(Cmol/kg)	0.12	0.20	0.17
ECEC (Cmol/kg)	1.16	2.94	4.78

ECEC = Effective Cation Exchange Capacity

Source: Department of Agronomy, Soil analytical laboratory

Table 2: Chemical properties of the poultry manure used in 2019, 2020 and 2022

Properties	Yr 2019	Yr 2020	Yr 2022
pH 1:2.5 water	9.25	9.53	9.39
Organic Carbon (%)	45.63	47.35	46.49
Total Nitrogen (%)	1.71	1.80	1.79
Total P (mg kg^{-1})	3.38	6.03	4.81
Exchangeable Ca^{2+}(Cmol/kg)	7.50	7.43	7.47
Exchangeable Mg^{2+} (Cmol/kg)	12.19	12.16	12.18
Exchangeable K^{+}(Cmol/kg)	1.48	1.44	1.46
Exchangeable acidity(Cmol/kg)	0.16	0.17	0.17
ECEC (Cmol/kg)	21.33	21.20	21.27

Source: Department of Agronomy, Soil analytical laboratory

Effects of Treatment on Tissue N, P and K in 2019, 2020 and 2022

Result of analysis of variance of treatment effects on cowpea tissue N, P and K at harvest is presented in Table 3. Result showed that poultry manure application had no significant effects ($p<0.05$) on tissue N concentration in 2019, and 2022. However, in 2020, the application of 6 t ha^{-1} of poultry manure significantly ($p<0.05$) increased tissue N concentration, which was at par with 3 t ha^{-1}. In all the three years, time of nitrogen application, varieties and the respective factors interaction **were** not significant ($p<0.05$). The lack of significant difference in tissue N concentration with increase**d** application of poultry manure may be due to the high remobilization of nutrients from the leaves to the grains. In this trial, sampling for tissue analysis was carried out at harvest. Rapid uptake of the applied nitrogen by maize and pumpkin could be responsible for the poor uptake of nitrogen by cowpea tissues. Split application**s** of nitrogen have been reported to be very effective for optimal utilization by maize for increased productivity (Umoh *et al.* 2021). Cowpea tissue P concentration followed similar trend as earlier reported for N whereby poultry manure application significantly increased tissue P concentration in 2019 and 2020. The highest concentration of P in cowpea tissue was reported in 6 t ha^{-1} applications in 2019 and 2020 which was consistently at par with 3 t ha^{-1} poultry manure rates. Also, time of N application, varieties and main factors interaction **were** not significant in all the years.

The concentration of K in cowpea tissue was significantly ($p<0.05$) influenced by poultry manure application in 2019 and 2020. Highest K values were consistently reported in 6 t ha^{-1} which was at par with 3 t ha^{-1}. This higher value of K reported in the plant tissue at higher rate of poultry manure may be due to the high soil moisture retention capacity of poultry manure which perhaps provided the needed moisture for the solubilization and rapid translocation of K from the soil to the plant. Subsequently, early cessations of rains must have prevented the free mobility of K thereby increasing its retention in older leaves; thus contributing to high K concentration in the plant tissue. Characteristically, K is a highly soluble and mobile nutrient (Ellie *et al.* 2021). Application of nitrogen in three split doses significantly increased tissue K concentration. However, there was no significant ($p<0.05$) varietal effect on K concentration in all the years. Similarly, no significant ($p<0.05$) interaction was observed among the main factors in 2019, 2020 and 2022

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Table 3: Effects of poultry manure, time of nitrogen application and varieties on tissue N, P and K concentration at harvest in 2019, 2020 and 2022

	N (%)			P (mg kg^{-1})			K ($Cmolkg^{-1}$)		
	2019	2020	2022	2019	2020	2022	2019	2020	2022
Poultry manure (t ha^{-1}) (PM)									
0	1.09	1.11	1.00	0.33	0.33	0.36	0.13	0.13	0.13
3	1.13	1.14	1.02	0.40	0.43	0.38	0.14	0.15	0.13
6	1.12	1.14	1.09	0.40	0.44	0.38	0.15	0.15	0.14
SE±	0.402	0.101	0.102	0.022	0.104	0.031	0.007	0.014	0.012
Significance	NS	*	NS	*	*	NS	*	*	NS
Time of N application (N)									
Double dose	1.10	1.13	0.99	0.38	0.36	0.38	0.14	0.14	0.13
Triple dose	1.13	1.14	1.10	0.38	0.39	0.36	0.15	0.15	0.13
SE±	0.033	0.021	0.023	0.018	0.026	0.018	0.006	0.111	0.101
Significance	NS	NS	NS	NS	NS	NS	*	*	NS
Varieties (V)									
Sampea 14	1.10	1.13	1.02	0.38	0.36	0.38	0.14	0.14	0.13
Sampea 11	1.13	1.14	1.10	0.38	0.40	0.38	0.14	0.13	0.13
SE±	0.033	0.021	0.022	0.017	0.026	0.016	0.006	0.104	0.101
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions									
PM X N	NS	NS	NS	NS	NS	NS	NS	NS	NS
PM X V	NS	NS	NS	NS	NS	NS	NS	NS	NS
V X N	NS	NS	NS	NS	NS	NS	NS	NS	NS
PM X N X V	NS	NS	NS	NS	NS	NS	NS	NS	NS

*NS=Not significance at 5%, PM=poultry manure, N= methods of N application. * and ** represent significance difference at 5 and 1 % level of probability. Means having the same letter within a column are statistically similar while those with different letters within the same column are statistically dissimilar.*

Nodulation (Nodule number and dry weight (g))

Results of the analysis of variance of the influence of poultry manure, methods of nitrogen application and varieties on number of nodules and nodules dry weight **are** presented in Table 4. Results **indicate** that poultry manure treatment had a highly significant ($P<0.001$) effects on nodule number of cowpea in 2019, 2020, and 2022. Averages from the three years **indicate** that the highest number of nodule was reported with the application of 6 t ha^{-1} of poultry manure closely followed by 3 t ha^{-1} with an average of 15 nodules whereas the least number of nodules was reported in the control. Furthermore, methods of nitrogen application and varieties had significant ($p<0.05$) effects on nodule number in 2020, 2022 and combined where the highest number of nodules was reported with double split dose application of nitrogen. **No** significant difference was reported for nodule dry weight in all the years and **when combined**. Time of N application, varieties as well as their respective interactions had no significant effects on nodule dry weight in all the years. The higher number and weight of nodules reported with higher rates of poultry manure may be due to the improvement of soil physical condition due to buildup of organic matter which tends to increase the soil water holding capacity thereby allowing the retention of dissolve nutrients within the root zone. Paraphrasing the figure of the available nutrient**s** concentration obtain**ed** in this trial with those obtain**ed** by other researcher**s**, it is observe**d** that poultry manure contain higher proportions of macro and other beneficial element like Fe and Mn which play significant role in the initiation of legume-rhizobium symbiosis. The overall result agreed with the work conducted by Madukwe *et al*. (2015) who reported higher number of nodules and yield of cowpea with the application of 10 t ha^{-1} of poultry manure. Double split **application** produced more nodule number and dry weight over triple split dose probably due to the higher availability of nitrate with triple split nitrogen within the crop root zone which tends to suppress nodulation. This may be a function of excessive nitrate enrichment from both the inorganic nitrogen fertilizer and those released from poultry manure. Praragbara et al. 2017 observed that among organic nutrient sources, poultry manure was reported to have higher concentration of nitrate compared to other farm yard manure

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Table 4: Effects of poultry manure, time of nitrogen application and varieties on cowpea nodule number and dry weight per plant in 2019, 2020 and 2022

Treatment	Nodule number				Nodule dry weight (g)			
	2019	2020	2022	Combined	2019	2020	2022	Combined
Poultry manure (t ha^{-1}) (PM)								
0	14c	12b	10c	12c	0.41b	0.39b	0.36c	0.39c
3	16b	13b	12b	14b	0.45b	0.43b	0.40b	0.43b
6	23a	20a	18a	20a	0.71a	0.66a	0.63a	0.67a
SE±	1.739	1.780	1.797	1.772	0.077	0.097	0.098	0.091
Significance	**	**	**	**	*	*	*	*
Time of N application (N)								
Double dose	17	16a	14a	16a	0.59	0.51	0.48	0.53
Triple dose	15	14b	12b	14b	0.50	0.48	0.45	0.48
SE±	1.444	1.454	1.814	1.571	0.093	0.079	0.802	0.325
Significance	NS	*	*	*	NS	NS	NS	NS
Varieties (V)								
SAMPEA 14	17	14	12b	14b	0.50	0.48	0.45	0.48
SAMPEA 11	15	16	14a	15a	0.59	0.51	0.48	0.53
SE±	1.266	1.397	1.814	1.492	0.100	0.080	0.085	0.088
Significance	NS	*	*	*	NS	NS	NS	*
Interactions								
PM X N	NS	NS	NS	NS	NS	NS	NS	NS

PM X V	NS	NS	NS	NS	NS	NS	NS	NS
V X N	NS	NS	NS	NS	NS	NS	NS	NS
PM X N X V	NS	NS	NS	NS	NS	NS	NS	NS

*NS=Not significance, PM=poultry manure, N= methods of N application. * and ** represent significance difference at 5 and 1 % level of probability. Means having the same letter within columns are statistically similar while those with different letters within the same columns are statistically dissimilar.*

Correlation analysis

Result of the correlation matrix of nodulation parameters and cowpea tissue N, P and K concentration is shown in Table 5. Result indicates that nodule number is significantly correlated with nodule dry weight and total P concentration.

Table 5: Combined correlation matrix of tissue N, P and K concentration Nodulation parameters

	TK	TN	NDW	NN	TP
TK					
TN	0.157				
NDW	-0.012	-0.003			
NN	0.140	-0.099	0.579**		
TP	0.014	-0.160	0.273*	0.271*	

TK= Total K, TN=Total N, NDW=Nodule dry weight, NN= Nodule number, TP=Total P

Conclusions

Result from the finding showed that poultry manure application from 0 to 6 t ha^{-1} significantly increased both nodule number and dry weight of cowpea. Whereas, application of nitrogen in double split dose was more favorable to nodulation attributes than triple split dosage. The selected varieties had similar effects to the **amendments applied**. Furthermore, concentration of nitrogen, phosphorus and potassium in cowpea tissue at harvest was influence by poultry manure addition. Whereas, application of triple split dose of 45 kg ha^{-1} of nitrogen to maize/pumpkin resulted in higher concentration of K in cowpea tissue. This research suggests the need to apply 6 t ha^{-1} of poultry manure and triple split application of 45 kg N ha^{-1} for enhance cowpea nodulation and improved tissue NPK concentration

References

Adeoye, G. O. and Agboola, A. A. (1985). Critical levels for soil pH, available P, K, Zn, Mn and maize earleaf content of P, and Mn in sedimentary soils of South-western Nigeria. *Fertilizer Research* 6:65-71.

Adeoye, P.A., Adebayo, S.E. and Musa, J.J. (2011). Growth and yield response of cowpea (*Vigna unguiculata*) to poultry and cattle manure as amendments on sandy loam soil plot. *Agricultural Journal*, 6(5):218-22

Agah, Boniface Unimke., Emwanta, Idehen., Jeremiah, Idongesit Mbre and Magaji, Tagwai (2016). Nodulation and Symbiotic Nitrogen Fixation by Groundnut (*Arachis hypogaea* L) Genotypes as Influence by Inorganic Nitrogen Fertilizer in the Northern Guinea Savanna of Nigeria. *International journal of plant and soil science*, *IJPSS, 13(5): 1-15, 2016; Article no.IJPSS.30413*. **Available online** http://www.sciencedomain.org/issue/2112.

Agboola, A. A. and Ayodele, O. J. (1987). Soil test calibration for upland rice in southwestern Nigeria. *Fertilizer Research*, 14:227-234

Batish, D.R., Kaur, S., Singh, H.P and Kohli, R.K. (2005). Herbicidal activity of volatile oils from Eucalyptus citriodora. Abstracts, 11 European Allelopathy Symposium, Allelopathy from understanding to application. July 19. Vigo, Spain. Pp. 29.

Detpiratmongkol, S, T. Ubolkerd and S. Yoosukyingstaporn. (2014). Effects of chicken, pig and cow manures on growth and yield of Kalmegh (*Andrographis paniculata* Nees), *Journal of Agricultural Technology*, 10(2): 475-482. Available online http://www.ijat-aatsea.com

Ellie, M.A., Sire, K., Evie, E.S., Patrick, H.B., and Sat, D.S.K. (2021). A review of potassium rich crop residues used as organic matter amendments in tree crop agroecosystems. *Agriculture*, 11(7):580-588. Doi:10.3390/agriculture/11070580

FAO Statistics (2006): www.fao.org.

FAO-UNESCO. (1994). *Soil Map of The World. Revised Legend.* Tech. paper No.20. FAO/Rome and ISRIC/Wageningen, the Netherlands.

Fasoyiro, S.B and Taiwo, S.A. (2011). Strategies for Increasing Food Production and Food Security in Nigeria. *Journal of agricultural and food information*, 13, 2012 – issue 4.

Fening, J. O., Adjei- Gyapong, T., Yeboah, E., Ampottah, E. O., Tuah, E. O., Qunsah, G., Danso, S. K. A. (2005). Soil fertility status and potential organic input for improving small holder crop produc-in the Savannah zone of Ghana. *J. Sustain. Agric.*, 25: 69-92.

Klinczyk, M., Siczek, A and Schimmelpfennig, L. (2021). Improving the Efficiency of Urea-Based Fertilization Leading to Reduction in Ammonia Emission, *Science of the Total Earth,* vol.771, 1 June 2021.145483. https://.doi.org/10.1016

Madukwe,D., Christo, I.E.C and Onuh, M.O. (2010). Effects of organic manure and cowpea (*Vigna unguiculata* (L) walp) varieties on the chemical properties of the soil and root nodulation. *Science World Journa*l, 3(1):231-237

Msaakpa, T. S. (2016). Effects of Variety and Poultry Manure on Growth and Yield of Selected Cowpea (*Vigna unguiculata (L)Walp*) Varieties at Makurdi, Nigeria. International Journal of Scientific and Research Publications, Volume 6, Issue 8, August 2016 522.

Nadine Gobron (2005). Leaf Area Index, GTOS standards activity: www.fao.org/gtos/ECV-T11.html

Odedina, J., Ojeniyi, S., Odedina, S., Fabunmi, T., Olowe, V. (2015). Growth and Yield Responses of Cassava to Poultry Manure and Time of Harvest in Rainforest Agro-Ecological Zone of Nigeria. *International Journal of Agricultural Sciences and Natural Resources.* 2(3): 67-72.

Odunze, A. C., (2003). Effects of forage incorporation on selected soil chemical properties in the Northern Guinea Savanna of Nigeria. *Journal of Sustainable Agric.* **22:1-12.**

Ogunwole, J .O.; Babalola, O. A.; Oyinlola, E. Y. and Raji, B. A. (2001). A Pedological Characterization of Soils in the

Samaru Area of Nigeria. *Samaru journal of Agricultural research, 17:71-77.*

Oluwasemire, K. O., and Alabi S. O. (2004). Ecological impact of changing rainfall pattern, processes and environmental pollution in the Nigeria Sudan and Northern Guinea Savanna agro- ecological zones. *Nigeria Journal of soil Resources, 5:23 – 31*.

Onofiok, O.E. (2002). Unpublished lecture notes on **Introduction to soil science. Lecture notes on soil physics and biology, university** of Nigeria, Nsukka

Premanandarajah, P. and Prapagar, K (2015). Locally available soil amendments as a partial substitute for inorganic fertilizers on soil and groundwater qualities. *Asian Journal of Pharmaceutical Science and Technology,* 5(1):1-7

Rashid, Z., M. Rashid, S. Inamullah, S. Rasool and F. Bahar (2013). Effect of different levels of Farmyard manure and nitrogen on the yield and nitrogen uptake by stevia (*Stevia rebaudiana* Bertoni). *African Journal of Agricultural Research,* 8(29):3941-3945.

Singh, G., Jalota, S. K. and Singh, Y. (2007). Manuring and residue management effects on physical properties of a soil under the rice-wheat system in Punjab, India. *Soil Tillage Research, 94: 229–238.*

Sobulo, R.A and Osinamen, A.O. (1981). Soils and fertilizer use in western Nigeria. University of Ife Institute of Agricultural Research and Training Research Bulletin, pp. 193-203

Tate, R.L. (1995). Soil microbiology (symbiotic nitrogen fixation) New York, N.Y: John Wiley and Sons; Inc; pp 307-333

Umoh, F.O., Essien, O.A., Ijah, C.J., and Sunday, A.E. (2021). Determination of phosphorus fixation capacity on alluvium, sandstone and shale soils of akwa ibom state, Nigeria. *International Journal of Sustainable Agricultural Research*, 8(2):105-113

Wani, S.P., Rupela, O.P. and Lee, K.K. (1995). Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. ***Journal of Plant soil,*** 174: 29-49

Yellamanda Reddy, T and Sankara Reddy, G.H. (2013). Principles of Agronomy (1^{st} ed.). Kalyani publishers, New Dehli, Pp 89.

Yusuf, A. A., Abaidoo, R. C., Iwuafor, E.N.O., and Olufajo, O. O. (2008). Genotypic Effects of cowpea and Soybeans on nodulation, N_2 fixation, and N-Balance in the Northern Guinea Savanna of Nigeria. *Journal of Agronomy,* 7:258-264

Zahran, H.H. (1999). Rhizobium-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. *Microbiology and molecular biology review*, 63(4):968-989. Doi:10.1128/mmbr.63.4.968-989.1999

PHYTOREMEDIATION OF HYDROCARBON POLLUTED AGRICULTURAL SANDY LOAM ALFISOLS BY PHRAGMITES AUSTRALIS (COMMON REED) PLANT IN KANO, NORTHERN SUDAN SAVANNAH ECOLOGICAL ZONE OF NIGERIA

[1]Aliyu, R.W., [1,2]Sani, A., [2]Abdullahi, R., [3]Aliyu, J.A., [4]Abubakar, M.B., [5]Musa A. U., [4] Kafinga, M.H., [1]Abdulkadir N.A, [1]Almu, H. and [1,6]Auwal, M.

[1]Soil Science Department, Aliko Dangote University of Science and Technology, Wudil, PMB 3244, Kano State, Nigeria *Corresponding author; (abdulrikegam25@gmail.com)*

[2]Department of Crop Science, Umaru Musa Yar'adua University Katsina, PMB 2218 Katsina State, Nigeria

[3]National Agricultural Extension Research and Liaison Services, PMB 1067, Ahmadu Bello University Zaria, Nigeria

[4]Department of Forestry and Wild Life Management, Aliko Dangote University of Science and Technology, Wudil, PMB 3244, Kano State, Nigeria

5Kano Bioresource Center, National Biotechnology Research and Development, Abuja, Nigeria

[6]Institutes of Soil and Water Resources and Environmental Science, Zhejiang Provincial Key Laboratory of Agricultural Resources and Environment, Zhejiang University, Hangzhou 310058, China

abdulrikegam25@gmail.com

ABSTRACT

Hydrocarbon pollutants are carcinogenic and mutagenic, and can deteriorate agricultural soil quality. Phragmites australis is a sustainable and easy to grow phytoremediation plant that treats and depurates hydrocarbons in polluted soil bodies. The aim was to explore the efficacy of the plant in polycyclic aromatic hydrocarbons (PAH) removal and its effect on the hydrocarbon polluted soil properties. Collected plants were transplanted in plastic pots filled with soils polluted with different levels of inflow hydrocarbon fuel concentrations; 100mg/kg, 150mg/kg and 200mg/kg and their controls (without Phragmites plant), and replicated three times in a Completely Randomized Design (CRD) arrangement for the period of one month in the nursery of the Department of Forestry and Wildlife Management of the Aliko Dangote University of Science and Technology, Wudil, Kano state. Findings indicated that Phragmites australis showed a highest PAH removal efficiency in all the treatments (80%) with 95% depuration efficiency under 200mg/kg contamination. Moreover, the leftover PAHs concentration in the soil achieved permissible limit compliance according to standard of environmental regulatory agencies. Pertaining polluted soil properties, significant differences (P<0.05) were recorded in almost all the soil parameters after planting Phragmites australis with the exception of OC, P and K respectively with some of the soil properties recording reduced values while others indicating increased values compared with their initial concentration before planting the Phragmites australis. Overall, this study indicated that Phragmites australis is very effective in removing PAH and has a variable effect on the contaminated soil parameters. As a result there is a need to continue with the experiment beyond thirty days to fully ascertain the actual role of the plant on the soil properties.

Keywords; PAH, Quality, Phytoremediation, Phragmites australis , Hydrocarbon

1.0 Introduction

Global environment is facing a serious threat due to the release of substantial amount of toxic chemical compounds as the result of anthropogenic activities. These include both organic and inorganic pollutants such as heavy metals, nutrients, and hydrocarbons among others. Petroleum hydrocarbons involve total petroleum hydrocarbons (TPH), volatile organic compound (VOCs), aliphatic (AH) and aromatic hydrocarbons (PAHs), from diesel and other petroleum compounds, which are usual harmful to human health (carcinogenic, mutagenic, and teratogenic) (Tang *et al.,* 2010; and Sani, *et al.,* 2015) even at low concentrations and may negatively affect environmental ecosystem (Guittonny-Philpe *et al.,* 2015). Among the hydrocarbons compounds, PAHs are major category of organic pollutants that attracted serious concern among researcher due to its adverse effect on human and environmental ecosystem (Rong *et al.,* 2007; Zheng *et al.,* 2015 and Abbas, *et al.,* 2018). PAHs are generally generated from both natural and anthropogenic, with forest fire and volcanic eruptions as natural ones, whereas, urbanization, industrialization, petroleum drill and refining, fertilizers or pesticides, and other organic chemicals used to increase the yield of agricultural products as the anthropogenic source (Maliszewska-Kordybach *et al.,* 2008). These compounds are unsusceptible to degradation and present in the environment for a longer duration; hence, they are referred to as persistent organic pollutants (Flowers *et al.,* 2002; Alshaarawy *et al.,* 2016; Cao *et al.,* 2016; White *et al.,* 2016; Hu *et al.,* 2017). The release of these hydrocarbons into soil bodies causes soil quality deterioration, with resultant negative effects on the crops grown on the affected soils. Subsequently, upon consumption of the affected crops, the hydrocarbons enter the consumer's food web, where they exert their carcinogenic, neurotoxic, teratogenic, and mutagenic effects (Al-Muktar *et al.,* 2018; Sani *et al.,* 2020). Moreover, they naturally have the ability to circulate into soil and cause diseases like tumour growth, poor reproduction, poor development, poor immunity, and an excess risk of lung cancer (Abdel-Shafy and Mansour, 2016) when ingested through crops grown on the soils affected by them. As a result of rapid industrialization, population growth, and complete negligence for environmental health, pollution of soil environments with petroleum hydrocarbons such as PAH is becoming a common problem, particularly in oil producing countries like Nigeria. The release of these hydrocarbons into soil bodies causes soil quality deterioration, with resultant negative effects on the crops grown on the affected soils. Subsequently, upon consumption of the affected crops, the hydrocarbons enter the consumer's food web, and cause diseases like tumour growth, poor reproduction, poor development, poor immunity, and an excess risk of lung cancer. When ingested through crops grown on the soils affected by them, treating them is essential but difficult with common elimination methods (chemical, physical, and biological) that are not appropriate everywhere because of their high cost, irreversible changes in soil properties, destruction of soil microbes, and creation of unwanted by-products during the process of hydrocarbon abatement. Hence, searching for and applying a standard hydrocarbon removal technique that is environmentally friendly, ecologically balanced, cost effective, less energy-intensive, and easy to operate with public acceptance, like phytoremediation using common reed, remains essential.

Reed grass (*Phragmites communis* Trin.) is commonly found worldwide due to its adaptability under diverse environmental conditions such as saline, drought, and heavy metal pollution (Hronec and Hajduk, 1998). This plant has important ecological functions because it is a perennial, fast growing grass with high-yield potential that provides a habitat for many wildlife species. With recent attention to environmental problems, natural purification of wastewater using wetlands and aquatic macrophytes is in the limelight as an alternative to conventional wastewater treatment (Lee *et al.,* 2012).

According to Milijiana Prica *et al.,* (2019), common reed (*Phragmites australis*) is a helophytic perennial plant species typical of different wetland ecosystems. It is a robust and highly productive grass, with shoots up to 4 m tall and an extensive system of rhizomes and stolon in its vegetative propagation. *Phragmites australis* (common reed) is highly resistant in relation to most abiotic factors, such as temperature and salinity. It also demonstrates high resistance to PAH pollution and inhabits very clean to highly polluted sediments and waters. Due to its fibrous roots and their large contact areas, as well as its production of large amounts of aboveground biomass, common reed was reported to be very efficient in the phytoremediation of PAH. Shaltout, *et al.,* (2006) show that *P australis* grows in marshes and swamps, along streams, lakes, ponds, ditches, and wet wastelands, often weedy and very difficult to eradicate, as its stoloniferous rhizomes may reach 10 m or more in length. It grows best in firm mineral clays, and is resistant to moderate salinity, where the water level fluctuates from 15 cm below the soil surface to 15 cm above. It is also resistant to burning if water is above the soil surface, but burning is not essential for management. It is found that common reeds require an annual precipitation of 3.1 to 24.1 dm, an annual temperature of 6.6 to 26.6 °C, and a pH of 4.8 to 8.2.

Despite many conducted experiments on soil and water contamination with hydrocarbons (Sani *et al.,* 2021, 2022), none of them have ever focused on the assessment and reclamation of contaminated soil with PAH hydrocarbons using *P. australis*, hence, this necessitates conducting this research with the aim of assessing the removal efficiency of the common reed plant on PAHs as a hydrocarbon model in.

2.0 Materials and Methods

2.1 Description of the Study Site

This research was conducted at Aliko Dangote University of Science and Technology, Wudil Nursery Section of the Forestry, Fisheries, and Wild Life Department. Wudil is located at latitude 11.7942N and longitude 8.8390E. The climate of the area is normally wet and dry, and the mean annual rainfall is about 850 mm (Olofin, 1987). The mean annual temperature in the area is about 26°C; however, the monthly mean temperature value ranges between 21 °C during the coolest month of December/January and 31 °C in the hottest months of April/May (Olofin, 1987).

2.2 Experimental Materials:

Soil, cow dung manure, common reed plant, used engine oil, weighing balance, plates, hand trowel, hand gloves, and pots.

2.3 Experimental Procedure:

The experiment was an open-pot experiment to simulate the natural environmental conditions of the research area.

2.3.1 Material selection:

Healthy common reeds were collected from healthy parent stocks that are naturally growing in their environment.

2.3.2 Plant population:

Five (5) plants were planted per experimental pot and thereafter contaminated with used engine oil as a source of hydrocarbon at different rates.

2.4 Soil Sample Preparation:

The Fine River sand and cow dung manure were sterilized and mixed at a ratio of 3:2 using a head pan, then potted and set into a nursery.

2.4.1 Treatments Combination Preparation

The three replication treatments were placed in a nursery; each replication has three treatment combinations with varying levels of contamination. Used lubricant oil was poured on each pots with different rates (50k/kg and 250k/kg) respectively and then planted the common reeds (Phragmites autralis) after two weeks of contamination.

2.5 Soil Sample Collection for Laboratory Analysis

The soil sample was collected from experimental pots at a rate of 0.5 kg per pot before contaminating the soil. Nine samples from three replicates were collected and kept under shade to dry before analysis. After contaminating the soil, the procedure was repeated twice at a 30-day interval, and samples were taken to the laboratory for physicochemical analysis.

2.6 Laboratory analysis

2.6.1 PAHs analysis

The study used Soxhlet extraction to measure polycyclic aromatic hydrocarbons (PAHs) concentrations in soil samples. The extracted compounds were evaporated, purified, and gas chromatography was used to evaluate PAH concentration (USEPA, 1984, and Christopher et al., 1988).

2.6.2 Determination of Soil pH

The pH meter was calibrated using known buffers, and a soil sample was mixed and stirred. A 40 ml sample was added to the beaker, and the temperature stabilized for 1 hour. After stirring, the temperature was measured and adjusted in the pH meter. This process ensures homogeneity and accuracy in soil analysis (Udo, 2009, and Rhoades, 1982).

2.6.3 Determination of Cation Exchange Capacity (Ammonium Saturation Method)

The CEC was determined using the ammonium saturation method, which involves adding neutral 1N NH4OAC to a soil sample, shaking it, and letting it drain. The soil is then filtered and distilled into a 2% Boric acid solution. The titration process involves adding bromocresol green-methyl red mixed indicator and observing the color change from bluish green to pink. The titrate NH4- is corrected with a blank result (Anderson and Ingram, 1993).

2.6.4 Determination of Electrical Conductivity (EC)

The electrical conductivity (EC) of soil was measured in mmhos/cm after adjusting the soil solution temperature to 250C and using an EC meter. Five samples were socked for 24 hours, and then measured using a DD5-307 MODEL (Brower and Wilcox 1965).

2.6.5 Determination of Organic Carbon

The wet oxidation method of Walkley-BBlack (1934) was used to determine soil organic carbon. The process involved digesting soil with a 1N potassium dichromate solution, adding distilled water, and titrating with a 0.5 N ferrous sulfate solution (Nelson and Sommers, 1982).

2.6.6 Determination of Total Nitrogen

The Micro-Kjeldhal technique was used to determine total nitrogen content in soil. The soil was digested with concentrated sulfuric acid, NaOH, and boric acid. The digest was then distilled, and the resulting distillate was titrated with 0.05 N H2SO4 to obtain a pink end point (Bremmer and Mulvaney 1986).

2.6.7 Determination of Phosphorus

A gram of sieved soil is weighed, p-extracting solution is added, and the suspension is centrifuged. The filtrate is transferred to a beaker, ammonium molybdate reagent and stannous chloride solution are added, and color development is measured. Adsorption is read using the same method (Nelson and Sommer, 1982).

2.6.8 Exchangeable Bases (Ca, K, Mg, Na)

The Neutral ammonium acetate procedure was used to determine the exchangeable bases of soil samples, including calcium, magnesium, potassium, and sodium, using atomic absorption spectrophotometers and flame photometers (Anderson and Ingram, 1986).

2.7.1 Statistical analysis:

The experimental data obtained was subjected to analysis of variance (ANOVA) using the one-way procedure of the SPSS 1999 statistical package, and where the means were significant, they were separated using Duncan's Multiple Range Test (DMRT) at 5% level of probability.

3.0 Results and Discussion

3.1 MEAN VALUES OF SOME SELECTED SOIL CHEMICAL PROPERTIES

3.1.1 EFFECT OF PAHs AND COMMON REED PLANT ON pH.

The results from Table 1 show the mean values of some selected soil chemical properties from the soil contaminated with hydrocarbons and planted with common reed. The value of the initial pH of soil contaminated with hydrocarbons before planting common reed was 2.99 and 6.60 after planting. It indicated that the pH was highly acidic before common reed planting, but after, the pH recorded 6.60. This pH value was close to neutral and within the permissible recommended limit (6.5–8.5) of health and environmental agencies (WHO, 2008; FAO, 2021). However, in statistical table, results showed that there was a significant difference recorded ($p<0.05$) for pH and the hydrocarbon in all the treatments (Table 3.3)

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Table 1: Impact of common reed specie (P. australis) on PAHs and some soil chemical parameters

Parameters	Mean ± S.D	P-value
pH (Initial)	2.99 ± 1.99	0.001*
pH (Final)	6.60 ± 0.62	
EC (Initial)	4.52 ± 3.01	0.002*
EC (Final)	0.08 ± 0.04	
OC (Initial)	3.33 ± 2.22	0.192
OC (Final)	2.40 ± 0.90	
P (Initial)	43.54 ± 29.03	0.980
P(Final)	43.27 ± 17.16	
N(Initial)	2.26 ± 1.51	0.004*
N(Final)	0.34 ± 0.11	
K(Initial)	0.30 ± 0.20	0.448
K(Final)	0.24 ± 0.57	
Na (Initial)	0.15 ± 0.10	0.003*
Na (Final)	0.34 ± 0.11	
Ca (Initial)	0.76 ± 0.51	0.001*
Ca (Final)	2.01 ± 0.40	
Mg (Initial)	1.02 ± 0.68	0.008*
Mg (Final)	0.29 ± 0.13	
CEC(Initial)	2.38 ± 1.59	0.004*
CEC(Final)	6.77 ± 2.04	

Key: * Statistically significant $p<0.05$. H_2O: Water, KCL: Potassium chloride, OC: Organic Carbon, P: Phosphorus, N: Nitrogen, K: Potassium, Mg Magnesium, Na: Sodium, Ca: Calcium, PAH: Polycyclic aromatic hydrocarbon, CEC: Cation exchange capacity.

3.1.2 EFFECT OF PAHs AND COMMON REED PLANT ON ELECTRICAL CONDUCTIVITY (EC)

The initial EC mean values of soil contaminated with hydrocarbons before planting common reed were 4.58 dS/m and 0.08 dS/m after planting (Table 1). This indicated that the EC values were reduced to 0.08 ds/m after planting common reed. The EC values after planting common reed were in the range of recommended values (0–4 dS/m) advocated by FAO (2003) in soils for arable crop production. However, in the statistical table, results showed that there was a significant difference recorded ($p<0.05$) for EC and hydrocarbon in all the treatments (Table 3)

3.1.3 EFFECT OF PAHs AND COMMON REED ON ORGANIC CARBON (OC%).

The mean organic carbon value of the soil contaminated with hydrocarbons before planting was 3.33 g/kg and 2.40 g/kg after planting. This indicated that the OC was reduced to 2.40 g/kg after planting common reed. Furthermore, the OC values are within the low class (Table 3) of the soil fertility rating range, according to Adamu et al. (2021). However, in the statistical table, the results showed that there was a significant difference recorded ($p<0.05$) for OC and hydrocarbon in all the treatments (Table 3)

3.1.4 EFFECT OF PAHs AND COMMON REED PLANT ON PHOSPHOROUS (P).

The initial mean value of soil contaminated with hydrocarbons before planting common reed was 43.54 mg/kg and 43.27 mg/kg after planting. This shows that the P was reduced slightly to 43.27 mg/kg after planting common reed. According to Adamu et al., (2021) ranking, the mean values of available phosphorous recorded in the soil fell into the high class of soil fertility rating (Table 3). However, in the statistics table, the result indicated that there was no significant difference recorded ($p > 0.05$) for P and hydrocarbon in all the treatments (Table 3).

3.1.5 EFFECT OF PAHS AND COMMON REED PLANT ON NITROGEN (N).

The initial mean values of nitrogen in soil contaminated with hydrocarbons before planting common reed, as shown in Table 1, was 2.26 mg/kg and 0.34 mg/kg after planting, and this show that nitrogen was reduced to 0.34 mg/kg after planting common reed. According to Adamu et al., (2021) ranking, the mean values fell into the high class of soil fertility (Table 3). However, in the statistical table, results indicated that there was no significant difference recorded ($p > 0.05$) for N and hydrocarbon in all the treatments (Table 3).

3.1.6 EFFECTS OF PAHs AND COMMON REED PLANT ON CATION EXCHANGE CAPACITY (CEC)

The initial mean CEC values of soil contaminated with hydrocarbons before planting common reed was 2.38cmol/kg and 6.77cmol/kg after planting. This shows that CEC was increased to 6.77cmol/kg after planting common reed. As reported by Adamu et al., (2021) soil fertility rating, the CEC values fell into the moderate class of soil fertility (Table 3). However, in the statistical table, the result shows that there was a significant difference recorded ($p<0.05$) for CEC in all treatments (Table 3).

3.1.7 EFFECT OF PAHs AND COMMON REED PLANT ON EXCHANGEABLE BASES (K, Ca, Mg, Na)

The initial K, Ca, Mg, and Na mean values of soils contaminated with hydrocarbons before and after planting common reed were 0.30 Cmol/kg and 0.21 Cmol/kg, 0.76 Cmol/kg and 2.01 Cmol/kg, 1.02 Cmol/kg and 0.29 Cmol/kg, and 0.15 Cmol/kg and 0.34 Cmol/kg. However, in the statistical table, results showed that there was no significant difference recorded in K ($p > 0.05$), but a significant difference was observed in Ca, Mg, and Na ($p < 0.05$) in all the treatments (Table 3.3). According to Adamu et al.'s (2021) ranking, K and Mg fell into the moderate class of fertile soils, while Na and Ca fell into the high and low classes of soil fertility rating, respectively (Table 4.3).

3.2 PAHs REMOVAL BY COMMON REED

Finally, Table 2 indicates the value of inflow and outflow of PAHs in each treatment, removal efficiency, and environmental quality standard according to the literature rating, and they have proved from table 2 and Figure 1 that the inflow of treatments 1, 2, and 3 is 200, 1000, and 600, and the outflow is 37, 112, and 11; the removal efficiency is 86%, 87%, and 95%; and all the treatments achieved compliance of 0-1.5 mg/kg (Yadav et al., 2021).

Table 2: PAH Removal Efficiencies after Common reed treatment and their environmental quality permissible limit all in g/kg

Treatments	Inflow	Outflow	Removal%	Permissible limit
TREATMENT 1	200	37	86	0-1.5mg/kg
TREATMENT 2	1000	112	87	0-1.5mg/kg
TREAMENT 3	600	11	95	0-1.5mg/kg

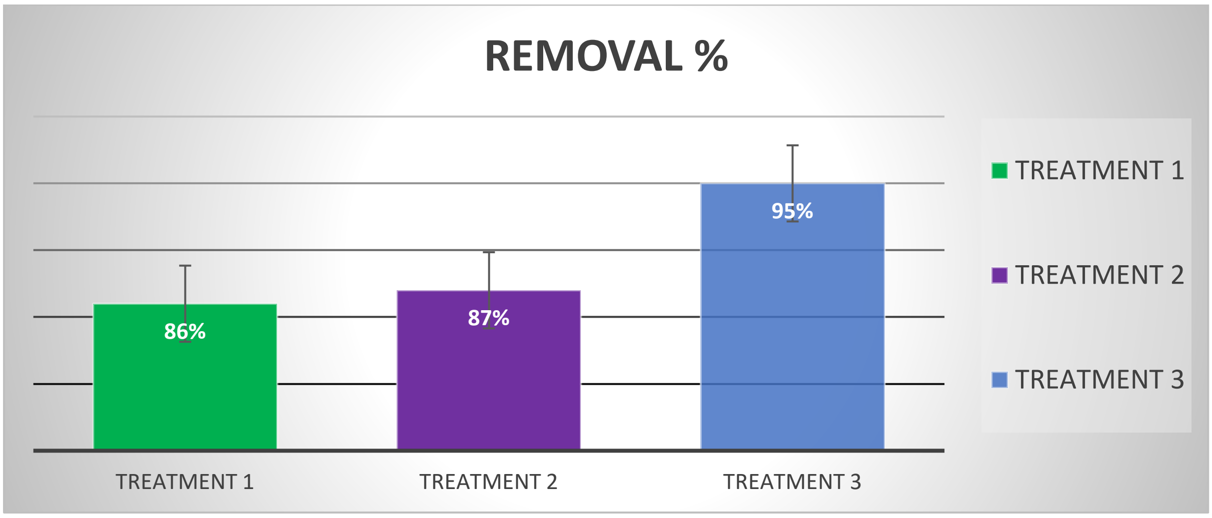


Figure 1: PAH Removal Efficiency by *Phragmites australisspp*

Table 3: Soil parameters recommended fertility ratings

Parameter	Low	Medium	High	Unit
pH	<5.4	5.4-7.5	>7.5	(-)
OC	<10	10-15	>15	g/kg
EC	<5	5.0-10.0	>10	dS/m
CEC	<6	6-12	>12	Cmol/kg
N	<0.1	0.1-0.2	>0.2	g/kg
P	<10	10-20	>20	Mg/kg
Ca	<2	2-5	>5	Cmol/kg
Na	<0.1	0.1-0.30	>0.30	Cmol/kg
K	<0.15	0.15-0.30	>1.0	Cmol/kg
Mg	<0.3	0.30-1.0	>1.0	Cmol/kg

Modified by Adamu et al (2021)

Reference

Abbas I, Badran G, Verdin A, Ledoux F, Roumié M, Courcot D, Garçon G (2018) Polycyclic aromatic hydrocarbon derivatives in airborne particulate matter: sources, analysis and toxicity. Environ Chem Lett 16:439–475. https://doi.org/10.1007/s10311-017-0697-0.

Abdel-Moghny T, Ramadan S, El-Sayed E, Shoukry M, Moustafa (2012) Effect of moisture on the remediation of hydrocarbon contaminated soil at El-Mina district, Upper Egypt. Chem Eng 13:1-13. https ://doi.org/10.5402/2012/40659

Abdel-Moghny T, Ramadan S, El-Sayed E, Shoukry M, Moustafa (2012) Effect of moisture on the remediation of hydrocarbon contaminated soil at El-Mina district, Upper Egypt. Chem Eng 13:1-13. https ://doi.org/10.5402/2012/40659

Abdel-Shafy HI, Mansour MS (2016) A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. Egypt J Pet 25(1):107–123. https://doi.org/10.1016/j.ejpe.2015. 03.011.

Abdulfattah, A. A., J. Saima, M. Arif, and S. Rawand. 2016. Effects of Crude Oil Spillage on the Physico-chemical Properties of Soil, Tarian, Kurdistan Region, Iraq. Journal of Environment and Earth Science 6 (6):27-32.

Achterberg, M. Mowlem Determination of nitrate nitrogen in sea water in panamo International Journal of Current Research, 6 (2008), pp. 3910-3913, 10.24941/ijer.31970.05.2019 Google Scholar

Adam G., Duncan H. (2003): The effect of diesel fuel on common vetch (Vicia sativa L.) plants. Environmental Geochemical and Health, 25: 123-130.

Afzal M. Yousaf S. Reichenauer TG, Kufiner M, Sessitsch A (2011). Soil type affects plant colonization, activity and catabolic gene expression of inoculated bacterial strains during phytoremediation of diesel. J. Hazard. Mater. 186:1568-1575.

Agarwal T, Khillare PS, Shridhar V, Ray S (2009) Pattern, sources and toxic potential of PAHs in the agricultural soils of Delhi, India. J Hazard Mater 163(2):1033–1039. https://doi. org/10.1016/j.jhazmat.2008.07.058

AGENCY FOR TOXIC SUBSTANCE AND DISEASE REGISTRY (ATSDR). (2010). Public Health Statement. August 1995.[Accessed 1st March, 2021

Agriculture Reviews 50 to 211 https://doi.org/10.1007/978-3-030-

63249-6_8 212 negative impacts of polycyclic aromatic hydrocarbons, an immediate attention is required from the policymakers to frame out a policy for checking the emission and management of these harmful chemical compounds. yadav et al (2021)

Almuktar, S.A.A.A.N., Abed, S.N and Scholz, M. (2018). Wetlands for Wastewater Treatment and Subsequent Recycling of Treated Effluent: A Review. Environmental Science and Pollution Research 3, 1-29.

Alshaarawy O, Elbaz HA, Andrew ME (2016) The association of urinary polycyclic aromatic hydrocarbon biomarkers and cardiovascular disease in the US population. Environ Int 89:174–178. https://doi.org/10.1016/j.envint.2016.02.006

Anderson J. M. and Ingram I. S. 1993. Tropical Soil Biology and Fertility: A handbook of methods. 2nd edition. C.A.B International Walling-ford UK

Becker-Ross Determination of phosphorus, sulphur and the halogens using hightemperature molecular absorption spectrometry in flames and furnacesa review Anal. Chem. Acta, 647 (2007), pp. 137148

Bremmer, J. M. and Mulvaney, C. S. 1986. Nitrogen total. In: Page, A. L., R. H. Miller and D. R.

Caravaca F, Figueroa D, Roldan A, Azcon-Aguilar C (2003). Alteration in Rhizosphere soil

Carvalho MM, Vila MC, Delerue-Matos C, Oliva-Teles MT, Fiúza M (2015). Assisted bioremediation tests on three natural soils contaminated with benzene. Eur. J. Soil Sei. 4(3):153-160.

Christopher, S., Hein, P., Marsden, J. and Shurleff, A.S (1988). Evaluation of Methods 3540 (Soxhlet) and 3550 (Sonication) for Evaluation of Appendix IX Analyses from Solid Samples, S-CUBED. Report for EPA Contract 68-03-33-75. Work Assignment No.03. Document No, SSS-R-88-9436

Collins, J.F., J. P. Brown, G. V. Alexeeff, and A. G. Salmon. (1998): Potency equivalency factors for some polycyclic aromatic hydrocarbons and polycyclic aromatic hydrocarbon derivatives. Regulatory Toxicology and Pharmacology, 28: 45-50. Effect of polycyclic aromatic hydrocarbon on the enviromenr review (Anyahara jessica nene 2021)

Dec, D., Dorner, J., Becker-Fazekas, O., and Horn, R. 2008. Effect of bulk density on hydraulic properties of homogenized and structured soils. J. Soil Soc. Plant Nutr. 8:1 - 13 Department for Environment, Food and Rural Affairs, (2002). Description of the methodologyapplied by the Secretary of State in identifying additional nitrate vulnerable zones in England (2002). Defra, London.

Edenborn HM, Zenone VE (2007). Rapid estimation of TPH reduction in oil-contaminated soils using the MED method. Publication no. DOENETL-IR-2007-142. Department of Energy, National Energy Technology Laboratory, Pittsburg. https://www.etde.org/etdeweb/servlets/purl/915479/

Edeogu, 2007 C.O. Edeogu Nitrate, sulphate, phosphate and chloride status of staple food crops, soils and water as indicator of environmental base anion pollution load in Ebony State, Nigeria J. Biol. Sci., 7 (5) (2007), pp. 745-751 CrossRef View Record in Scopus Google Scholar

Edwin-Wosu, N. L., and E. N. Eleniwo. 2006. Crude oil exploration, an environmental double-edge sword in Nigeria:The Niger Delta experience. Journal of Nigerian Environmental Society 3 (3):268-79

Eghbal N, Nasrabadi T, Karbassi AR, Taghavi L (2019) Evaluating the potential of plants (leaves) in removal of toxic metals from urban soils (case study of a district in Tehrancity).Pollution5(2):387–394.https://doi.org/10.22059/poll.2019.272090.555.

Environ. Manag. 31(3):412-420

FAO (2003) User's manual for irrigation with treated wastewater. Food and AgricultureOrganization (FAO) of the United Nations. FAO Regional Office of the Near East, Cairo

Fazeli G, Karbassi AR, Nasrabadi T (2018) Anthropogenic share of metal contents in soils of urban areas. Pollution 4(4):697–706. https://doi.org/10.22059/poll.2018. 261506.474 Flowers L, Rieth SH, Cogliano VJ, Foureman GL, Hertzberg R, Hofmann EL, Schoeny RS (2002) Health assessment of polycyclic aromatic hydrocarbon mixtures: current practices and future directions. Polycycl Aromat Compd 22(3–4):811–821. https://doi. /10.1080/10406630290103960

Fester T, Giebler J, Wick LY, Schlosser D, Kästner M (2014). Plant microbe interactions as drivers of ecosystem functions relevant for the biodegradation of organic contaminants. Curr. Opin. Biotechnol. 27:168-175.

Flowers L, Rieth SH, Cogliano VJ, Foureman GL, Hertzberg R, Hofmann EL, Schoeny RS (2002) Health assessment of polycyclic aromatic hydrocarbon mixtures: current practices and future directions. Polycycl Aromat Compd 22(3–4):811–821. https://doi.org/10.1080/10406630290103960

Gong Z, Li P, Wilke B M. (2008). Effects of vegetable oil residue after soil extraction on physical-chemical properties of sandy soil and plant growth. Journal of Environmental Sciences, 20: 1458-1462. do: 10.1016/S1001-0742(08)62549-8

Gurska J, Wang W, Gerhardt KE, Khalid AM, Isherwood DM, Huang XD, Glick BR, Greenberg BM (2009). Three year field test of a plant growth promoting rhizobacteria enhanced phytoremediation system at a land farm for treatment of hydrocarbon waste. Environ. Sci. Technol. 43:4472-4479

Haritash, A. K., and Kaushik, C. P. (2009). Biodegradation Aspects of Polycyclic Aromatic Hydrocarbons (PAHs): A Review. Journal of Hazardous Materials, 169, 1-15.

Hrynczyszyn et al., 2010 P. Hrynezyszyn, A. Jastrzebska, E.S. Szlyk Determination of phosphate compounds in meat products by 31phosphorus nuclear magnetic resonance spectroscopy with methylene-diphosphonic acid after alkaline extraction Anal. Chem. Acta, 673 (2010), pp. 73-78

Hu Yalin, Wang Silong, Yan Shaokui, 2006. Research advances on the factors influencing the activity and community structure of soil microorganism. Chinese Journal of Soil Science, 37(1): 170-176. (in Chinese)

Huesemann MH, Hausmann TS, Fortman TJ (2004). Does bioavailability limit biodegradation a comparison of hydrocarbon biodegradation and desorption rates in aged soils.Biodegradation 15:261-274.

Jia Jianli, Liu Ying, Li Guanghe (2009). Contamination characteristics and its relationship with physicochemical properties of oil polluted soils in oilfields of China. Chemical Industry and Engineering

Society of China, 60(3): 726-732. (in Chinese)

K. h. Shaltout., Y. M. Al-Sodany, and E. M. Eid. (2006) "Biology of Common reed phragmites australis (cav.) Trin. Exstend.: review and inquiry (Book_January, 2006) htpps://www.researchgate.net./publication/281274973;

Kaimi E, Mukaidani T, Tamaki M (2007) Screening of twelve plant species forphytoremediation of petroleum hydrocarbon-contaminated soil. Plant Prod Sci10:211-218

Keeney (eds.) methods of soil Analysis Part 2 Chemical and Microbiological properties. American Society of Agronomy, Madison W.I. pp. 595-641.

Khan S, Afzal M, Iqbal S, Khan QM (2013) Plant-bacteria partnerships for the remediation of hydrocarbon contaminated soils. Chemosphere 90:1317-1332

Kisic I, Mesic S, Basic F. (2009). The effect of drilling fluids and crude oil on some chemical characteristics of soil and crops. Geoderma, 149(3-4): 209-216. doi: 10.1016/j-geoderma. 2008.11.041

Lee, A. N., and M. R. Charles. (2002). Phytodegradation of organic compounds. Current Opinion in Biotechnology15:225-30. do: 10.1016/.copbio.2004.04.006.

Lehmann, J., B, Q. Liang, D. Solomon, M. Lerotic, F, Luizao, J. Kinyangi, T. Schafer, S. Wirick, and C. Jacobson, 2005 Near-Edge X-ray absorption fine structure (NEXAFS) spectroscopy for mapping nano-scale distribution of organic carbon forms in soil; Application to black carbon particles. Global biogeochem. Cycles 19;1013,

Maliszewska-Kordybach B, Smreczak B, Klimkowicz-Pawlas A, Terelak H (2008)Monitoring of the total content of polycyclic aromatic hydrocarbons (PAHs) inarablesoilsinPoland.Chemosphere73(8):1284–1291.https://doi.org/10.1016/j.chemoshpere.2008.07.009

Marin-Garci' DC, Adams RH and Hera indez-Barajas H (2016). Effect of crude petroleum on water repellency in a clayey alluvial soil. Int. J. Environ. Sei. Technol. 13:55-64.

Merkl N., Schulze-Kroft R., Infant C. (2004): Assessment of tropical grasses and legumes forphytoremediation of petroleumcontaminated soils. Water, Air, and Soil Pollution,165: 195-209.

Motomizu and Li, S. Motomizu, Z.H. Li. Trace and ultratrace analysis for the determination of phosphorus flow by injection techniques Sci. Total Environ., 407 (2005), pp.60346043

Naidoo G, Naidoo Y, Achar P (2010) Responses of the mangroves Avicennia marina and Bruguiera gymnorrhiza to oil contamination. Flora 205:357-362

national crude oil spill fate and natural attenuation research site. In: Geological Society of America annual meeting, Minneapolis, MN, 9-12 October, paper 136-1.Availableathttps://gsa.confex.com/gsa/2011AM/finalprogram/abstract_193916.

Nelson, D. W. and Sommers, L. E. 1982. Total carbon, organic carbon and organic matter. In. A. L. Page et al. (ed.). Methods of soil analysis part 2 2nd ed. Agronomy Monograph 9. ASA and SSSA. Madison, WI. pp. 539-577.

Nieber J. Severson L., Grewe N (2011). Hydrologic characteristics of contaminated soils at the

Nioku KL, Akinola O, Oboh BO (2009). Phytoremediation of crude oil contaminated soil: the eflects of growth of Glycin Max. on the physico- chemistry and crude oil contents of soil. Nat. Sci. 7(10):7987.

Nuruddeen, Z. O., Adamu, A. and Ibrahim, F.B (2016). Quality assessment of irrigation water of kano river irrigation project (Kadawa sector). Gashua Joural of Irrigation and Desertification Studies, 2, (1) ISSN 2489 - 0030

Oladeji et al., 2016 S. Oladeji, F. Adelowo, K. Odelaide Evaluation of phosphate level in water samples (Ogbomosho) visible spectrophotometer analysis Agulu Lake, Anambra State, Nigeria Arch. Curr. Res. Int., 12 (2) (2016), pp. 1-9 CrossRef View Record in Scopus Google Scholar

Onwurah INE, Ogugua VN, Onyike NB, Ochonogor AE, Otitoju OF (2007). Crude oil spills inthe environment, effects and some innovative clean-up biotechnologies. Int. J.Environ. Res. 1(4):307320.

Osuji, L.C.; Adesiyan, S.O., 2005. The Isiokpo oilpipeline leakage: Total organic carbon/organic matter contents of affected soils. Chem. Biodiversity. 2: 1079 - 1085.

Patey et al., 2008 M.D. Patey, M.J.A Rijkinberg, P.S. Statham, M.C. Stinchcombe, E.P.

Pathek H, Bhatnagar K, Jaroli DP (2011). Physico-chemical Properties of Petroleum Polluted Soil Collected from Transport Nagar (Jaipur). IJ FALS 1(3):84-89

Pezeshki S, Hester M, Lin Q, Nyman J (2000) The effects of oil spill and clean-up on dominant US Gulf coast marsh macrophytes: a review. Environ Pollut 108:129-139

properties of afforested Rhamnus lycioides seedlings in short-term response to mycorrhizal inoculation with Glomus intraradices and organic amendment.

Quyum A (2000). Water migration through hydrophophobic soil. Master of Science Thesis.Department of Civil Engineering. Calgary, Canada.

Quyum A, Achari G, Goodman RI (2002). Effect of wetting and drying and dilution onmoisture migration through oil contaminated hydrophobic soils. Sei. Total Environ. 296:77-87.

Radaideh, J., Al-Zboon, K., Al-Harahsheh, A. and Al-Adamat, R. (2009). Quality assessment of harvested rain water for domestic uses, Jordan. Journal of Earth a reduce contamination of lettuce crops by Escherichia coli in reclaimed water irrigation.Water Research, 46, 6040-6050

Razafimbelo T, Chevallier T, Albrecht A, Chapuis-Lardy L, Rakotondrasolo FN, Michellon R, Rabeharisoa L, Bernoux M (2013). Texture and organic carbon contents do not impact amount of carbon protected in Malagasy soils. Sci. Agric. 70(3):204-208.

Redondo-Gomez S, Petenello MC, Feldman SR (2014) Growth, nutrient status, and photosynthetic response to diesel-contaminated soil of a cordgrass, Spartina argentinensis. Mar Pollut Bull 79:34 -38. doi: 10.1016/j.marpolbul.2014.01.009

Rhoades, J. D., P. A. Raats, and R. J. Prather. 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Science Society of America Journal 40:651-55.do: 10.2136/sssaj1976.0361599500400 0050017x.SAS. 2002.Institute Inc. SAS for Windows Release 9.1. Canny, United State America: Statistical Analysis Systems Institute Incorporated.

Rhodes, A. H., Carlin, A. & Semple, K. T. (2008). Impact of black carbon in the extraction and 882 mineralization of phenanthrene in soil. Environmental science & technology,42, 740-745. 883.

Rong H, Hong-Fu W, Yan-Tun S, Jiang H, Shao-Lin P (2007) Polycyclic aromatic hydrocarbons in agricultural soils of the southern subtropics, China. Pedosphere 17(5):673–680. https://doi.org/10.1016/S1002-0160(07)60081-2

Sani, A. (2015). Treatment Performance Assessments of Different Wetland Mesocosms. Unpublished PhD Thesis. University of Salford Manchester, UK.

Sani, A., Ahmad, R.S., Mohamed, U.M., Uzaifa, K.A and Abdulkadir, N.N. (2020). Discharged Industrial Effluents Quality Appraisal and Its Uses for Agricultural Production in Sudan Savannah Ecological Zone, Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), 13(3), 45-51.

Sani, A., Sanda, A.R., Musa, M.U., Hayatu, B.S, Lamido, A.K and Rabi'u, W.A (2020). Evaluation of heavy metals contamination in industrial effluents used for vegetables and crops irrigation in Semi-arid ecological Zone of Nigeria. International Journal of Applied Science and Research, 3, (4), 1-9.

Scherr K, Aichberger H, Braun R, Loibner AP (2007). Influence of soil fractions on microbial degradation behavior of mineral hydrocarbons. Eur. J. Soil Biol. 43:341-350.

Scholz, M. 2010. Wetland systems - storm water management control. Berlin: Springer, Verlag Pp 19-27.

Seifi, M. R., R. Alimardani, and A. Sharifi. (2010). How Can Soil Electrical Conductivity Measurements Control Soil Pollution? Research Journal of Environmental and Earth Sciences 2 (4):235-38. (2002). The fate of diesel hydrocarbons in soils and their effect on the Povicel. 1709:49-61

Six, J., Elliott, E. & Paustian, K. (2000). Soil macro aggregate turnover and micro aggregate formation: a 936mechanism for C sequestration under no-tillage agriculture. Soil Biology and Biochemistry, 937 32, 2099-2103.

Srogi, K. (2007). Monitoring of environmental exposure to polycyclic aromatic hydrocarbons: a review. Environmental Chemistry Letters, 5(4), 169–195. https://doi.org/10.1007/s10311-007-0095-0

Sublette K, Key KC, Bovaird B (2010) Combating hydrophobicity in the revegetation of hydrocarbon-impacted soils. In: 17th annual international petroleum biofuels environmental conference, San Antonio, TX, August 30-September http://ipec.utulsa.edu/Conf2010/Abstracts 2010/

Tang J. Wang R, Niu X, Wang M and Zhou O (2010). Characterization on the rhizoremediation of petroleum contaminated soil as affected by different influencing factors. Biogeosci. 7:4665-4688.

Tang L, Tang XY, Zhu YG, Zheng MH, Miao QL (2005) Contamination of polycyclic aromatic hydrocarbons (PAHs) in urban soils in Beijing, China. Environ Int 31(6):822–828. https://doi.org/10.1016/j.envint.2005.05.031

Tang, H., Yu, H., Li, Q., Wang, X., Gai, Z., Yin, G., Su, F., Tao, F., Ma, C and Xu, P., (2010). Genome sequence of Pseudomonas putida strain B6-2, a superdegrader of polycyclic aromatic hydrocarbons and dioxin-like compounds. J.bacteriol, 193, (23): 6789-6790.

Tejeda-Agredano MC, Gallego S, Vila J, Grifoll M, Ortega-Calvo JJ, Cantos M (2013). Influence of the sunflower rhizosphere on the

biodegradation of PAHs in soil.Soil Biol. Biochem. 57:830-840.
Thavamani P, Smith E, Kavitha R, Mathieson G, Megharaj M, Srivastava P, Naidu R (2015). Risk based land management requires focus beyond the target contaminants - A case study involving weathered hydrocarbon contaminated soils. Environ.Technol. Innov. 4:98-109.
Udo, E. J., Ibia, T. O., Ogunwale, J. A., Ano, A. O. and Esu, I. E. (2009). "Manual of Soil, Plant and Water Analysis". Sibon Books Ltd; Lagos, Nigeria.
US EPA (1984). Interalaboratory Comparison Stunt: Methods for Volatile and Semi-Volatile Compounds. Environmental Monitoring Systems Laboratory. Office of Research and Development. Las Vegas, NV, EPA. 600/4-84- 027
USDA (2011). Soil Quality Institute Natural resources conservation service Available at http://souls.usda gov/sqi/ (Retrieved on 20 February 2006.)
USEPA (2004) Guidelines for water reuse. United States Environmental Protection Agency (USEPA), Washington D.C.
USEPA (2006). Constructed Treatment Wetlands (EPA Report Number 843-F-03-013). Washington, DC: USEPA Office of Water.
USEPA, 1971. Methods for the Chemical Analysis of Water and Wastes (MCAWW) (EPA/600/479/020).
Wang K, Chen XX, Zhu ZQ, Huang HG, Li TQ, Yang X (2014). Dissipation of available benzo(a)pyrene in aging soil co-contaminated with cadmium and pyrene. Environ. Sei. Pollut. Res. 21:962-971.
Wang K, Huang H, Zhu Z, Li T, He Z, Yang X, Alva A (2013). Phytoextraction of metals and rhizoremediation of PAHs in cocontaminatedsoil by co-planting of Sedum alfrediiwith ryegrass (Loliumperenne) or castor (Ricinuscommunis). Int. J. Phytoremed. 15:283-298.
Wang X Y, Feng J, Zhao J M, 2010. Effects of crude oil residuals on soil chemical properties in oil sites, Momoge Wetland, China. Environmental Monitoring and Assessment, 161(1): 271-280. doi: 10.1007/10661-008-0744-1
Wang Xiaoyu, Feng Jiang, Wang Jing, 2009. Petroleum hydrocarbon contamination and impact on soil characteristics from oilfield in Momoge wetland. Environmental Science, 30(8): 2394-2401. (in Chinese)
Welz et al., 2007 B. Welz, E.G. Lepri, R.G.O. Araujo, S.L.C. Ferreira, M. Huang, M. Okruss, H.
White AJ, Bradshaw PT, Herring AH, Teitelbaum SL, Beyea J, Stellman SD, Conway K (2016) Exposure to multiple sources of polycyclic aromatic hydrocarbons and breast cancer incidence. Environ Int 89:185–192. https://doi.org/10.1016/j.envint.2016.02.009
Ying W, Jiang F, Qianxin L, Xianguo L, Xiaoyu W, Guoping W (2013). Effects of Crude Oil Contamination on Soil Physical and Chemical Properties in Momoge Wetland of China. Chin. Geogr. Sci. 23:708715
Zhang J, Liu G, Wang R, Liu J (2015) Distribution and source apportionment of polycyclic aromatic hydrocarbons in Bank soils and river sediments from the middle reaches of the Huaihe River, China. Clean (Weinh) 43(8):1207–1214. https://doi.org/10.1002/clen.201400054

EVALUATION OF THE LONG TERM EFFECT OF SOME SELECTED SOIL PHYSICAL PROPERTIES ON TILLAGE, CROP ROTATION AND NITROGEN FERTILIZATION IN A NORTHERN GUINEA SAVANNA (ALFISOL) SOIL OF NIGERIA

N.I. Usman[1], A. A Yusuf[2] and A. Abdulkadir[2]

[1] Department of Crop Production Technology, College of Agriculture, Science and Technology Lafia, P.M.B 33, Lafia, Nasarawa State, Nigeria.

[2] Soil Science Department, Faculty of Agriculture / Institute for Agricultural Research, Ahmadu Bello University, P.M.B. 1044, Zaria, Kaduna state, Nigeria.

[1]Corresponding author. E-mail: *nasiriusman@yahoo.com*

[2]Author. Email: *adamu_99@yahoo.co.uk*

[2]Author. Email: *akadir762001@yahoo.com*

ABSTRACT

A long term experiment was established in 2003 at the Institute for Agricultural Research, (I.A.R) Samaru, northern Guinea savanna of Nigeria to evaluate the effect of N fertilizer, Crop rotation and Tillage. In 2017, soil moisture content, saturated hydraulic conductivity and bulk density soil samples were collected at varying depth to determine the influence on the experimental treatments. To achieve these objectives, data were taken from the maize phase of the rotation where maize was grown in rotation with maize, maize in rotation with soybean and maize in rotation with cowpea, under conventional and reduced tillage, with N fertilization of 0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1}. The trial was arranged in a split plot design, replicated three times. Soil particle size was determined using Bouyocous hydrometer method. Saturated hydraulic conductivity (Ks) was determined using the constant head permeameter method. The Soil bulk density was determined using the core method. The gravimetric soil moisture content was determine to determine soil moisture content. The study showed that the result was not significant to N fertilization and Crop rotation, but it was significant to tillage across all selected soil physical properties with increasing soil depth. The conventional tillage had the highest level of Sand %, Silt % and Ks content while the reduced tillage had the highest Clay %, soil moisture content and soil bulk density. To improve the soil physical property of soils in the northern Guinea savanna of Nigeria over a long period of time, farmers are recommended to practice reduced tillage (conservation) to improve clay %, soil moisture and bulk density, while conventional tillage will improve sand%, silt % and Ks in a Northern Guinea savanna Alfisol of Nigeria.

Keywords: *Soil Physical Properties, Tillage, Crop rotation and Nitrogen fertilization*

INTRODUCTION

Long-term field experiments are expected to provide important information regarding soil properties as affected by cropping system and soil management practices. Legumes such as cowpea and soybean add both organic matter and nitrogen (N) to the soil (Sainju *et al*., 2003) and increase soil fertility. Studies have shown that legume-cereal rotation produce relatively higher grain yields than either crop grown alone (Dapaah *et al*., 2003). Long-term field experiments with N fertilization can give valuable information about how those changes occur and indicate the trends of the changes (Dragan *et al.,* 2010).

Nitrogen (N) is most often the yield limiting nutrient with respect to crop production (Factsheet, 2014). Nitrogen contributes firstly to grain yield and forage biomass production, and at the same time to protein (Eche, 2011). Therefore proper management of soil in terms of method of tillage practice and cropping system is very important in determining the amount of N in the soil (Veenstra *et al*., 2006).

Tillage is any physical, chemical or biological soil manipulation to optimize conditions for germination, seedling establishment and crop growth. Tillage helps in loosening and aerating the top layer of the soil, in destroying weed mechanically and in mixing crop residue, organic matter (humus), and nutrients evenly into the soil (Ray, 2013).

In Africa, three quarter of farmland is severely degraded due to poor soil quality. Agricultural production in Nigeria is mainly constrained by low levels of soil organic matter, low nutrient status and water holding capacity. Due to the fragile nature of the soils, they degrade rapidly under continuous and intensive cultivation (Abu and Abubakar 2013).

Crop rotation with grain legumes helps to improve soil fertility, through biological nitrogen fixation while tillage helps in soil aeration and soil aggregation thereby improving the soil physical properties (soil texture and soil structure). Tillage practices also affect soil organic matter in surface soils. Studies have also shown the effects of different tillage management systems on soil quality under different climatic conditions and fertilization (Melero *et al*., 2009). However, information on changes produced by the interaction of tillage system, crop rotation, rate of N fertilization soil soil physical property over a long time is very scarce. Therefore in an effort to reduce land degradation and soil nutrient depletion problems in the northern Guinea savanna of Nigeria, the contributions of crop rotation, tillage and N fertilization on soil physical properties were investigated.

Objectives

The main objective of this research was to determine the effect of long term rotation, nitrogen fertilizer and tillage on some selected soil physical properties in the northern Guinea savanna of Nigeria.

The specific objectives of this research were:

1. To determine the influence of long-term crop rotation, tillage and N fertilization on moisture content in the northern Guinea savanna Alfisol soil of Nigeria.
2. To determine the influence of long-term crop rotation, tillage and N fertilization on soil saturated hydraulic conductivity in the northern Guinea savanna Alfisol soil of Nigeria.
3. To determine the influence of long-term crop rotation, tillage and N fertilization on soil bulk density in the northern Guinea savanna Alfisol soil of Nigeria.

MATERIALS AND METHODS

Experimental Site

A long-term field experiment begun in 2002 at the Institute for Agricultural Research, (I.A.R) farm in Samaru, to evaluate the effect of long term N fertilization on crop rotation, the site was later modified to accommodate tillage as an additional experimental factor in 2009. Now the experimental field has N fertilization, crop rotation and tillage practices.

The study was carried out at the Institute for Agricultural Research (IAR) farm in Samaru, with coordinates 11° 09, 943N', 007° 37. 956E' and 686 m above the sea level in the northern Guinea savanna (NGS) of Nigeria. The soil type is an Alfisol derived from Pre-Cambrian Crystalline basement complex rocks with some quaternary Aeolian deposits. The main sub-group is Typic Haplustalf. The experimental field was relatively flat with a mono modal rainfall pattern and a mean annual rainfall of 1011 ± 161 mm concentrated almost entirely from May to October. Samaru has minimum and maximum temperatures of 21ºC and 33.5 ºC, with a mean daily temperature of 24 ºC and relative humidity of 55.23 %. This study was carried out in the wet season of 2013.

Treatment Structure and Experimental Design

The treatments were factorial combination of three crop rotations (Maize - Maize, Maize – Cowpea and Maize – Soybean), two tillage practices (Reduced and Conventional) and four N levels (0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1}), arranged in split plot design replicated three times. The main plot consisted of combinations of crop rotation and tillage, while the sub-plot consisted of N rate. Maize was sown on all the plots during this experiment.

Soil Sampling

Soil samples were collected from plots that received 0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1} since the commencement of the trial. Soil sampling was carried out at three depths; 0 – 5 cm, 5 – 15 cm and 15 – 25 cm before planting and after harvesting. The field moist soil was collected by air drying and also core samples (measuring 5 cm x 5cm in diameter) per plot were collected at 0 - 5 cm, 5 - 15 cm and 15 - 25 cm depth from plots that received 0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1} plots, then composited for further analysis.

Measurement of soil physical properties

a. Soil particle size determination

Bouyocous hydrometer method was used to determine soil particle size (Agbenin, 1995). Fifty grams of soil was weighed into a 250 mL plastic beaker. 100 mL of 50 % calgon was added into the beaker and stirred with a glass rod. Then 100 mL of distilled water was added and stirred. It was then left to stand for 30 minutes with occasional stirring. The mixture was then transferred into 1000 cm^3 measuring cylinder and was made to the mark with distilled water. The suspension was mixed vigorously using a long handled-plunger to disturb thoroughly the sediments at the bottom. A hydrometer was put carefully in the solution for the reading to be taken 40 seconds later. The hydrometer was removed from the suspension for it to be given another shaking. The hydrometer was inserted again to take 2 hours reading. The times are recommended for 20 micrometer and 2 micrometer fractions respectively. Blank was prepared in the same way but without soil and readings were taken for the blank. Also temperatures of suspensions and blank were taken.

Corrected hydrometer readings [C (g/L)] were obtained by subtracting the blank reading [RL(g/L)] from hydrometer reading in the soil suspension [R(g/L)] and adding 0.36 g/L for every degree above 20˚ C.

% Clay = R – RL + (0.36T)…………………………………… ……………………...eqn 1

% Silt = (C40 seconds x 100) / (weight of soil taken)) - % Clay……………………..eqn 2

% Sand = 100 – (% Silt - % Clay)……………………………………… ………..….eqn 3

(Girei, 2015).

b. Saturated hydraulic conductivity (Ks)

This was determined using the constant head permeameter method as follows:

The undisturbed core samples representing each plot was covered at one end with a piece of muslin cloth held in place with the aid of rubber bands and allowed to stand overnight in water to ensure complete saturation. These saturated samples were then arranged in a permeameter and the volume of flow and changes in hydraulic heads determined (Dipak and Abhijit, 2005). Saturated hydraulic conductivity was calculated using Darcy's equation.

$$Ks = \frac{VL}{At\Delta H} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eqn. 4}$$

Where

Ks = Saturated hydraulic conductivity (cm/min)

V = Volume of soil (cm^3)

t = Time (minutes)

A = Area (cm^2)

L = Length of soil core (cm)

ΔH = Change in hydraulic head (cm)

c. Bulk Density

This was determined by the core method (Blake and Hartge, 1986) and equation. 5 was used to calculate the bulk density

$$BD = \frac{Mass\ of\ Oven\ dry\ soil}{Bulk\ volume\ of\ soil\ (volume\ of\ core)} \ldots\ldots\ldots\ldots\ldots \text{eqn. 5}$$

d. Moisture content: Moist soil samples collected for determination of bulk density was covered at both ends and taken immediately to the lab and weighed. The sample was oven-dried for at least 24 hours at 105°C and then weighed. The soil moisture content was then determined by the following formula:

$$\text{Soil moisture content (g)} = \frac{Soil\ moist\ Weight - oven\ dry\ weight}{oven\ dry\ weight} \ldots\ldots\ldots\ldots\ldots\ldots \text{eqn. 6}$$

(Agbenin, 1995).

Statistical Analyses

The data obtained was analyzed using the standard ANOVA procedures for a Split plot design. Analysis of variance was performed using the General Linear Model Proc. of SAS (SAS, 2002); treatment means were compared using Duncan's Multiple Range Test (Duncan, 1955) at 5% level of significance ($p < 0.05$).

RESULT AND DISCUSSION

Particle size distribution

The effects of crop rotation, tillage and N rates on particle size distribution (PSD) are shown in Table 1.1. Crop rotation had no significant ($P>0.05$) effect on PSD. However, there was a significant difference ($P<0.05$) in PSD between tillage practices. The conventional tillage had more sand and silt separates and less clay than the reduced tillage. The result also shows that there was no significant difference ($P>0.05$) in N rates of clay, silt and sand particles. There was also no significant interaction ($P>0.05$) between tillage type and N rate in terms of the particle size distribution. This indicates that N rate had no contribution to type of soil texture.

Conventional tillage had higher PSD than the reduced tillage. This result conforms slightly to the work of Lawal (2015) who reported that silt plus clay associated carbon was significantly higher by 9.82 % in conventional tillage plots than in reduced or no till system in the year 2013.

Table 1.1: Effect of tillage and N rate on soil particle size distribution at 0 – 5 cm depth

Treatment	Particle Size Distribution		
	Clay (%)	Silt (%)	Sand (g/kg)
Rotation			
Maize	2.91	15.48	652.5
Cowpea	3.39	16.42	661.4
Soybean	3.15	16.08	661.0
SE±	0.16	0.36	51.3
Tillage			
Reduced	5.22[a]	18.11[b]	761.1[b]
Conventional	4.44[b]	19.67[a]	771.1[a]
SE±	0.19	0.38	3.4
Nitrogen rate (kg Nha^{-1})			
0	6.67	19.00	76.11

30			
60			
90	5.00	18.78	76.11
SE±	0.19	0.38	0.34
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

Saturated hydraulic conductivity (Ks)
The Ks was not significantly (*P>0.05*) influenced by crop rotation or nitrogen rate in all the three soil depths (0 – 5 cm, 5 – 15 cm, 15 – 25 cm), but it was significantly (*P>0.05*) affected by tillage practices (Table 1.2). The highest mean Ks was observed under conventional tillage across all the three soil depths and the reduced tillage had the lowest Ks across all the three soil depths. The interaction was not significant (*P>0.05*) at any of the studied soil depths. Saturated hydraulic conductivity was found to be significantly influenced by tillage with higher soil water conductivity under conventional tillage than under reduced tillage. This is because conventional tillage helps to improve water conductivity (Ahn and Hintze, 1990); also the presence of roots and plant materials after harvesting of the maize crop could also affect the Ks value (Girei, 2015), hence its influence on the conventional tillage practices.

Table 1.2: Long term effect of crop rotation, tillage and nitrogen rate on saturated hydraulic conductivity Ks (cm hr^{-1})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	0.37	0.37	0.48
Cowpea	0.38	0.36	0.48
Soybean	0.37	0.40	0.44
SE±	0.02	0.03	0.02
Tillage			
Reduced	0.33^b	0.32^b	0.37^b
Conventional	0.43^a	0.43^a	0.56^a
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	0.37	0.36	0.45
30	0.37	0.38	0.45
60	0.38	0.38	0.47
90	0.37	0.38	0.47
SE±	0.02	0.02	0.09
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

Bulk density

The effects of crop rotation, tillage and nitrogen rates on maize bulk density are shown in Table 1.3. Crop rotation and N rate had no statistical difference on soil bulk density. However, tillage influenced soil bulk density, with the reduced tillage giving higher means at all soil depths than the conventional tillage. The Interactions between the various factors were not significant in all the soil depths.

Bulk density is influenced by vegetation and aggregation; high bulk density is an indication of low soil porosity and high compaction which may cause restriction of root growth and poor movement of air and water through the soil. In this study, high bulk density values were observed at the soil depth of 15 – 25 cm and lower bulk density values were obtained at 0 – 5 cm and 5 – 15 cm soil depths. Reduced tillage was found to give higher BD values than conventional tillage due to compaction and aggregation of the soil particles. This result corroborates with the findings of Dhiman *et al*. (2001) who reported an increase in bulk density of a soil from 1.5 Mg m^{-3} in conventional to 1.58 Mg m^{-3} in no-tillage plots. This indicates that bulk density is influenced by tillage activities, hence its significance to tillage activities and crop rotation.

Table 1.3: Long term effect of crop rotation, tillage and nitrogen rate on bulk density (Mgm^{-3})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	1.43	1.43	1.50
Cowpea	1.48	1.48	1.52
Soybean	1.46	1.46	1.51
SE±	0.02	0.02	0.02
Tillage			
Reduced	1.83^{a}	1.83^{a}	1.90^{a}
Conventional	1.53^{b}	1.54^{b}	1.66^{b}
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	1.48	1.47	1.51
30	1.48	1.47	1.51
60	1.48	1.48	1.51
90	1.43	1.43	1.51
SE±	0.02	0.02	0.02
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P<0.05$ level of probability. NS = Not Significant.

Moisture content

Moisture content (MC) at field capacity was not statistically affected ($P>0.05$) by crop rotation or nitrogen rate across all soil depths, but it was statistically ($P<0.05$) affected by tillage practices in all the soil depths (Table 1.4), with the reduced tillage having the higher moisture content than conventional tillage at all the soil depths. The Interactions between factors were not significant ($P>0.05$) in all the soil depths.

The presence of plant residue left on the soil surface under reduced tillage will favor more water retention in the soil than the conventional tillage. This agrees with the findings of Melero *et al.* (2009) that conservation or reduced tillage are based on the principle of mulch farming and they usually conserve soil and water simultaneously by controlling runoff.

Table 1.4: Long term effect of crop rotation, tillage and nitrogen rate on moisture content (cm^3/cm^3) at field capacity

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	0.15	0.15	0.18
Cowpea	0.18	0.19	0.17
Soybean	0.15	0.17	0.17
SE±	0.02	0.02	0.02
Tillage			
Reduced	0.23^a	0.24^a	0.23^a
Conventional	0.10^b	0.10^b	0.12^b
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	0.16	0.17	0.19
90	0.17	0.17	0.16
SE±	0.02	0.02	0.02
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P<0.05$ level of probability. NS = Not Significant.

Conclusion

The study showed that the result was not significant to N fertilization and Crop rotation, but it was significant to tillage across all selected soil physical properties with increasing soil depth. The conventional tillage had the highest level of Sand %, Silt % and Ks content. The reduced or conservation tillage had the highest level of Clay %, Saturated moisture content and soil bulk density.

Recommendation

Therefore, in order to improve the soil physical property of soils in the northern Guinea savanna Alfisol of Nigeria over a long period of time, farmers are recommended to practice conservation tillage to improve soil physical properties like Clay %, soil moisture content and soil bulk density. However, Sand %, Silt % and Ks can be improved by practicing conventional tillage. Finally crop rotation and N fertilization had no physical effect over a long period of time to the soil in the

Northern Guinea savanna Alfisol of Nigeria.

REFERENCES

Abu, S. T. and Abubakar, I. U. (2013). Evaluating the effects of tillage techniques on soil hydro- physical properties in Guinea Savanna of Nigeria. *Soil and Tillage Research.* **126:** 159–168.

Agbenin, J. O. (1995). *Laboratory Manual for Soil and Plant Analysis,* Department of Soil Science, Faculty of Agriculture / Institute for Agricultural Research, Ahmadu Bello University, Zaria. Pp. 1-80.

Ahn, P. M. and Hintze, B. (1990). No tillage, minimum tillage and their influence on soil properties. In; organic matter management and tillage in Humid and sub-humid Africa. IBSRAM proceedings No. 10. Bangkok: Pp. 341-349.

Dapaah, H. K., Asafu-Agyei, J. N., Ennin, S. A. and Yamoah, C. (2003). Yield stability of cassava, maize, soya bean and cowpea intercrops. *Journal of Agricultural Science.* **140**: 73-82.

Dhiman, S. D., Om, H. M. and Kumar, H. (2001). Advantages and limitation of no tillage in wheat. *Indian Framing*, **51**(6): 8 - 10.

Dipak, S. and Abhijit, H. (2005). Physical and chemical methods in soil analysis; New Age International Publisher. Pp. 27–30.

Dragan, C., Elmira, S., Veljko, P., Darko, J. and Vesna M. (2010). Effect of Long-Term Nitrogen Fertilization on Main Soil Chemical Properties in CambisolInstitute of Soil Science, Teodora Drajzera 7, 11000 Belgrade, Serbia. Pp. 1-6.

Duncan, D. B. (1955). Multiple Ranges and Multiple ,*"F" Test, Biometrics*. Vol **11**: 1- 42.

Eche, N. M. (2011). Soil Properties affecting maize yield decline under long-term application of organic and inorganic fertilizers. Ph.D Thesis. Ahmadu Bello University, Zaria, Nigeria. Pp. 1-99.

Girei, H. A. (2015). Hydraulic characteristics and temporal variability of soil properties under a long term trial in Samaru, Northern Guinea Savanna of Nigeria. M.Sc Thesis, Ahmadu Bello University, Zaria, Nigeria. Pp. 21-76.

Lawal, H. F. M. (2015). Tillage and cover crop effects on soil quality and maize growth at Samaru, northern Nigeria. Ph.D thesis, Ahmadu Bello University Zaria. Pp 1-150.

Melero, S., Lo´ pez-Garrido, R., Madejo´ n, E., Murillo, J. M., Vanderlinden, K., Ordo´n˜ez, R. and Moreno, F. (2009). Long-term effects of conservation tillage on organic fractions in two soils in southwest of Spain. *Agriculture, Ecosystem and the Environment.* **133:** 68–74.

Ray, H. (2013). Soils in Agriculture. University of Washington. Retrieved 2013-08-28.

Sainju, U. M., Whitehead, W. F. and Singh, B. P., (2003). Agricultural management practices to
ustain crop yields and improve soil and environmental qualities. *Science World Journal.* **3:** 768–789.

SAS Institute. (2002). *SAS system for mixed models*. SAS Inst., Cary, NC.

Veenstra J. J., Horthwith, W. R.., Mitchell, J. P. and Munk, D. S. (2006). Conservation tillage and
cover cropping influence on soil properties in San Joanquin Valley cotton-tomato crop. http//californisagriculture.ucop.edu. Accessed in June, 2014

PREDICTING AND ESTIMATING RATES OF SOIL LOSS IN GIREI WATERSHED AREA OF ADAMAWA STATE, NORTHEASTERN NIGERIA

***Gundiri, J. W., I. E. Vahyala, I. B. Buji and A. L. Ngala.**
[1,3&4] Department of Soil Science, University of Maiduguri, Nigeria
[2]Department of Soil Science, Modibbo Adama University, Yola, Nigeria
Corresponding author email: gundirijohn@gmail.com

ABSTRACT
A field study was carried out to measure the rate of soil loss for 2 years in 41 gully locations in Girei watershed, Adamawa State of Nigeria and the data used in predicting the potential soil loss for 5, 10 and 25 years. The measured soil loss was estimated by determining the average gully length, depth, and width using measuring tape at the beginning and end of the rainy season. Long- and short-term erosion rates were equally estimated using AGERTIM (Assessment of Gully Erosion Rate Through Interviews and Measurement). The averaged short-term gully erosion rates (RS) for the 2 years measured was 0.018826553 t ha-1 yr-1, while the long-term rate (RL) for 5, 10 and 25 years predicted were: 0.01282227, 0.00641113 and 0.002564454 t ha-1 yr-1, respectively. The erosion per unit gully surface rate (RP) for the 41 gully locations ranged from 21.14 t ha-1 yr-1 to 453.27 t ha-1 yr-1. The rates of soil loss in these areas were alarming, and could amount into huge financial losses. It has actually become a threat to food security and lives in the region. It is evident that these gully erosions were aggravated by forces which may include climatic, anthropogenic, topographic, edaphic and vegetative. Controlling erosion menace in the area will require a combination of both engineering and agronomic control measures. Generally where slopes are not steeper than 2%, agronomic erosion control measures can be adopted.
Key: *Prediction, Erosion Rate, Watershed, Variables and Drainage*

INTRODUCTION

Gully erosion in the Tropical areas is a serious problem, which has resulted in land degradation and reservoir sedimentation with associated health and economic problems ((Tebebu *et al*., 2010 and Haregeweyn *et al*., 2005). The risk of gully erosion in the Savannah Zone of Northern Nigeria is further accentuated by the inability of the sparse vegetation prevalent in the region to provide the adequate protection required by the soil. The results of studies carried out in the zone revealed that exposure of the fragile soils prevalent in the area led to surface sealing and infiltration rate reduction (Gelder *et al*., 2018). Under this condition considerable loss of the loose top soil can occur due to runoff and water erosion. The Sudano-Sahelian zones in particular are characterized by short duration intense rainfalls. These short duration intense rainfalls seal the soil surface, reducing infiltration and causing considerable runoff and soil erosion. Many forms of land clearing are known to result in severe degradative changes especially in areas where slopes are steep, soils are shallow and rainfalls are heavy and concentrated in short period (Gundiri, 2023). The lack of sufficient data on soil erosion in these zones is a serious challenge particularly when viewed against the very light texture and highly erodible nature of the soils prevalent in this area.

Soil properties and soil types also play a role in gully formation and expansion. For example, Vertisols, heavy clay soils with a high proportion of swelling clays (IUSS Working Group WRB, 2015), form deep, wide cracks from the surface downward when they dry out and are prone to the development of pipes that can collapse and thereby turn into large rills or gullies (Valentin *et al.*, 2005; Frankl *et al.*, 2014 and Gundiri, 2023). This may be one of the reasons that most severe gully areas are often associated with Vertisols (Valentin *et al.*, 2005; Tebebu *et al.*, 2014; Frankl *et al.*, 2014). Similarly, in pasture bottom lands, piping often leads to development of permanent gullies (Zegeye *et al.*, 2014). These pipes are part of gully networks, and during the rain phase the infiltrating rainfall discharges through the pipes, which increases the lower soil horizon's vulnerability to erosion. The drainage area at the gully head is one of the parameters explaining linear, areal, and volumetric gully head-cut retreat (Vandekerckhove *et al.*, 2003; Frankl *et al.*, 2012, 2013b; Vanmaercke *et al.*, 2016). Runoff-contributing drainage area can be used as a surrogate for runoff, especially if it is assumed that the rainfall amount is equal for all drainage areas and that surface conditions and land use are also very similar (Wijdenes and Bryan, 2001). Gundiri. (2023) reported for the semiarid region in northern Nigeria that, among all environmental characteristics in a catchment, only the drainage area had a strong positive association with gully headcut retreat (hereafter, headcut retreat refers to the longitudinal gully growth, and bank failure refers to cross-sectional gully growth). Gully erosion control measures were mostly restricted to the construction of physical Soil and Water Conservation (SWC) measures such as check dams. Very recently, there have been efforts to integrate the physical and biological conservation measures, mainly by planting grass and forage tree species on gully banks and in between the physical SWC structures (Dagnew *et al.*, 2015).

The pattern of soil loss progress exhibited both increasing and decreasing paths in the various locations. The results depicts that the rate of soil loss in the watershed were highest at Safini 2 and lesser at Hona 1. These increasing and decreasing pattern may be attributed to the watershed characteristics, soil factors, and Human factors, geologic and climatic factors even as reported by Capra *et al.* (2004). While, the decreasing pattern were perhaps due to the relative conservation practices such as; vegetative barriers, soil deposition and sand-bag lines, diversion by the water ways to other channels leaving the original flow channel and ridging across the slope direction (Gundiri *et al.,* 2023). This study was aimed at assessing, predicting and evaluating the current, medium and long term rate of soil loss in the Girei watershed of Adamawa State.

MATERIAS AND METHODS

The Study Area

Girei Local Government Area is located between Latitude 9º00′ and 9º 32′ N and Longitude 12º10′ and 12º48′E and situated at an altitude of 158.5m above sea level (Adebayo *et al.,* 2020) in Adamawa state, it is bounded to the north by Song Local Government Area, to the South and West by Yola North and South Local Government Area and to the East by Fufore Local Government Area (Figure 1).

The climate of the area is comprised of typical wet and dry seasons with average annual rainfall ranging from 700 to 1000mm. The temperature ranges from 15 to 39ºC. The amount of sunshine hours ranges from 2500 in the south to 3000 hours in the extreme north (Adebayo *et al.,* 2020).

The vegetation in the area is comprised of few grasses and shrubs, which is typical of savannah region with scattered trees mainly shear-butter, acacia, eucalyptus and locust bean tree, while the dominant grass species include *panicum maximum, aristida longiflora* and *anddropogon gayanus* (Adebayo, 2004; Tekwa and Usman, 2006 and Adebayo *et al.,* 2020). All the gully sites occurred on both cultivated and non-cultivated lands, while some occurred on cattle route path, and there were fewer grasses, shrubs and trees observed at all the sites.

The Geology of Girei according to Nigerian Geological Survey Agency [NGSA] (2006) is described as upper cretaceous rocks, Precambrian basement complex, a mixture of rock types and minerals. Most of the area is underlain by Magmatite and some Porphyritic Granite especially in the Eastern part of the Local Government. Some medium to coarse granite biotite are also found. The relief of Girei LGA comprises flat, relatively flat and rugged terrain with hills and mountains spread across all the districts.

The hydrology of the area is dependent on the rainfall pattern and the underground reservoir mostly in areas underlain by sedimentary rock formations. According to Adebayo (1999), the water resources available in the State (Adamawa) including Girei LGA are adequate if utilized properly. The rivers in the area are seasonal in nature. The parent materials are heterogonous and comprised predominantly loamy sand, clays and sandy clays of a range of colors (Vahyala, *et al.,* 2018). Which are also predominantly alfisols, luvisols, regosols, leptosols, cambisols, vertisols, and lithosols having lithic and paralithic

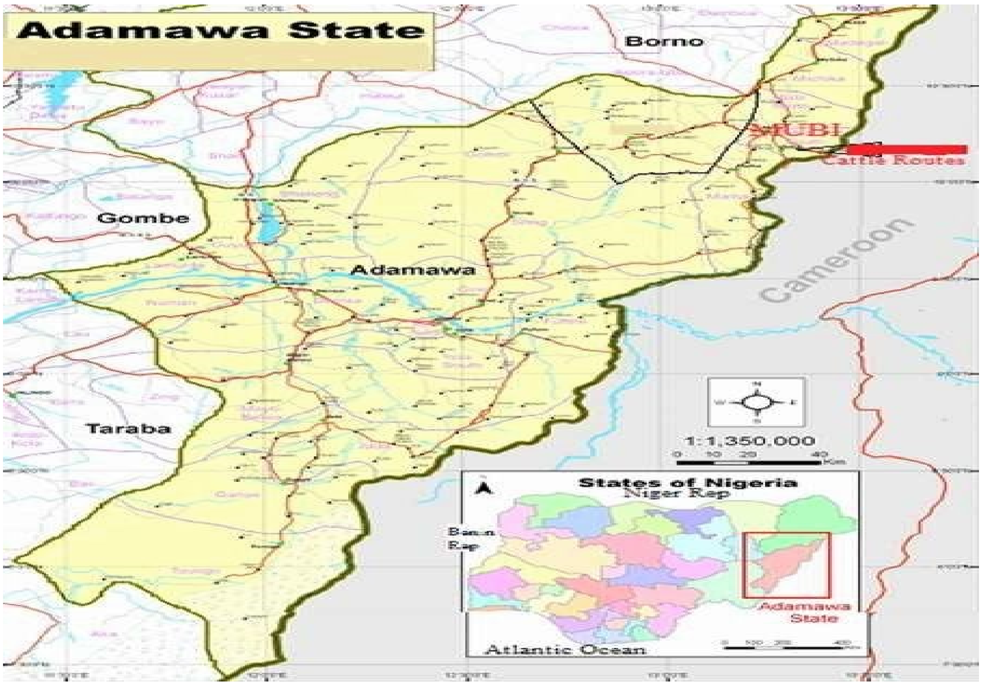


Figure 1: Map of Nigeria Showing Adamawa State.

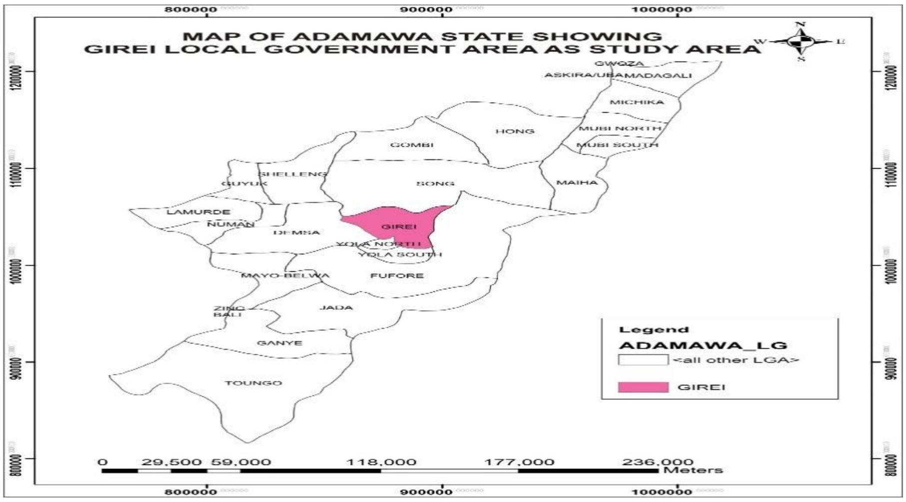


Figure 2: Map of Adamawa Showing Girei LGA

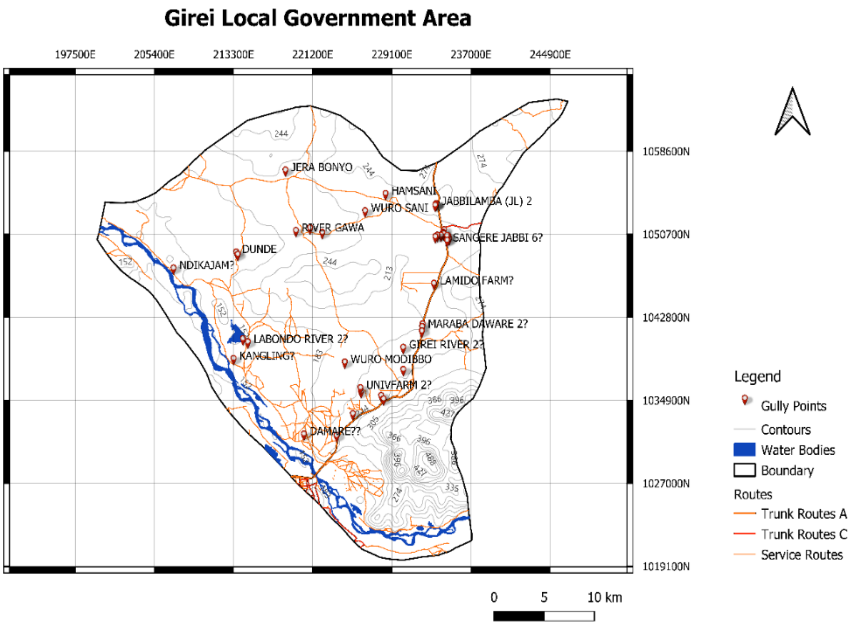


Figure 3: Map of Girei LGA showing Gully locations, Roads, Topography and Water Bodies

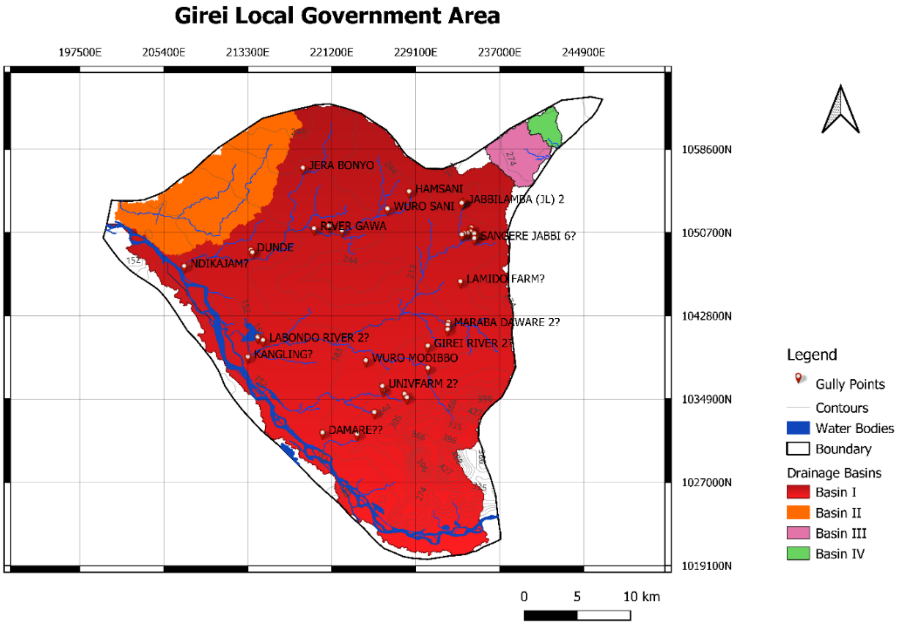


Figure 4: The Map of Girei Showing the Drainage Basins (Watershed) and Gully Points

Determination of gully erosion channel parameters (length, depth, and width)

During the 2019 and 2020 wet seasons, the following measurements were made in the selected gullies: (1) the head-cut retreat (longitudinal growth) and gully widening (or lateral retreat) downslope from the head-cut, and (2) the gully expansion rates and associated amount of soil loss along the total gully length. To estimate gully expansion and the amount of soil loss from total gully reach, three gully topographic surveys (before and after the rain phases of 2019 and 2020) was conducted. The soil loss in the various sites were then computed using the measured length (l), width (w), and depth (d) of each gully feature. Thus, actual soil loss estimates were determined using mathematical expressions relating gully length, width, and depth as follows:

Width = (W)

Average width $= \frac{(WT+WM+WB)}{3}$ -- -- -- -- (1)

Where: WT= Top width

WM = Middle width

WB = Bottom width

Depth = (D)

Average depth $=\sum\left(\frac{(d1+d2+d3+d4+d5+--\mp d)}{n}\right)$ -- -- - (2)

Length = (Li)

Where L is the length of considered gully segment (m)

Cross-sectional area (A) = Average depth × Average width=, Gully $V = A \times L$ (3)

The gully volume was estimated using the formula: **V=Σ**$\boldsymbol{L_i A_i}$ -- -- -(4)

Where Li is the length of considered gully segment (m) and Ai is the representative cross-sectional area of the gully segment (m^2)

Determination of Rate of Soil loss*:*

Long- and short-term erosion rates were estimated using AGERTIM (Assessment of Gully Erosion Rates through Interviews and Measurements) developed by Nyssen, *et al.* (2006) was chosen allowing us to understand the historic context of the gully development (Nyssen *et al*., 2006). As part of this method the watershed area was visited with interviewees as a group and on an individual basis. The field visit allowed the interviewees to recall the changes in the area when they were young.

Long-term gully erosion rates **(RL)** in tone ha^{-1} yr^{-1} were calculated using the equation:

$$\mathbf{RL} = \frac{VBd}{TC} \quad (5)$$

Where, V= estimated current volume of the gully (m^3), Bd= average bulk density of soils in the watershed, T= Time span of gully development in years, C= the watershed area in hectares.

Short-term erosion rates **(Rs)** in t ha^{-1} yr^{-1} were determined to estimate the erosion rate in the study period.

$$\mathbf{Rs} = (V - V_0)\frac{Bd}{TC} \quad (6)$$

Where V= Gully volume at the end of study period, VO=Initial gully volume at the beginning of the study period. T= Time span of gully development in years, C= the watershed area in hectares.

Erosion per unit gully surface (RP), in tone m^{-2} was determined by the formula:

$$\mathbf{Rp} = \frac{VBd}{Ap} \quad (7)$$

Where V= the current volume of the gully, AP= Plane area of the gully (m^2).

The rainfall data was the twenty-four-hour (24-hr) rainfall events (appendix 22) during the study period. The 24-hr rainfall was the amount of rainfall received using a rain gauge situated at the Modibbo Adama University Yola, between 9.00 am (the first day) and 9.00 am (the next day) totaling 24 hours duration. The 2 year 24-h rainfall events were computed from the expression described by the Pennsylvania State Climatologist (PSC) (2009).

The PEI was determined in accordance with the method described Lal (2015). The PEI for each gully site was computed in terms of percentage of days with erosive 24-h rainfall (>20 mm and >25 mm) over the total rainfall days in a season as:

$$\text{PEI} = \frac{\text{Number of erosive 24-h rainfall (>20 mm) days}}{\text{Total number of rainfall days in a year}} \times 100 \quad (8)$$

RESULTS AND DISCUSSION

Rate of Soil Loss and Expansion at the Study Area during the Study Period

The results of study on the rates of soil loss within the study period, and for the projected 5, 10, and 25-year periods in the watershed are presented in Table 1 and 2 for current loss during the study period, the rates of soil loss for 2 years, 5 years, 10 years and 25 years revealed the Long-term gully erosion rates (RL) for: 5 years, 10 years and 25 years with the values of: 0.01282227 ton ha^{-1} yr^{-1}, 0.00641113 ton ha^{-1} yr^{-1} and 0.002564454 ton ha^{-1} yr^{-1} respectively. While, the Short-term gully erosion rates (Rs) for 2 years was 0.018826553 ton ha^{-1} yr^{-1} for the whole watershed. The Erosion per unit gully surface rate (RP) for the 41 gully locations are presented in Table 2. The highest rate was recorded at Safini 2 with the value of 453.27 ton ha^{-1} yr^{-1}, followed by Mashi with the value of 451.79 ton ha^{-1} yr^{-1} then Labondo 1 with value of 358.36ton ha^{-1} yr^{-1}.

On the other hand, the lowest rate was recorded at Hona 1, with value of 21.14ton ha^{-1} yr^{-1} followed by Hona 2 with the value of 21.60ton ha^{-1} yr^{-1}, then Jera with value of 21.95ton ha^{-1} yr^{-1}. The difference in rate of soil loss may be as a result of prevailing factors to be high in other locations than others. Hona was a growing gully with little contributing variables than Safini which was located at a steeper slope. The location of Hona that was situated on a milder slope might have contributed to its less vulnerability. Other factors which might have been responsible for variation in rate of soil loss were rainfall amount and intensity, erodibility index, soil type, human activities and altitude even as reported by Amare (2019) that the combined influence of hydrology and topography affects soil stability by reducing the shear strength and soil anti-erodibility. The pattern of soil loss progress exhibited both increasing and decreasing paths in the various locations. The results depict that the rate of soil loss in the watershed were highest at Safini 2 and lesser at Hona 1. These increasing and decreasing patterns may be attributed to the watershed characteristics, soil factors, and Human factors, geologic and climatic factors even as reported by Capra *et al.* (2004) who stated that the influence of topography on the development of gullies is reflected in the slope length, slope gradient, soil erodibility, human factors, climatic factors and catchment area. The altitude of the locations must have played a vital role in influencing the runoff, since areas located at the steep slope were observed to be having a higher rate of soil erosion than places located at the bottom. This argument could be supported by the findings of Tang *et al.* (2021) who observed that Slope length provides sufficient runoff for the development of the gullies, indirectly enhancing the erosive power of water. It can be said according to this study that Slope is the key factor affecting runoff shear stress, and it is also the key topographic factor of gully formation.

On the contrary, the decreasing pattern were perhaps due to the relative conservation practices such as; vegetative barriers, soil deposition and sand-bag lines, diversion by the water ways to other channels leaving the original flow channel, ridging across the slope direction etc. As reported by Idowu *et al.* (2013) that the major soil conservation strategies are broad-based terraces and cover cropping of bare soils. This study was also in accordance with the findings of Deng *et al.* (2015) who reported that diversion of water away from erosion prone gullies (for example, with diversion banks) this disperses the erosive power of the water over well-vegetated areas. This singular reason may be why there were diversion of some gully channels, example is that of Sangere 5. Also, in line with this is the conclusion of Jim (2018) that tillage and cropping practices, as well as land management practices, directly affect the overall soil erosion problem and solutions on a farm. In another study by Eng (2018) who stated that when crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of approaches or more extreme measures might be necessary. For example, contour plowing, strip-cropping or terracing may be considered. In more serious cases where concentrated runoff occurs, it is necessary to include structural controls as part of the overall solution – grassed waterways, drop pipe and grade control structures, rock chutes, and water and sediment control basins. These were some of the control measures observed.

Also, a more comprehensive soil conservation method will involve the application of certain hydrological or bioenvironmental processes so as to control the overland flow and excessive runoff. Therefore, to prevent, control or reduce all the damages due to soil erosion, the best way to combat in each area, identification of the factors which affect soil erosion as the first measure. Understanding the controlling factors of gully head mi-gration and lateral expansion of gullies is crucial to design appropriate gully control measures. Retreat rates depended most strongly on the stability of the top soil and the volume of runoff flowing down from the high hill percentage of silt silty loam and silty clay loam predominate the soil surface and subsurface, thereby reducing the soil erosion resistance. An unsterilized surface aggregates may also lead to wall collapse. Additionally, the gully head depth and the drainage area, which is representative of surface runoff magnitude, were other factors controlling gully erosion in the Girei watershed. Therefore, conservation practices that address these parameters may be most effective even as reported by Zegeye *et al., (*2016), who stated that, the longitudinal retreat for deep gullies contributes the most to the volumetric gully erosion in the Girei watershed (Table 1 and 2). Therefore, re-grading the gully head and bank slopes could reduce the occurrence of gravity-induced bank collapse for deep gullies.

Table 1: Long and Short-Term Rate of Soil Loss.

Period	Average Bd (mg/cm^3)	Current Volume (m3)	Watershed area (ha)	Gully Erosion rates (ton ha^{-1} yr^{-1}) 2ys.	5ys.	10ys.	25ys.
RL	I.51	293814.27	8735405.99		0.1282227	0.00641113	0.00256445
Rs	1.51	172206.89	17470811.99	0.0188266			

Key: Long-term gully erosion rates =RL, Short-term gully erosion rates = Rs, Erosion per unit gully surface rate = RP

Table 2: Erosion per Unit Gully Surface Rate (RP)

LOCATION	Current volume (m³)	Area of gully(hectare)	Bulk density (Kg/cm^3)	RP (ton ha^{-1} yr^{-1})
Jabbilamba 1	3802.5	61.25	2.05	127.27
Jabbilamba 2	3072	100.24	1.85	56.70
Jabbilamba 3	2551.1	80.11	2.07	65.92
Jabbilamba 4	14241	128.84	2.17	239.86
Safini 1	9580	97.7	2.24	219.64
Safini 2	24891.2	108.73	1.98	453.27
Safini 3	393	28.5	1.91	26.34
Madalu 1	1365	68.3	1.86	37.17
Madalu 2	196.8	14.76	2.17	28.93
Sangere 1	509.3	24.6	1.97	40.79
Sangere 2	433.5	30.7	2.17	30.64
Sangere 3	5230	52.9	1.97	194.77
Sangere 4	4406	42.2	1.93	201.51
Sangere 5	2277.4	42.81	2.07	110.12
Sangere 6	2400	27.94	1.87	160.63
Lamido farm	1286.5	27.53	2.04	95.33
Daware Junct 1	186.6	14.05	2.17	28.82
Daware Junct 2	392.5	37.95	2.17	22.44
Daware Junct 3	2648.3	40.77	2.26	146.80
Girei river 1	731.52	29.76	2.25	55.31

Girei river 2	10069.5	147.7	1.86	126.81
Hona 1	197.28	19.3	1.97	20.14
Hona 2	470.49	33.98	1.56	21.60
Profesorial Q	957.28	52.76	2.07	37.56
Federal housing	1904	24.64	1.97	152.23
Damare	10527.5	62.3	1.89	319.37
Lambondo 1	27795	136.51	1.76	358.36
Lambondo 2	35937.6	185.17	1.80	349.34
Ndikajam	27930	159.09	1.54	270.36
Kangling	38019	257.3	1.87	276.31
University farm 1	5260	64.1	1.82	149.35
University farm 2	1482.4	37.24	2.03	80.81
Amsami	3400	76.4	1.80	80.10
Jera	750	55	1.61	21.95
Dunde	16500	175	1.53	144.26
Jatau	14040	158.4	1.57	139.16
Ngawa	4705	99.8	1.61	75.90
Mashi	4650	17.6	1.71	451.79
Kaftarare	2225	27	1.70	140.09
Sani	3400	19.6	1.75	303.57
Modibbo	3000	14	1.56	334.29

Key: Lamido Farm =LF, Professorial Quarters = PQ, Federal Housing = FH, Kangling = KLG, Damare = Dam, Jatau = J, Amsami = A, Sani = S, Mashi=M, Modibbo = M, Girei River = GR, Jabbilamba = Jabbi, Daware Junction = DJ, Hona = H, University farm = UF, Labondo River =LR

Stages of Rate of Development of Gullies in The Study Area

PLATE 1: A typical example of a gully erosion showing an actively migrating headcut in upstream direction at Sangere 6

Plate 2: A diagram of a gully erosion showing an active expansion of headcut and width in upstream direction at Sangere 6 in April, 2019

Plate 3: A diagram of a gully erosion showing an active expansion of headcut, width and length in upstream direction at Sangere 6 in November, 2019

Plate 4: A typical diagram of a gully erosion showing an active expansion of headcut, width and length in upstream direction at Sangere 6 in November, 2020 with some sand deposition

CONCLUSION

Erosion rates for the gullies were 0.0188266 t/ha/yr, 0.1282227 t/ha/yr, 0.00641113 t/ha/yr and 0.00256445 t/ha/yr for two, five, ten and twenty-five years, respectively. The gullies in the watershed with the conservation practices showed some reduction as a result of control measures. while the areas without conservation practices were drastically affected. Erosion per unit gully surface and short-term soil loss rates were many times greater indicating that these gullies were in their acceleration phase. Active gully formation occurred by surface flow and not by subsurface flow. From the study, it can be concluded that natural processes associated with more intensive agriculture can accelerate the ongoing expansion of gullies. The combination of structural and biological conservation measures that have shown promising results in reducing infiltration excess should be improved further through close technical support. It could be good to understand mechanisms for gully expansion. Gully catchment should be improved with properly designed cutoff drains so that weak points in gully head cut areas could be protected from overland flow, while improving proper drainage structure in the treated mid-slope and bottom part of the watershed could also reduce expansion rate.

Recommendation

Gully catchment should be improved with properly designed cutoff drains so that weak points in gully head cut areas could be protected from overland flow (outside gully).

Heavy stone deposition in the gullies close to the headcut should be advised, encouraged and practiced (inside gully).

References

Adebayo, A.A. (1999). Climate I: Sunshine, Temperature, Evaporation and Relative Humidity. In: *Adamawa State in Maps*. Adebayo, A.A. and A.H. Tukur (Eds.) Paracletes Publishers and Department of Geography Federal University of Technology Yola, Nigeria. Pp: 3-5.

Adebayo, A.A. (2004). *Mubi Region:A Geographical synthesis* (Ist Ed.) Paraclete Publisher, Yola-Nigeria. P 32-38

Adebayo, A.A., A.H. Tukur and Zemba, A.A. (2020). Climate I: Sunshine, Temperature, Evaporation and Relative Humidity. In: *Adamawa State in Maps*. Adebayo, A.A., A.H. Tukur and Zemba, A.A. (Eds.) Paracletes Publishers and Department of Geography Federal University of Technology Yola, Nigeria. Pp : 3-5.

Amare S.D., Keesstra S.D., van der Ploeg M.J., Langendoen E.J., Steenhuis T.S., Tilahun S. Causes and controlling factors of valley bottom gullies. *Land.* 2019; **8**:141. doi: 10.3390/land8090141. [Cross Ref] [Google Scholar]

Capra, A., Mazzara, L. M., & Scicolone, B. (2004). Application of the ephemeral gully erosion model to predict ephemeral gully erosion in Sicily, Italy. *Catena*, *59*(2), 1-13.

Dagnew, D. C., Guzman, C. D., Zegeye, A. D., Tibebu, T. Y., Getaneh, M., Abate, S., Zemale, F. A., Ayana, E. K., Tilahun, S. A., Steenhuis, T. S.: Impact of conservation practices on runoff and soil loss in the sub-humid Ethiopian Highlands: The Debre Mawi watershed, *Journal of Hydrology and Hydromechanics*, 63, 214-223, 2015.

Deng, R. X., Wang, W. J., Fang, H. Y., and Yao, Z. H. (2015). Effect of farmland shelterbelts on gully erosion in the black soil region of northeast china. *J. For. Res.* 26, 941–948. doi: 10.1007/s11676-015-0110-4

Frankl, A., Poesen, J., Deckers, J., Haile, M., Nyssen, J.(2012.). Gully head retreat rates in the semi-arid highlands of Northern Ethiopia, *Geomorphology,* 173: 185-195,

Frankl, A., Poesen, J., Haile, M., Deckers, J., Nyssen, J. (2013.). Quantifying long-term changes in gully networks and volumes in dryland environments: The case of Northern Ethiopia. *Geomorphology,* 201: 254-263, Frankl, A., Deckers, J., Moulaert, L., Van Damme, A., Haile, M., Poesen, J., Nyssen, J.(2014) Integrated solutions for combating gully erosion in areas prone to soil piping: innovations from the drylands of Northern Ethiopia, Land Degradation & Development,.

Gelder, B., Sklenar, T., James, D., Herzmann, D., Cruse, R., Gesch, K., & Laflen, J. (2018). The Daily Erosion Project–daily estimates of water runoff, soil detachment, and erosion. *Earth Surface Processes and Landforms*, 43(5): 1105-1117.

Gundiri J. W. (2023). Impacts of Soil Hydro-physical Properties and Watershed Characteristics on development of Gully Erosion sites in Girei Local Government Area of Adamawa State, Nigeria (Ph.D Thesis 2023)

Haregeweyn, N., Poesen, J., Nyssen, J., Verstraeten, G., De Vente, J., Govers, G., Deckers, S., Moeyersons, J. (2005) Specific sediment yield in Tigray-Northern Ethiopia: assessment and semi-quantitative modelling, *Geomorphology,* 69: 315-331,.

Idowu, T. O., Edan, J. D., & Damuya, S. T. (2013). Estimation of the quantity of surface runoff to determine appropriate location and size of drainage structures in Jimeta Metropolis, Adamawa State, Nigeria. *Journal of Geography and Earth Science*, 1(1): 19-29.

IUSS Working Group WRB.: World Reference Base for Soil Resources (2014), update (2015), International soil classification system for naming soils and creating legends for soil maps, World Soil Resources Reports No. 106, FAO, Rome, 2015.

Jim Ritter, P. Eng. (2018). Factsheet, Soil Erosion – Causes and Effects, Soil Management Order No. 87-040. (**ag.info.omafra@ontario.ca**)

Nigeria Geological Survey Agency (NGSA). (2006). Published by the Authority of the Federal Republic of Nigeria.

Nyssen, J., Poesen, J., Veyret-picot, M., Moeyersons, J., Mitiku, H., Deckers, J., Dewit, J., Naudts, J., Teka, K., Govers,G. (2006). Assessment of gully erosion rates through interviews and measurements: a case study from northern Ethiopia. *Earth Surface Processes andLandforms* 31: 167-185.

Oostwoud Wijdenes, D.G. and Bryan, R.B. (2001) Gully-head erosion processes on a semi-arid valley floor in Kenya: a case study into temporal variation and sediment budgeting, *Earth Surface Processes and Landforms* 26: 911–933,doi: 10.1002/esp.225,.

Tang J., Liu G., Xie Y., Dun X.W., Wang D.A., Zhang S. (2021). Annual variation of ephemeral gully erosion in a cultivated catchment. *Geoderma.* ;401:115166 doi: 10.1016/j.geoderma.2021.115166. [CrossRef] [Google Scholar]

Tebebu, T., Abiy, A., Dahlke, H., Easton, Z., Zegeye, A., Tilahun, S., Collick, A., Kidnau, S., Moges, S., Dadgari, F.(2010.) Surface and subsurface flow effect on permanent gully formation and upland erosion near Lake Tana in the northern highlands of Ethiopia, Hydrology and Earth System Sciences Discussions, 7, 5235-5265,

Tebebu, T.Y., Zegeye, A. D., Langendoen, E. J., Ayele, G. K., Tilahun, S. A., Ayala, E. K., and Steenhuis, T.S.(2014). Arresting gully formation in the Ethiopian Highlands, in: proceeding of rainwater management for resilient livelihoods in Ethiopia, ILRI, W. Mekuria, Nairobi,Kenya, 196–203,.

Tekwa, J. I., & Usman, B. H. (2006). Estimation of soil loss by gully erosion in Mubi, Adamawa State, Nigeria. *FUTY Journal of the Environment*, *1*(1), 35-43.

Vahyala, I.E., John, W.G. and Solomon, R.I. (2018). Infiltration Characteristics of Soils Affected by Gully Erosions in Girei Local Government Area of Adamawa State-Nigeria. *International Journal of Science, Environment and Technology,* Vol. 7, No 3, 1093-1107

Valentin, C., Poesen, J., Li, Y.(2005) Gully erosion: impacts, factors and control, *Catena* 63: 132-153, doi:10.1016/j.catena.2005.06.001,.

Vandekerckhove, L., Poesen, J., Govers, G.(2003). Medium-termgully headcut retreat rates in Southeast Spain determined from aerial photographs and ground measurements, *Catena* 50: 329-352,.

Vanmaercke, M., Poesen, J., Van Mele, B., Demuzere, M., Bruynseels, A., Golosov, V., Bezerra J. F. R., Bolysov, S., Dvinskih, A., Frankl, A.(2016). How fast do gully headcuts retreat Earth Science Reviews;

Zegeye, A., Damtew, S., Tilahun, A., Langendoen, E., Dagnew, D., Guzman, C., Tebeby, T., Steenhuis, T.(2014). Gully development processes in the Ethiopian Highlands, In: 2nd International Conference on the Advancements of Science and Technology, eds B. Bantyirga, M. Mehari, VS Rao, BL Manocha, KK Singh, S. Geremew, and E. Tadesse(Bahir Dar: Bahir Dar Institute of Technology). pp 220-229,.

Zegeye, A. D., Langendoen, E. J., Stoof, C. R., Tilahun, S. A., Dagnew, D. C., Zimale, F. A., ... & Steenhuis, T. S. (2016). Morphological dynamics of gully systems in the subhumid Ethiopian Highlands: the Debre Mawi watershed. *Soil*, *2*(3), 443-458.

APPENDIX I

Table of VSL, ASL, MSL and the 13 Relevant Predictor Variables

	VOLUME (M³)	AREA (M²)	M S L (Kg/ac)	BD (g/cm3)		ERODIBILITY	OM (g/kg)	SHEAR STRENGTH τ_c (Nm)	SITE SLOPE R %	VOL OF RUNOFF (m3/sec)	KSat 10^{-1} cm/s	IR (cm/h)	%WSA	POROSITY ~~%~~	h. cut Height (m)	Altitude (M)
Jabbilamba 1	2497.5	7.95	5119.88	2.05	28.80	0.21	20.46	0.008848	4	101.42	1.66×10^{-3}	1.8	19.30	43.60	2	244
Jabbilamba 2	624	3	1154.4	1.85	20.80	0.2	15.99	0.00581	4	101.36	9.35×10^{-4}	1.2	16.00	35.88	1.6	244
Jabbilamba 3	1823.9	25.57	3775.47	2.07	22.80	0.2	15.13	0.007857	4	296.25	7.67×10^{-4}	1.5	17.10	41.50	2.5	244
Jabbilamba 4	279	-10.24	605.43	2.17	16.80	0.2	15.99	0.00482	4	45.32	8.46×10^{-4}	3	22.30	36.25	3.3	244
Safini 1	6380	37.2	14291.2	2.24	10.80	0.1	23.73	0.008518	4	777.22	2.97×10^{-3}	6	8.10	47.50	3.8	244
Safini 2	14868.8	39.52	29440.2	1.98	12.80	0.03	19.09	0.00964	4	2415.11	5.79×10^{-3}	6	13.80	44.90	4	244
Safini 3	228	8	435.48	1.91	18.80	0.16	21.5	0.007923	4	37.03	2.35×10^{-3}	0.9	23.80	44.50	2.7	244
Sangere 1	228.5	6.7	450.145	1.97	8.80	0.22	27.69	0.008914	4	37.11	2.41×10^{-3}	2.4	13.80	47.13	3.5	244
Sangere 2	280.5	5.7	608.685	2.17	4.80	0.19	20.29	0.007197	4	45.56	1.65×10^{-3}	2.7	18.20	49.25	1.7	244
Sangere 3	2530	10.4	4984.1	1.97	22.80	0.21	23.22	0.007923	4	410.94	2.83×10^{-3}	6	8.20	32.13	2	244
Madalu 1	915	22.5	1701.9	1.86	16.80	0.06	23.9	0.009904	4	148.62	5.76×10^{-4}	0.9	8.80	38.40	4	244
Madalu 2	0	0	0	2.17	26.80	0.19	17.37	0.007197	4	0.00	5.01×10^{-4}	0.6	31.10	39.25	0.6	244
Sangere 4	626	2.2	1208.18	1.93	8.80	0.10	27.17	0.00832	4	25.42	1.46×10^{-3}	8.8	14.50	44.50	2	244
Sangere 5	2168.6	23.34	4489	2.07	14.80	0.11	21.67	0.006933	4	88.06	1.56×10^{-3}	6	17.70	49.38	2.6	244
Sangere 6	1680	11.8	3141.6	1.87	14.80	0.12	21.84	0.007725	4	68.22	1.61×10^{-3}	1.5	14.30	52.75	1.6	244
Lamido Farm	1161.5	14.05	2369.46	2.04	20.80	0.02	9.8	0.00416	4	47.17	7.25×10^{-4}	0.6	8.10	42.80	1.8	244
Daware J 1	119.4	2.9	259.098	2.17	8.80	0.16	17.54	0.005018	9	3.15	3.68×10^{-3}	3.3	19.80	43.75	1	275
Daware J 2	287.5	19.75	623.875	2.17	20.80	0.17	6.71	0.004754	9	7.59	1.89×10^{-3}	4.2	15.00	44.98	2.5	275
Daware J 3	2526.7	13.45	5710.34	2.26	8.80	0.14	12.38	0.004688	9	66.69	2.32×10^{-3}	9.3	16.00	35.88	2.5	275
Girei River 1	-46.08	3.6	-103.68	2.25	16.80	0.07	16.85	0.00581	9	-5.61	2.37×10^{-3}	11.6	20.90	41.20	1.6	244
Girei River 2	8746.5	35.7	16268.5	1.86	8.80	0.10	20.46	0.006141	9	1065.51	2.49×10^{-3}	12	8.80	40.75	7	244
Hona 1	162.72	13.08	320.558	1.97	8.80	0.08	10.32	0.008848	9	19.82	1.33×10^{-3}	13.2	22.00	51.06	2.5	244

Hona 2	455.79	24.68	711.032	1.56	6.80	0.04	10.83	0.006999	4	55.52	2.12×10^{-3}	14.1	17.60	44.88	3.1	244
Prof Q	809.16	28.68	1674.96	2.07	6.80	0.07	20.29	0.009244	4	98.57	9.88×10^{-4}	12	14.50	46.38	4.3	275
Fed Housing	1162	4.92	2289.14	1.97	10.80	0.01	8.77	0.005612	4	141.56	1.18×10^{-3}	1.5	14.60	47.85	1.4	244
Damare	6147.5	22.4	11618.8	1.89	2.80	0.16	13.24	0.003367	4	249.63	3.95×10^{-4}	2.4	11.40	46.75	2.3	305
Lambondo 1	6715	7.14	11818.4	1.76	4.80	0.22	19.78	0.006141	4	272.68	6.76×10^{-4}	36	11.80	50.70	1.7	336
Lambondo 2	12422.4	26.88	22360.3	1.80	20.80	0.19	22.7	0.007593	4	504.44	1.99×10^{-3}	0.3	3.10	38.40	2	336
Ndikajam	14154	40.71	21797.2	1.54	10.80	0.16	14.62	0.005744	4	1724.25	1.30×10^{-3}	2.4	16.70	27.60	4.5	336
Kangling	36069	199.3	67449	1.87	14.80	0.04	17.02	0.009838	4	1464.65	1.52×10^{-3}	1.2	15.90	41.60	6	336
Univ Farm 1	4820	46	8772.4	1.82	6.80	0.05	22.87	0.007989	9	587.18	1.27×10^{-3}	16.2	9.80	38.13	2	244
Univ Farm 2	884	12.92	1794.52	2.03	10.80	0.07	22.7	0.008782	9	107.69	1.86×10^{-3}	18.6	12.50	48.53	2	244
Jatau	2600.4	26.5	4186.64	1.61	8.80	0.06	0.06	0.006075	4	7.36	1.55×10^{-3}	12.4	14.80	47.88	4	275
Amsami	1090.7	17.9	1712.4	1.57	10.80	0.11	0.11	0.008716	4	3.90	6.80×10^{-4}	18.6	15.20	38.13	2	275
Dunde	5505	66.5	8422.65	1.53	12.80	0.15	0.15	0.007197	4	22.42	1.75×10^{-3}	18	17.40	50.50	3	244
Jera	221	7	397.8	1.80	6.80	0.10	0.10	0.00832	4	16.19	1.28×10^{-3}	16.2	9.30	51.25	1	244
Sani	1792	9.6	2795.52	1.56	10.80	0.08	0.08	0.006273	4	22.60	6.71×10^{-4}	8.8	13.50	42.00	1.5	244
Kaftarare	884	9	1502.8	1.70	12.80	0.09	0.09	0.009178	4	1.97	4.71×10^{-4}	12	11.00	46.00	1	244
Mashi	1934	6	3307.14	1.71	4.80	0.01	0.01	0.008584	4	0.97	2.22×10^{-3}	20.6	25.90	38.40	2	275
Modibbo	1310	3	2109.1	1.61	8.80	0.09	0.09	0.009178	4	0.71	1.55×10^{-3}	12	17.30	47.13	1	244
Ngawa	7820	65.5	13685	1.75	20.80	0.14	0.14	0.007857	4	0.41	6.56×10^{-4}	1.3	13.80	48.63	3.5	305

ASSESSMENT OF POTASSIUM LEACHING POTENTIALS IN SOILS FORMED ON DIVERSE PARENT MATERIALS IN AKWA IBOM STATE

[1*]Ijah, C. J., [1]Udoh, A. B., [2]Iyanam, M.V., [3]Udounang, P.I., and [1]Effiong, I. B.
[1]Department of Soil Science, Akwa Ibom State University, Obio Akpa Campus
[2] Ministry of Agriculture, Uyo, Akwa Ibom State
[3]Department of Crop Science, Akwa Ibom State University, Obio Akpa Campus
Corresponding author email:christianaijah.gmail.com

ABSTRACT
Soils formed from Coastal Plain Sands (CPS), Beach Ridge Sand (BRS) and Sandstone (SS) parent materials in Akwa Ibom State were studied for potassium (K) leaching potentials. Composite soil samples were collected with an auger at 0-20 cm depth. A treatment solution containing 0, 20,40 and 80 mgL^{-1} of K prepared from potassium chloride (KCl) were added to 20g of soil in specified cups, with the bottoms perforated. The cups were covered and allowed to incubate for 1,7, 21 and 28 days, respectively. The experiment was a 3x4 factorial fitted into a completely randomized design (CRD) with a total of 144 experimental units. Distilled water was added to the mixture at weekly intervals during the incubation period to maintain the moisture content of 60% of the maximum water holding capacity of the soil. At the set days, the concentrations of K in the leachate were measured using flame Photometer and the K data plotted accordingly against the days of incubation. The results showed that soils of sandstone origin had the highest leaching potentials (0.16mgL^{-1}), followed by soils formed on beach ridge sand (0.14 mg L$^{-1)}$), while the least was in the soils of coastal plain sand (0.11mg L^{-1}). Soils of BRS and CPS were found to have low leaching potentials while soils formed on sandstone had higher leaching potentials. Leached K correlated positively with pH (r= 0.998), available K (r = 1.000*), exchangeable Ca (r = 0.998*), EC (r = 1.000*) and exchangeable Mg (r = 0.0998*). To reduce the risk of K leaching in these soils, soil testing coupled with appropriate soil management practices, such as liming, application of potassium fertilizers and organic manure in acidic soils can help sustain the productivity of these soils.*
Keywords: Potassium, leaching potentials of K, parent materials, incubation time,

Introduction

Potassium (K) leaching in tropical soils is one of the major factor**s** affecting nutrient availability and crop productivity. According to Kabata-Peldias and Pendias, (2001) many tropical soils have a low cation exchange capacity (CEC) which makes them prone to leaching of cation including potassium. Studies by Sanchez and Logan, (1992) and Obia *et al.,* (2014), among others, have also shown that inappropriate timing of K-rich fertilizer application, over- use of K fertilizers coupled with high rainfall and poor management practices can exacerbate potassium leaching in soils. Intensive cultivation of crops can result in higher potassium uptake, which may further contribute to potassium depletion and leaching (Nziguheba *et al*., 2016). Malavolta (1985) reported that soil type affects K leaching because the final amount of K lost depends on the soil available K, which is related to the soil texture. Similarly, Pal *et al, (*1999) observed that soluble K is negatively related to the proportion of coarse sand and positively related to the amounts of clay and silt. Thus, greater K leaching losses might be expected from sandy soils than from clayey soils. Furthermore, Umoh *et al.,* (2018) reported short lasting effects of added K in high clay soil and higher leaching potential in soils with high sand content amongst diverse soils in Akwa Ibom State.

Sandy soils have a higher leaching potential for potassium (Havlin *et al.,* 2014) due to their larger pore spaces and lower cation exchange capacity (CEC), which reduces the soil's ability to retain potassium ions. Marschner (2012) in a related study observed that acidic soils (low pH) tend to have a higher leaching potential for potassium than alkaline soils, as the acidic conditions can promote the release of potassium ions from the exchange sites. Low soil pH can result in increased competition between hydrogen ions (H^+) and potassium ions (K^+) for binding sites on soil colloids, leading to the displacement of K^+ ions, making them more susceptible to leaching (Kabir and Koide, 2000).

High cost of fertilizers, and low soil fertility coupled with poor yield of crops have motivated interest to improve the efficiency in the use of fertilizers by farmers. Less attention has been paid on K leaching potentials and information on the leaching of K in soils formed on diverse parent materials in Akwa Ibom State is limited. Therefore, the study aimed at assessing the leaching potentials of K in soils formed on diverse parent materials in Akwa Ibom State.

MATERIALS AND METHODS

The study was carried out on soils developed on three different parent materials; Sandstone from Odoro Ikpe in Ini local government area (L.G.A), Beach ridge sand from Uta-Ewa in Ikot Abasi L.G.A., and Coastal plain sand in Obio Akpa in Oruk Anam L.G.A. in Akwa Ibom State. The State is located within the tropical rainforest zone, with mean annual rainfall of about 2500 mm to 3000 mm along the coast. Mean annual temperature range is about 24- 30°C with relative humidity of 75-80% (SLUK-AK, 1998).

Soil Sampling and Preparation

Composite soil samples were taken from three representative locations with an auger at 0-20 cm depth. The location Map of the study area is shown in Figure 1. The soil samples were air-dried, passed through 2 mm sieve and placed in a labeled polythene bag before being sent to the laboratory for routine analysis and potassium leaching studies.

Leaching Studies

Twenty grams (20g) of the sieved soil was weighed into duplicated cups that the bottom was perforated to make it easy for solution to leach thoroughly and to dry up. A treatment solute containing 0, 20,40 and 80mg/$L^{-1}$of prepared Potassium Chloride (KCL) were added to the 20g of soil in specified cups and the cups were allowed to incubate for 1,7, 21 and 28 days respectively. Distilled water was added to the mixture at weekly intervals during the incubation period to maintain the moisture content of 60% of the maximum water holding capacity of the soil. A total of one hundred and forty four (144) experimental units were generated and the treatment combinations were fitted into a completely randomized design (CRD), with three (3) parent materials representing the block for each of the incubation days and four (4) rates of K. On the set days, the concentration of potassium (K) in the leachate on each of the incubation cups were determined using flame Photometer.

Laboratory Analysis

Particle size analysis was determined by the Bouyoucous hydrometer method using sodium hexametaphosphate (Calgon) as a dispersing agent. Soil pH was determined potentiometrically using a glass electrode pH meter in a 1:2.5 soil-water ratio. Electrical conductivity was determined in a 1:2.5 soil: water ratio using Conductivity Bridge. Total nitrogen was determined by the micro Kjeldahl digestion method**.** Organic carbon was determined using the Walkley- Black wet dichromate oxidation method. The value was multiplied by 1.724 (conventional van Bemmelen factor) to obtain organic matter content. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N ammonium acetate (NH_4OAc) at pH 7.0 using 1:10 soil-liquid ratio. Calcium and Mg in the extract were determined by EDTA (Ethylene Diaminetetra Acetate Acid) titration method as described by Udo *et al.,* (2009) while Na and K in the extract were determined using a flame photometer. The analyses were conducted following procedures as described by Udo *et al.* (2009). Exchangeable acidity was extracted with 1M KCl solution and the acidity from the extract was titrated with 0.01M NaOH. Effective cation exchange capacity (ECEC) was obtained from the summation of exchangeable cations and exchangeable acidity. Base saturation was calculated by dividing the total exchangeable bases by the effective cation exchange capacity and multiplied by 100.

Statistical Analysis

The data generated were subjected to analysis of variance (ANOVA). Significant means were compared using Fisher least significant difference ($p<0.05$). Pearson's product moment correlation was used to access the relationship between K leaching susceptibility and some soil properties.

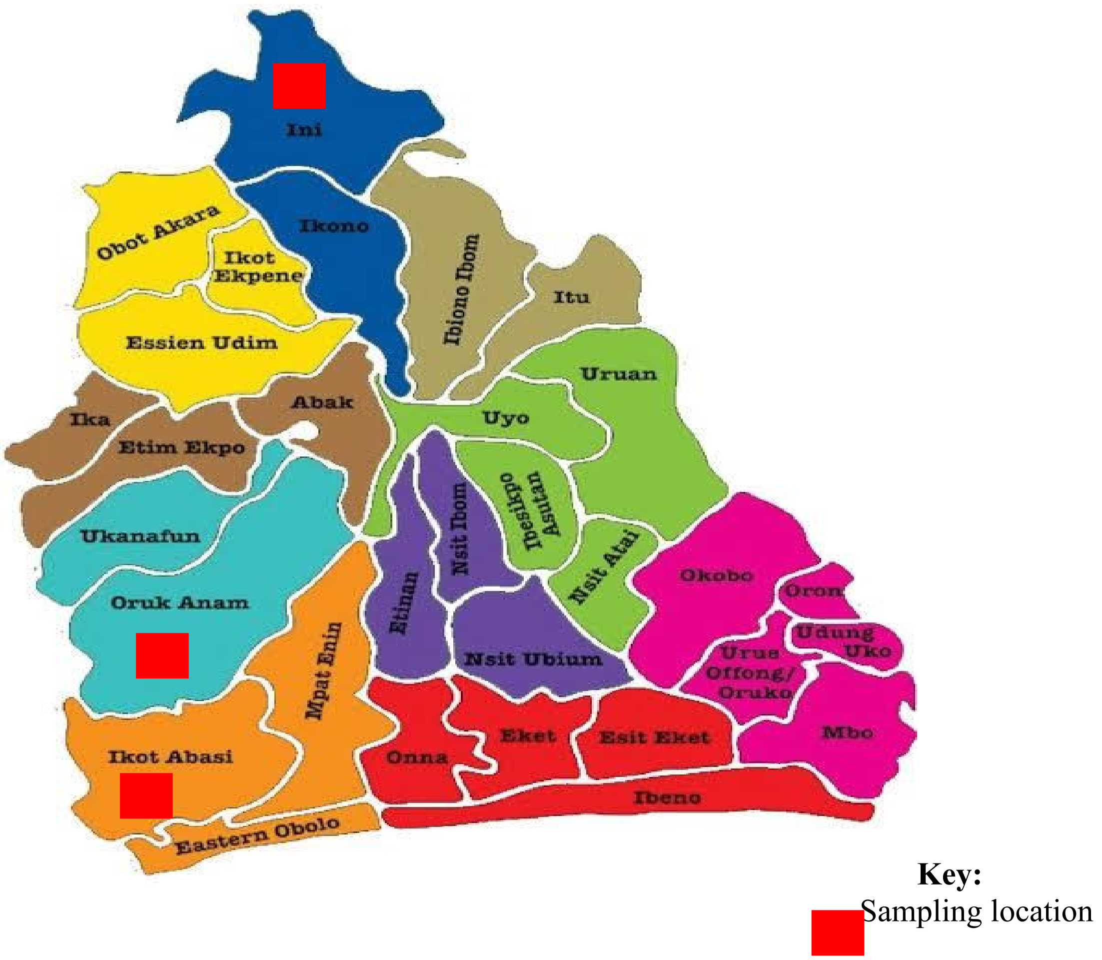


Figure 1: Map of Akwa Ibom State showing sampling locations

Results and Discussion

Physical and chemical characteristics of the studied soils

The physical and chemical characteristics of the studied soils are presented in Table 1. At 0-20cm depth, the beach ridge sand had the highest sand fraction (909.4gkg^{-1}) while the coastal plain sand had the least sand content of (717.0gkg^{-1}). The silt content was higher in sandstone (44.5gkg^{-1}) while the coastal plain sand had the least silt content of (20.0gkg^{-1}). The clay content was higher in coastal plain sand (263.0gkg^{-1}) while the beach ridge sand had the least clay content of (54.0gkg^{-1}). The texture of the soils was loamy sand for sandstone, sand for beach ridge sand, and sandy loam for coastal plain sand, respectively. The difference in textural classes may be due to the different parent material in which the soil was formed. This finding is in line with that of Ijah *et al*, (2023) who reported differences in textural classes in different parent materials in Akwa Ibom State. The pH of the soil was acidic to slightly acidic, with values ranging from (6.09) in sandstone, (5.29) in beach ridge sand and (5.46) in coastal plain sand. The electrical conductivity was generally low in all the parent materials studied. The organic matter content was fairly high (2.31%) in sandstone and low in beach ridge sand and coastal plain sand as proposed by (Aduayi*et al*, 2002) for the soils of Eastern Nigeria. Total nitrogen was generally low in all the locations. The available P was high in all the soils studied and ranged from 18.34mgkg^{-1} in the BRS to 30.23mgkg^{-1} in SS. The order of abundance of exchangeable cations were: Ca > Mg > K > Na. The effective cation exchange capacity (ECEC) was higher in soils formed from BRS (8.22cmol/kg^{-1}) and was low in CPS (5.61cmolkg^{-1}). The base saturation values were high ranging from (62.40cmolkg^{-1}) in sandstone, (65.45cmolkg^{-1}) in beach ridge sand and (54.20cmolkg^{-1}) in coastal plain sand.

Table 1: Physical and Chemical characteristics of the Three Parent materials

Tested parameters	Unit	Depth	Sand Stone (SS)	Beach Ridge Sand (BRS)	Coastal Plain Sand (CPS)
Particle size analysis		0-20cm			
Sand	gkg^{-1}		827.6	909.4	717.0
Silt	gkg^{-1}		44.5	36.6	20.0
Clay	gkg^{-1}		127.9	54.0	263.0
Textural class			Loamy Sand	Sand	Sandy Loam
pH			6.09	5.29	5.46
EC	dS/m		0.01	0.04	0.02
Organic matter	%		2.31	1.28	1.43
Total Nitrogen	%		0.08	0.06	0.07
Available P	mgkg^{-1}		30.23	18.34	26.72
			Exchangeable bases		
Ca	cmol/kg^{-1}		3.01	3.08	2.02
Mg	cmol/kg^{-1}		0.80	2.06	0.89
K	cmol/kg^{-1}		0.23	0.16	0.11
Na	cmol/kg^{-1}		0.01	0.08	0.02
EA	cmol/kg^{-1}		2.44	2.84	2.57
ECEC	cmol/kg^{-1}		6.49	8.22	5.61
Base saturation	%		62.40	65.45	54.20

EC = Electrical conductivity, Av. P = Available Phosphorus, Ca = Exchangeable calcium, Mg= Exchangeable Magnesium, K= Exchangeable potassium, Na = Exchangeable Sodium, EA = Exchangeable Acidity, ECEC = Effective Cation Exchange Capacity, B. sat = Base Saturation.

Effect of parent materials and K rates on amount of available K in the leachate at Day 1

The effect of parent materials and K rates at day 1 is presented in Table 2. The amount of available K in the leachate was higher in the sandstone while coastal plain sand had the least. The amount of K loss increases with increasing rate of addition of K. The trend is as follows; sandstone (0.15 mg/kg) > beach ridge sand (0.12mg/kg) > coastal plain sand (0.09mg/kg). The high leaching observed in soils developed on sandstone parent material could be attributed to the sandiness of the soils as well as acidic nature of the soil. According to Marschner (2012), acidic soils tend to have a higher leaching potential for K as the acidic condition can promote the release of potassium ions from exchange sites.

Table 2: Effect of parent material and K rates on amount of available K in the leachate at Day 1 (mg/l)

Parent material	0	20	40	80	PM Total	PM means
CPS	0.03	0.05	0.07	0.23	0.38	0.09
BRS	0.06	0.07	0.11	0.23	0.47	0.12
SS	0.1	0.08	0.17	0.24	0.59	0.15
Rate Total	0.19	0.2	0.35	0.70		
Rate Mean	0.06	0.07	0.12	0.23		

CPS = Coastal plain sand, BRS= Beach ridge sand, SS = Sandstone

Effect of parent materials and K rates on amount of available K in the leachate at Day 7

The effect of parent materials and K rates at day 7 is presented in Table 3. The amount of available K in leachate at day 7 increased with increasing rate of K added. At $0mgL^{-1}$ rate being the lowest and $80mgL^{-1}$ being the highest for the three parent materials studied. The amount of K loss increases with increasing rate of k addition. Sandstone soils had the highest leaching rate of (0.16mg/kg) while the Coastal Plain Sand (0.11mg/kg) had the least. The finding from this study is in line with the work of Gikonyo *et al, (2010*) who reported that the amount of nutrient leached increase with increasing rates of fertilizer applied and total nutrient concentration in leachate is higher than in soils.

Table 3: Effect of parent material and K rates on amount of available K in the leachate at Day 7 (mg/l)

Parent material	0	20	40	80	PM Total	PM means
CPS	0.03	0.06	0.09	0.26	0.44	0.11
BRS	0.06	0.08	0.12	0.26	0.52	0.13
SS	0.11	0.09	0.18	0.27	0.65	0.16
Rate Total	0.20	0.23	0.39	0.79		
Rate Mean	0.07	0.07	0.13	0.26		

CPS = Coastal plain sand, BRS= Beach ridge sand, SS = Sandstone

Effect of parent material and K rates on amount of available K in the leachate at Day 21

Table 4 shows the effect of parent materials and K rates on amount of available K in the leachate at day 21. The amount of K released also increases with increasing rate of K addition. Sandstone soils had the highest leaching (0.17mg/kg) while the Coastal Plain Sand recorded (0.12mg/kg) the lowest leaching rate. According to Sanchez and Logan, (1992) acidic soils common in tropical areas can enhance potassium leaching because the acidity can increase the solubility of potassium compounds. Similarly, (Kabir and Koide, 2002) reported that low pH can result in increased competition between hydrogen (H^+) and potassium ions (k^+) for binding sites on soil colloids lending to the displacement of k^+ ions, making them more susceptible to leaching.

Table .4: Effect of parent materials and K rates on amount of available K in the leachate at Day 21 (mg/l)

Parent material	0	20	40	80	PM Total	PM means
CPS	0.04	0.07	0.09	0.27	0.47	0.12
BRS	0.07	0.07	0.14	0.27	0.55	0.14
SS	0.13	0.11	0.17	0.28	0.69	0.17
Rate Total	0.27	0.27	0.28	0.82		
Rate Mean	0.08	0.08	0.13	0.27		

CPS = Coastal plain sand, BRS= Beach ridge sand, SS = Sandstone

Effect of parent materials and K rates on amount of available K in the leachate at Day 28

Similar trend was also observed at day 28, Table 5. The amount of available K in leachate at day 28 increased with increasing rate of K added with $0mg/l^{-1}$ being the lowest and $80mg/l^{-1}$ being the highest for the three parent materials studied. The rate of leaching in the soils shows a uniformed pattern on the incubation days (1-28 days). Sand recorded the highest leaching rate (0.16mg/kg) while the coastal plain sand had the lowest leaching rate of (0.13).Umoh *et al.,* (2018) observed low leaching of K in high clay soil and higher leaching of K in sandy soils and the amount of K in leachate increased with the concentration of K added. They varies as follows: 0mgl (0.08), 20mgl (0.08), 40mgl (0.13) and 80mgl (0.27).

Table 5: Effect of parent materials and K rates on amount of available K in the leachate at Day 28 (mg/l)

Parent material	0	20	40	80	PM Total	PM means
CPS	0.05	0.07	0.11	0.28	0.51	0.13
BRS	0.07	0.08	0.16	0.30	0.61	0.15
SS	0.04	0.12	0.21	0.30	0.67	0.16
Rate Total	0.28	0.30	0.30	0.88		
Rate Mean	0.05	0.09	0.16	0.29		

CPS = coastal plain sand, BRS= beach ridge sand, SS = sandstone

Interactive effect of leaching on soil parent materials at Day 1, 7, 21 and 28 (mg/l)

The interactive effects of leaching on soils derived from different parent materials is shown in Table 6. Sandstone soil had the highest mean of available K (0.16mg/kg) in the leachate while coastal plain sand had (0.11mg/kg) the least. The trend was as follows: Sandstone (0.16mg/kg) > beach ridge sand (0.14 mg/kg)> coastal plain sand (0.11 mg/kg). The rate of K loss in this soil was not significantly different from each other but show a uniform pattern on incubation days. The result also revealed that the highest K losses were observed with longer days of incubation. Highest K loss was observed with increasing rates of K addition, the ranged from 0.07 $mgkg^{-1}$ ($0mgl^{-1}$ - control) < 0.08 $mgkg^{-1}$ ($20mgl^{-1}$) < 0.14 $mgkg^{-1}$ ($40mgl^{-1}$) < $0.27mgkg^{-1}$($80mgl^{-1}$).

Table 6: Interactive effect of leaching on soil parent materials at Day 1, 7, 21 and 28 (mg/l)

Parent material	Day 1	Day 7	Day 21	Day 28	Mean
CPS	0.09	0.11	0.12	0.13	0.11
BRS	0.12	0.13	0.14	0.16	0.14
SS	0.15	0.16	0.17	0.16	0.16
LSD (p<0.05)	0.005	0.003	0.005	0.009	
K Rates					
0	0.06	0.07	0.08	0.05	0.07
20	0.07	0.08	0.08	0.09	0.08
40	0.12	0.13	0.14	0.16	0.14
80	0.24	0.26	0.27	0.29	0.27
LSD (p<0.05)	0.006	0.003	0.004	0.011	
Parent Material x K Rate Interaction					
LSD (p<0.05)	0.011	0.006	0.009	0.019	

CPS = Coastal plain sand, BRS= Beach ridge sand, SS = Sandstone

Plots of the concentration of K in leachate and amount of rate of K added days 1, 7, 21 and 28

The graphs are plots of the concentration of P in leachate and amount of rate of P added days 1, 7, 21 and 28. It was observed from figures (1, 2, 3 and 4) that the rate of leaching increases with increasing rates of P added in all the days. Among the soils studied, sandstone soil had the highest leaching potentials of added P as shown in day 1, 7, 21 and 28 while the coastal plain sand had the least. . The retention of P in the coastal plain sand could be attributed to the presence of iron and aluminum oxides which formed complexes with P in the soil and reduce P mobility and make it less prone to leaching (Reitemeier*et.al.,* 1967).

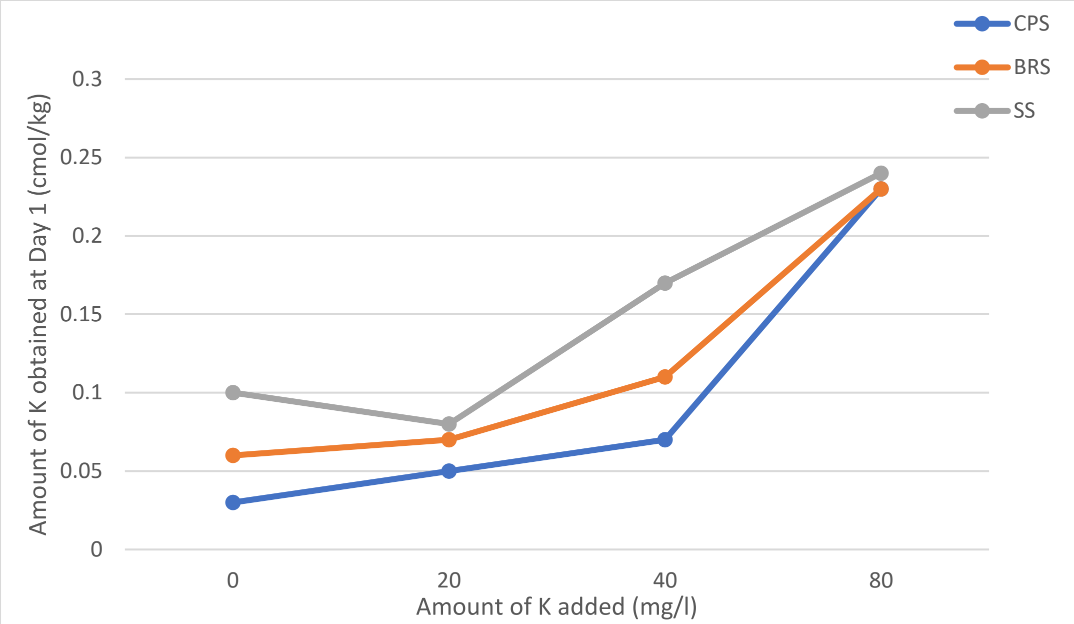


Figure 2: Amount of K added (mg/l)

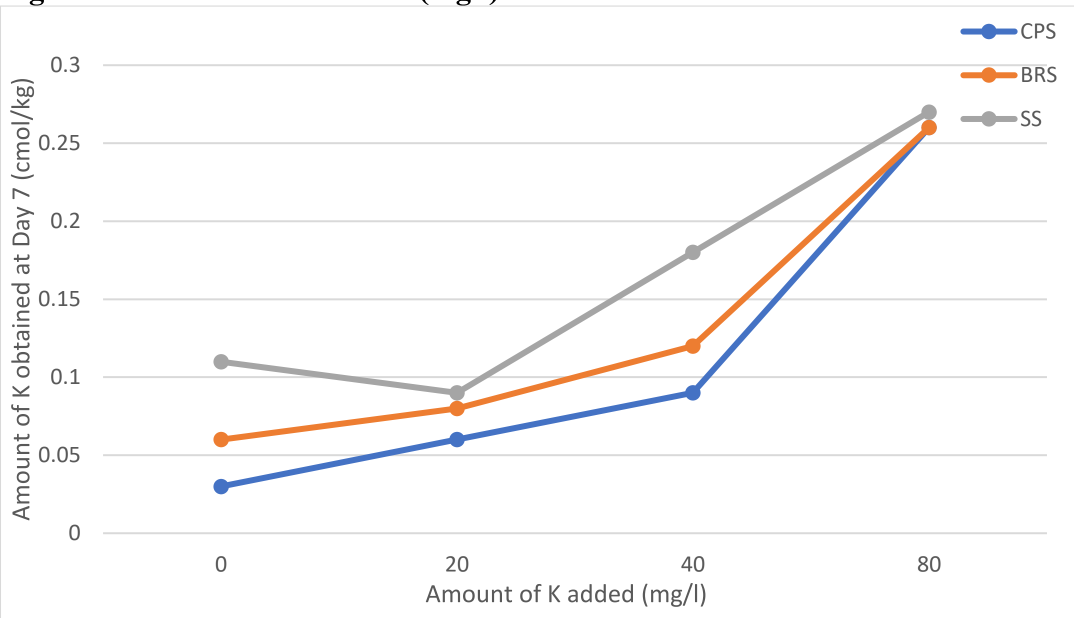


Figure 3: Amount of K added (mg/l)

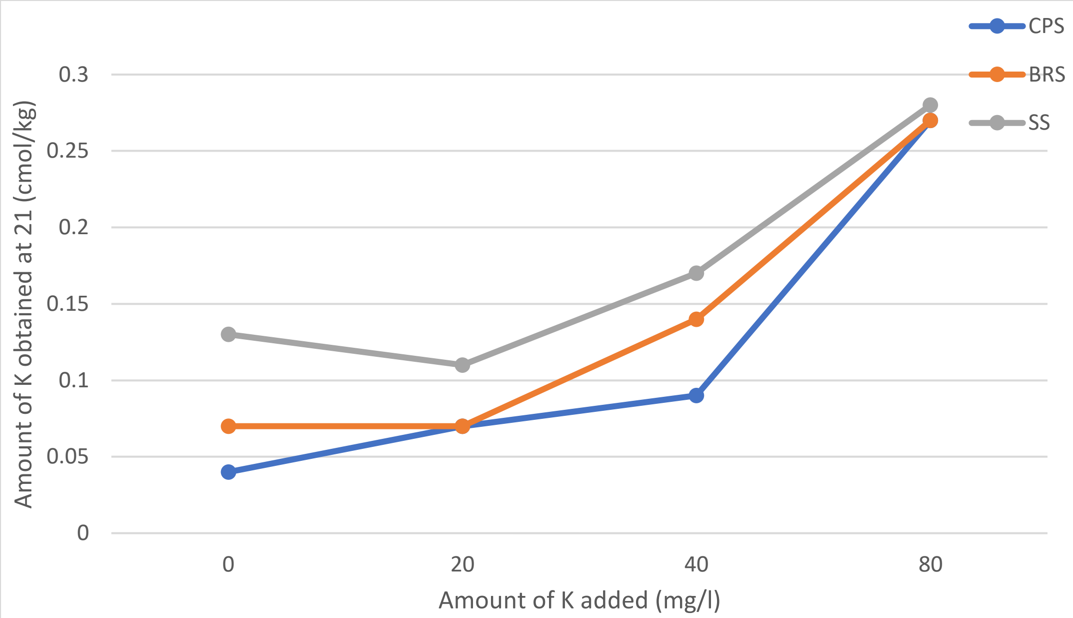


Figure 4: Amount of K added (mg/l)

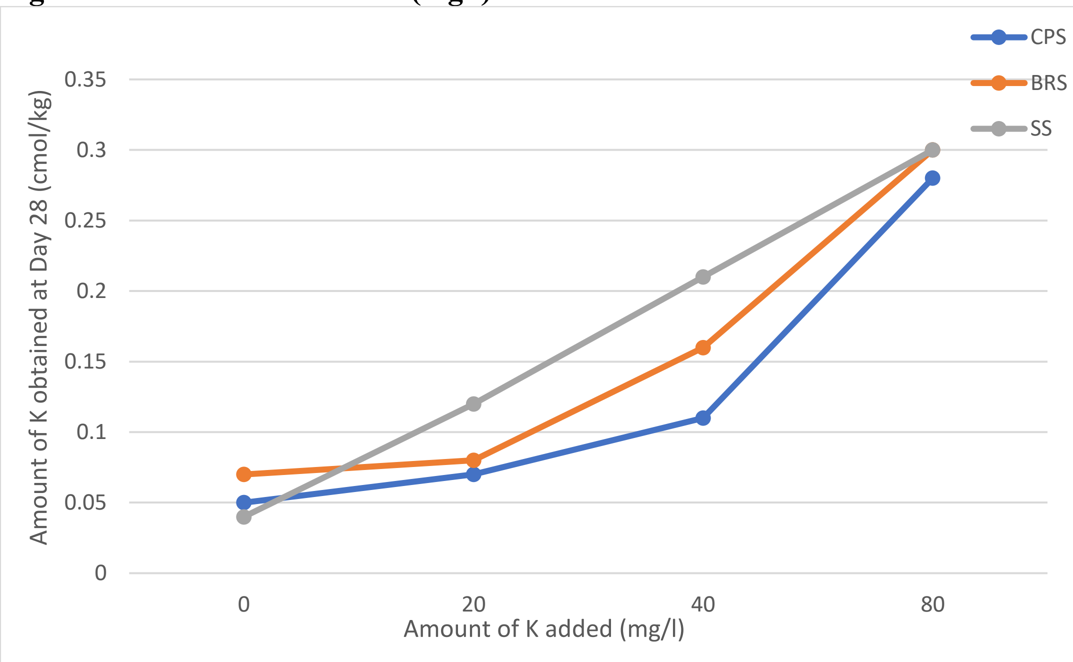


Figure 5: Amount of K added (mg/l)

Correlation matrix between K in leachate and some soil physicochemical properties

Table 7 shows the correlation between K in leachate and some soil physico-chemical properties. K in leachate correlated positively with pH (r=0.998*), available k ($r = 1.000^*$), exchangeable Ca ($r = 0.998^*$), EC ($r = 1.000^*$) and exchangeable Mg ($r = 0.0998^*$). The positive correlation that existed between available K, exchangeable Ca, EC and exchangeable Mg suggested that these factors contributed to K leaching in the soils.

Table 7: Correlation between K leaching potentials and some soil physico-chemical properties

	Day 1	Day 7	Day 21	Day 28	Sand g/kg	Silt g/kg	Clay g/kg	pH	EC sd/m	OM %	TN %	Av.Kcmol/kg	Ca cmol/kg	Mg cmol/kg	Na cmol/kg	EA cmol/kg	ECEC cmol/kg	BS %
Day 1	1																	
Day 7	0.993	1																
Day 21	0.993	1.000*	1															
Day 28	0.866	0.803	0.803	1														
Sand	0.573	0.475	0.475	0.906	1													
Silt	0.980	0.950	0.950	0.949	0.726	1												
Clay	-0.637	-0.545	-0.545	-0.937	-0.997	-0.779	1											
pH	0.747	0.819	0.819	0.315	-0.117	0.599	0.039	1										
EC	-0.327	-0.434	-0.434	0.189	0.587	-0.131	-0.519	-0.872	1									
OM	0.791	0.856	0.856	0.379	-0.049	0.652	-0.032	0.998*	-0.837	1								
TN	0.500	0.596	0.596	0.000	-0.424	0.316	0.349	0.949	-0.982	0.926	1							
Av. K	0.995	1.000*	1.000*	0.814	0.492	0.956	-0.561	0.808	-0.416	0.846	0.581	1						
Ca	0.835	0.766	0.766	0.998*	0.929	0.928	-0.956	0.258	0.247	0.323	-0.059	0.778	1					
Mg	-0.064	-0.178	-0.178	0.444	0.781	0.138	-0.728	-0.711	0.964	-.0.662	-0.896	-0.159	0.496	1				
Na	-0.132	-0.245	-0.245	0.381	0.737	0.070	-0.680	-0.757	-0.980	-0.711	-0.924	-0.226	0.435	0.998*	1			
EA	-0.319	-0.425	-0.425	0.198	0.595	-0.122	-0.527	-0.868	1.000*	-0.832	-0.980	-0.408	0.256	0.966	0.982	1		
ECEC	0.331	0.221	0.221	0.759	0.963	0.514	-0.938	-0.379	0.783	-0.316	-0.651	0.239	0.796	0.920	0.891	0.789	1	
Bs	0.697	0.610	0.610	0.962	0.987	0.827	-0.997	0.044	0.449	0.112	-0.273	0.625	0.977	0.671	0.619	0.458	0.908	1

EC = Electrical conductivity, Av. P = Available phosphorus, Ca = Exchangeable calcium, Mg= Exchangeable magnesium, K= Exchangeable potassium, Na = Exchangeable sodium, EA = Exchangeable acidity, ECEC = Effective cation exchange capacity, B. sat = Base saturation.

**Correlation is significant at the 0.01 level (2-tailed)

- Correlation is significant at the 0.05 level (2-tailed).

CONCLUSION

Results from this study revealed that the texture of the soils was loamy sand for sandstone, sand for beach ridge sand and sandy loam for coastal plain sand, respectively. The pH of the soil was acidic to slightly acidic with fairly high organic matter in soils formed on sandstone. The concentration of available K in the leachate at different incubation day's increase with increasing rate of K added. Soils formed from beach ridge sand and coastal plain sand had long lasting effect of added K and found to have low leaching susceptibility while soils formed on sandstone had short leaching effect of added K and higher leaching susceptibility. K leaching correlated positively with pH (r=0.998*) available k (r =1.000*), exchangeable Ca (r = 0.998*), EC (r = 1.000*) and exchangeable Mg (r = 0.998*). To reduce the risk of K leaching and also to sustain the productive susceptibility of these soils, integrated nutrient management involving the wise use of organic and inorganic nutrient sources with regular soil testing to monitor the content of available K should be adopted.

References

Aduayi, E.A., Chude, V.O., Adebusuyi, B.A. and Olayiwola, S.O. (2002) Fertilizer Use and Management Practices for Crops in Nigeria. 3rd Edition, Federal Ministry of Agriculture and Rural Development, Abuja, 28-73.

Gikonyo, E. Zatharah, A. R, Hanafi, M. M and Anuar, R (2010). Phosphorous leaching in an acid tropical soil. "Recapitalized with Phosphate rock and triple superphosphate. *Scientific World Journal* W:1499 – 1508.

Havlin, J.L., Beaton, J.D., Tisdale, S.L. and Nelson, W.L. (2014) Soil Fertility and Fertilizers; An Introduction to Nutrient Management. 6th Edition, Prentice Hall, Upper Saddle River, NJ.

Ijah, C.J, Umoh, F. O., Essien, O. A., Uduak, G. O and Moses, V, I. (2023). Profile Distribution of Iron and Zinc in Soils Developed from Three Parent Materials in Akwa Ibom State, Nigeria. *AKSU Journal of Agriculture and Food Science,* 7 (2) 40 -51.

Kabata-Pendias, A., and Pendias, H. (2001). Trace Elements in Soils and Plants. CRC Press.

Kabir, Z., and Koide, R. T. (2000). The effect of dandelion or a cover crop on mycorrhiza inoculum potential, soil aggregation and yield of maize. Agriculture, Ecosystems & Environment, 78(2), 167-174.

Malavolta E. (1985). Potassium status of tropical and subtropical region soils. In: Potassium in agriculture,(ed) R Munson, ASA CSSA & SSSA Madison WI pp 163±200.

Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants. Academic Press.

Nziguheba, G., Merckx, R., Palm, C. A., and Mutuo, P. (2016). Does long-term residue addition have a positive or negative effect on maize yield? A synthesis of long-term trials in sub-Saharan Africa. *Agronomy Journal,* 108(4), 1388-1400.

Obia, A., Cornelissen, G., Mulder, J., and Bader, N. (2014). Potassium availability and soil fertility management in tropical crop production. Soil Use and Management, 30(4), 470-481.

Pal, Y. Wong T and Gilkes R (1999). The forms of potassium and potassium adsorption in some virgin soils from south Western Australia. *Australian Journal of Soil Research* 37, 695±709. Potash Institute 9: 15-31.

Reitemeier, R. F., Dahnke, W. C., & Wiese, A. F. (1967). Potassium in soils and plants. University of Wisconsin Press.

Sanchez, P. A., and Logan, T. J. (1992). Myths and Science about the Chemistry and Fertility of Soils in the Tropics. *Soil Science Society of America Journal,* 56(3), 901-917.

SLUS-AK (1989). Physical background soil and land use and physical problems. Technical report of the task force on soil and land use survey, Akwa Ibom State. The Government Printer, Uyo.

Udo, E. J., Ibia, T. O, ,Ogunwale, A. J, Ano, A. O and Esu, I. E. (2009). Manual of Soil, Plant and Water Analysis. Lagos, Sibon Book Ltd.

Umoh, F.O., Osodeke, V. E and Akpan, U.S (2018). Assessment of Potassium Leaching Behaviour in Selected Soils of Southeastern Nigeria. *International Journal of Sustainable Agricultural Research* 5 (1): 10-18.

COMPARING THE ACID REDUCTION POTENTIALS OF MORINGA-BASED COMPOST AND CALCIUM OXIDE IN FERRALLITIC SOILS OFUNWANA

*Azu, D. E. O., A. F. Osisi, S. L. Ijearu, L. C. Agim and E. D. Chukwu.[1]*Department of Horticulture and Landscape Technology, Akanu Ibiam Federal Polytechnic, Unwana*
[2, 4 & 5]*Department of Soil Science Technology, Federal University of Technology, Owerri*
[3]*Department of Agricultural Technology, Akanu Ibiam Federal Polytechnic, Unwana*
Corresponding author email:donblessed01@gmail.com

ABSTRACT
Acidification of agricultural soils under intense cropping in Unwana, southeastern Nigeria is of increasing concern. Lime application is the most common strategy for raising soil pH. Several materials can serve as lime. The objective of this study was to compare the potentials of -Moringa-based compost(MBC) and agricultural lime (Calcium oxide) in reducing the acid reaction and soil acidity in the hydromorphic soils of Unwana under a green house condition. Soil samples were collected from the Teaching and Research farm of the Akanu Ibiam Federal Polytechnic, Unwana at the depth of 0-20cm using soil Auger. 5kg of the soils were weighed into 10-liter capacity pots perforated at the bottom in the green house. The treatment comprised of three rates (0, 1 and 2 ton/ha) of MBC and three rates (0, 1 and 2 ton/ha) of commercial lime (Calcium oxide). The treatments were arranged in a Completely Randomized Design (CRD) in a factorial arrangement with three replications. After three months of incubation, soils were sampled from each pot and analyzed for pH at intervals of 2, 4 and 6 weeks. The pH data were subjected to analysis of variance (ANOVA) and the mean separated using LSD. Results showed that relative to control, the two materials significantly reduced the acidity in these soils and the reduction was proportional to the rates of amendments of these materials. At 2 weeks after incubation, lone application of CaO reduced the acidity better than the lone application of MBC. However, the addition of 2ton/ha MBC and 2ton/ha CaO had the highest reduction effect (6.027) on the acidity. At 4 and 6 weeks after incubation, the lone treatment of MBC consistently reduced the acidity better than the lone application of CaO and it is therefore recommended for hydromorphic soils of Unwana.
Keywords: Acidity, Moringa, Calcium oxide, lime and Ferrallitic

Introduction

Agriculturally driven soil acidification is of increasing concern in most regions of Southeastern Nigeria. Unwana soils are dominated with high clay and high concentration of oxides of iron and aluminum which serve as precursor to acidity in soils. Consequently, the soils of Unwana are known to be very acidic, a major constraint to sustainable crop production (Azu *et al*., 2018). Also, the widespread use of ammonium fertilizers, synthetic pesticides in recent times and loss of basic cations through leaching and crop harvest (Onwuka *et al.,* 2007, Eneje and Azu, 2009, Azu *et a.l.,* 2018) have accelerated acidification of most soils in southeastern Nigeria.

According to Osodeke and Ubah (2005), acidity in soils hinders the solubility and availability of phosphorus to plants. In acid soils, most major nutrient basic cations are deficient, while the micro nutrient elements occur at high concentration up to toxic level (Eyasu, 2016; Takashi, et al., 2016). Apart from soil chemical reactions, acidity also affects the biological lives of the soil through the inhibition of their populations and useful activities (Brady and Weil, 2008).

Many Farmers within Unwana are not conversant with the phenomenon of soil acidity and its threat to crop production. Their attention have been on the use of mineral fertilizers especially NPK and urea to promote soil fertility and crop production. However, over the years, there is no measurable direct yield response to this consistent mineral fertilizers application. By this practice, the already acidic soils are acidified more.

Conventionally, acid soils are treated with lime to reduce acidity and promote soil productivity (Caires *et al*., 2015). Commercial limes such as calcium oxide, and calcium carbonates are most preferred in the neutralization of acidity in soils. The high cost of commercial lime, coupled with the ignorance of most Farmers on acidity and liming have limited lime use in Unwana. However, some farmers are unconsciously treating acidity in soils using organic materials especially animal wastes.

Moringa is an important tropical plant that is known mainly for its medicinal values (Brockman, and Brennan, (2017).Apart from its medicinal properties, Azu *et al*., (2020) has reported the soil enriching potentials of moringa leaf compost.Azizi , *et al.,*(2012), Moringa acts as a natural fertilizer, enriching the soil with essential minerals and significantly increases soil pH, organic carbon content, nitrogen, phosphorus, potassium, calcium and magnesium levels.

However, there are no available literatures to support the use of organic materials such as Moringa based compost and mineral limes such as calcium oxide in the remediation of acid soils of Unwana. This study was therefore aimed at bridging the information gap and provides an important index on Moringa-calcium oxide used in the management of soil acidity in Unwana.

Materials and Method

The study was carried out in the Green House, Department of Horticultural and Landscape Technology, Akanu Ibiam Federal Polytechnic Unwana. Unwana is located at the South Eastern ecological zone of the Nigeria and lies at latitudes $05^{0}48^{1}$N and longitude $07^{0}55^{1}$E. The climate and vegetation type are general humid tropical rain forest with mean annual rainfall of about 3,500mm and mean daily temperature range of 32^{0} to 21^{0}. (Njoku, 2006). The soil sample was collected with soil augers at 0-20 cm depth. 5kg of soil was weighed into 10 litres capacity bucket perforated at the bottom.

The Moringa-based compost was formed using Moringa, Cassava peel, carbonated rice husk and Poultry manure which were obtained from Unwana and other places within Ebonyi State. These were placed in a pit of about 60cm deep; with paper as bedding. These materials were placed in layers at the quantity ratio of 50:20:20:5 (Moringa, Poultry manure, Carbonated rice husk, cassava peel) respectively. The pit was slightly covered with top soil. An incubation period of 2 months was allowed to enhance decomposition.

Appropriate weights of Moringa-based compost and Calcium oxide were weighed into each of the buckets. The treatment comprises of three rates (0, 1 and 2t/ha) Moringa-based compost and three rates (0, 1 and 2t/ha) Calcium oxide arranged in Completely Randomized Design (CRD) in factional pattern in three replications. Three months of incubation was allowed after treatments. Adequate moisture was maintained by adding water occasionally at field capacity, while proper aeration was ensure through occasional turning of the buckets.

Soil Samples were collected from each bucket at 2, 4 and 6 weeks after incubation period for pH analysis. Data generated from pH were subjected to analysis of variance

(ANOVA) and the mean separated using LSD.

Results and Discussion

Properties of the Soil and the Moringa based Compost used for the Study

Results showed that the textural class of the soil was a clayey-loam with clay occurring at 43.67% (Table .1). The soil was acidic and relatively low in most essential nutrients. These results corroborated with the findings of earlier researchers on soils of Unwana, (Azu *et al*., 2017; Azu *et al*., Eneje and Azu, 2009).

Table. 1: Some properties of the Soil and the Moringa based Compost used for the Study

Properties	Soil	Moringa-based compost
Sand %	39.98	-
Silt %	16.35	-
Clay %	43.67	-
Texture	Clayey-loam	-
pH (H_2O)	5.14	7.23
pH ($CaCl_2$)	4.08	7.01
Organic carbon (%)	2.55	5. 11
Organic matter (%)	4.42	8.90
Total nitrogen (%)	0.23	1.55
Available phosphorus (mg/kg)	7.53	26.44
Ca^{2+} cmol/kg	3.21	4.66
K^{+} cmol/kg	0.16	3.87
Mg^{2+} cmol/kg	1.94	2.99
Na^{+} cmol/kg	0.01	2.17
TEA cmol/kg	3.04	-
ECEC cmol/kg	8.36	-
BS (%)	63.64	

The organic carbon, organic matter and total nitrogen were moderately high, the available phosphorus was low (7.53 mg/kg). The high clay content with their corresponding high concentrations of Fe^{2+} and Al^{+3}oxides favour P sorption and thus low available P (Osodeke and Ubah, 2005; Azu *et al*., 2017;). Total exchangeable bases were moderately high, with Ca^{2+} occurring more than others (3.21 cmol/ kg). This may be related to high occurrence of limestone in most soils of Ebonyi State (Azu etal., 2018). The exchangeable acidity was high (3.04 cmol/ kg), owing to the high concentration of sexquoxides in the soil. High concentration of sexquoxides has been known to increase soil acidity (Brady and Weil, 2008). The effective cation exchange capacity (ECEC) and base saturation were moderately high (8.36 cmol/ kg and 63.64%), respectively.

Chemical analysis of the Moringa-based compost showed alkalinity in both salt and water (Table 1).This is an indication of its potentials in reducing soil acidity and suitable replacements for commercial lime. Organic carbon and organic matter were higher in Moringa-based compost. Other researchers have also reported high concentration of organic carbon and organic matter in moringa leaf extract (Brockman and Brennan, 2017; Utietiang *et al*, 2013). Except Ca+, other nutrients including nitrogen, available P and the basic cations were higher in Moringa-based compost. Thus high nutrient content in Moringa-based compost if appropriately harnessed can provide nutrients to both soil and growing plants in the nutrient deficient and poor structured soils of Unwana, South-eastern Nigeria.

Effect of Moringa-based compost and calcium oxide on pH at 2 weeks after incubation

The result of the effect of Moringa-based compost (MBC) and CaO on soil pH in water and salt are shown in table 2 and 3. Both lone and combined application of MBC and CaO significantly (P>0.05) influenced the pH. It was observed that at two weeks after incubation, the main effect of CaO (Mean = 4.952**)** was slightly higher than that of MBC (Mean = 4.914). This resulted could be attributed to the fact that organic materials take longer time than mineral inputs to release the calcium content in them (Brady and Weil, 2008). Results also indicated better acid reduction when the MBC and CaO were combined and the increase in the pH were proportional to the rate of treatment application. Adediran *et al.,* (1999) and Ano and Asumugha (2000) had earlier reported better improvement in soil conditions when mineral and organic inputs are combined compared to the application of either of the amendment.

Table 2.Effect of Moringa-based compost and CaO on pH (H_2O) 2 weeks after incubation

	CaO			
Moringa-based compost	**0**	**1**	**2**	**Mean**
0	4.440	5.003	5.413	**4.952**
1	5.000	5.653	5.753	**5.469**
2	5.303	5.863	6.027	**5.731**
Mean	**4.914**	**5.506**	**5.731**	
Lsd 0.05 MBC	0.2266			
Lsd 0.05 CaO	0.2266			
Lsd0.05 MBCxCaO	0.3925			

Table 3. Effect of Moringa-based compost and CaO on pH $CaCl_2$ 2 weeks after incubation

	CaO			
Moringa-based compost	**0**	**1**	**2**	**Mean**
0	3.297	4.053	5.010	**4.120**
1	3.590	4.107	5.013	**4.237**
2	4.020	4.421	5.560	**4.667**
Mean	**3.636**	**4.194**	**5.194**	
Lsd 0.05 MBC	0.2458			
Lsd 0.05 CaO	0.2458			
Lsd0.05 MBCxCaO	0.2458			

Effect of Moringa based compost and CaO on pH (H_2O) 4 weeks after incubation

The main and interactive effects of the MBC and CaO significantly improved the pH and the observed improvements were proportional to the rate of amendment. On like at 2 weeks after incubation, the single application of MBC was consistently superior to the lone application of CaO at 4 weeks after incubation (Tables 4 and 5). Similarly, the interactive effects of the two materials consistently had better improvement on the pH than their lone addition. Even though mineral inputs acts rapidly, but they may also lose their potency quick. Organic materials are known to release their nutrient content slowly, but have the potential of providing long term effects (Ghabbour and Davis, 2001)

Table 4. Effect of Moringa-based compost and CaO on pH (H_2O) 4 weeks after incubation

	CaO			
Moringa-based compost	**0**	**1**	**2**	**Mean**
0	3.215	5.125	6.002	**4.781**
1	5.228	6.684	6.744	**6.219**
2	7.112	6.800	7.081	**6.998**
Mean	**5.185**	**6.203**	**6.609**	
Lsd 0.05 MBC	0.2266			
Lsd 0.05 CaO	0.2266			
Lsd0.05 MBCxCaO	0.3925			

Table 5. Effect of Moringa-based compost and CaO on pH $CaCl_2$ 4 weeks after incubation

Moringa-based compost	**0**	**1**	**CaO 2**	**Mean**
0	3.697	4.998	5.777	**4.824**
1	5.000	5.827	5.928	**5.585**
2	6.820	6.651	6.260	**6.557**
Mean	**5.172**	**5.825**	**5.988**	
Lsd 0.05 MBC	0.2458			
Lsd 0.05 CaO	0.2458			
Lsd0.05 MBCxCaO	0.2458			

Effect of Moringa-based compost and CaO on pH (H_2O) 6 weeks after incubation

Significant effects of MBC and CaO addition of soil pH both in water and salt were observed (Tables 6 and 7). Similar to the observations at 4 weeks after incubation, MBC as a lone consistently increased the pH better than the CaO as lone treatment. However the interactive effects of the two materials were superior to the application of either of them. Organic manure, are known to improve soil basic cations and thus can reduce soil acidity. Azu *et al* (2018) supported by Onwuka *et al* (2007) have reported reduced acidity due to organic manure application.

Effect of poultry Moringa-based compost and CaO on pH (H_2O) 6 weeks after incubation

Moringa-based compost	**0**	**1**	**CaO 2**	**Mean**
0	4.290	5.003	6.413	**5.235**
1	6.213	6.653	6.753	**6.540**
2	7.103	6.863	7.027	**6.998**
Mean	**5.869**	**6.173**	**6.731**	
Lsd 0.05 MBC	0.2266			
Lsd 0.05 CaO	0.2266			
Lsd0.05 MBCxCaO	0.3925			

Effect of poultry Moringa-based compost and CaO on pH $CaCl_2$ 6 weeks after incubation

	CaO			
Moringa-based compost	**0**	**1**	**2**	**Mean**
0	3.647	4.053	6.340	**4.680**
1	6.590	6.407	7.000	**6.666**
2	6.820	6.651	7.011	**6.827**
Mean	**5.686**	**5.704**	**6.784**	
Lsd 0.05 MBC	0.2458			
Lsd 0.05 CaO	0.2458			
Lsd0.05 MBCxCaO	0.2458			

CONCLUSION

Soil acidity has continued to be one the most limiting factor to profitable and sustainable crop production in Unwana, southeastern Nigeria. Addition of MBC and CaO to the highly acidified soils of Unwana improved significantly the pH of these soils. Treatment combination of 2ton/ha MBC and 2ton/ha CaO at 6 weeks of incubation produced the most appreciable decrease in soil acidity and is thus recommended for better growth and yield of crops in Unwana

REFERENCES

Adediran, J.A, Akande, M.O., Taiwo, L. B., and Sobulo (1999). Comparative effectiveness of organic based fertilizer with mineral fertilizers on crop yield In: Management of the soil resources of Nigeria for sustainable Agricultural Production in the 211st century. Proceedings of the 25th Annual Conference of the Soil Science Society of Nigeria (SSSN), Benin City pp91-93

Ano, A.O. and Asumugha G. N. (2000).On-Farm testing of sustaianable soil management technology for cassava production on utisol of Southeastern Nigeria. Paper presented at 34th Annual Conference of Agricultural Society of Nigeria, Bauchi

Azizi, M.J et al.(2012) Moringa oleifera leaf powder: a soild organic nitrogenous resource for sustainable agriculture in developing countries. Agriculture, Ecosystem and Environment, 157,11-16).

Azu Donatus EO, Osodeke VE, Nwanja OU.(2017Effect of algae on phosphorus sorptioncharacteristicsof anultisolof SoutheasternNigeria.Direct Research Journal ofAgricultureandFoodScience.; 5(2):88-95.

Azu, D.E.O., Osodeke, V.E., Ukpong, I.M. & Osisi, A.F. (2018). Chemistry and mineralogy of soils derived from different parent materials in Southeastern Nigeria. Int. J. of Plant and Soil Science, 25(25):1-16.

Azu, Donatus E.O., Nkechi Uche and O.U. Nwanja (2020). Effect of Moringa and Poultry Manure on Soil, Growth and Yield of (*Amaranthus Cruentus*) in Afikpo, Nigeria. Journal of Sustainable Agriculture and Environment. 18(1):169-179

Brady,N.C.andWeil,R.R.(2008).The Nature and Properties of Soils,12thed.ParsonPrentice–HallUpper Saddle River,New Jersey. Pp. 111-112.

Brockman, H.G. and Brennan, R.F. (2017). Effect of foliar application of Moringa leaf extract on biomass, grain yield of Wheat and applied nutrient efficiency. Journal of Plant Nutrition 40(9):2728-2736

Carires, A.F., Haliski, A., Bimi, A.R. and Scharr, D.A. (2015). Surface liming and nitrogen fertilization for crop grain production under no-till management in Brazil. Eur. J. Agron. 66:41-53.

Eneje, R. C. and Azu E. O. (2009). Algae compost effect on soil nutrient status and aggregate stability. Journal of Soil Society of Nigeria.

Eyasu, E. (2016). CASCAPE Project ALTERA Wageningen University and Research Centre (Wageningen UK);The Nertherlands: Soil of the Ethiopian Properties.

Ghabbour, E.R., and Davies, G. (2001). Humic substances, structure and its uptake by plants. Aust. J.Soil Res. 35:227-239.

Njoku, J.C., Okpara. D.A and Asiegbu, J.E. (2006). Growth and yield response of Sweet potato to inorganic Nitrogen and potassium in a tropical ultisol. Nig. Agric. J. 32:30-41.

Onwuka, M.I., Osodeke, V.E. and Okolo, N.A.(2007). Amelioration of soil acidity using cocoa husk ash for maize production in Umudike area of southeastern Nigeria .Tropical and Subtropical Agroecosystem 7:41-45.

Osodeke, V. E. and Uba, A. F. (2005). Determination of Phosphorus Fraction in Selected Soils of Southeastern Nigeria. *International Journal of Natural and Applied Sciences,* **1**(1):10-14.

Takashashi, T., Dahlgren, R.A.(2016). Nature, properties and function of aluminum humus complexes in volcanic soils. Geoderma, 263.

UtietiangL. Undie’ Michael A. Kekong&TomO.

Ojikpong[3](2013) Moringa *(Moringa Oleifera*Lam.)LeavesEffect On SoilPh And Garden Egg (SolanumAethiopicumL.)Yield InTwo NigeriaAgro- Ecologies EuropeanJournalofAgriculture andForestryResearch, Vol No. 1, pp. 17-25

COMBINED EFFECT OF MORINGA LEAVES POWDER AND COMPOUND FERTILIZER ON SOME SOIL CHEMICAL PROPERTIES

G.A. Abubakar[1], Abdulazeez Abdullahi[1], A.I. Gabasawa[2]
[1]Department of Soil Science and Land Resources Management, Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto, Nigeria
[2]Department of Soil Science, Institute for Agricultural Research, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria
Corresponding author email:garba.aliyu@udusok.edu.ng

ABSTRACT
Field experiment was conducted during the 2023 rainy season at the Dryland, Teaching and Research Farm of Usmanu Danfodiyo University, Sokoto State, Nigeria. The study investigates the combined effect of Moringa leaf powder and NPK fertilizer on some selected soil chemical properties in a Randomized Complete Block Design (RCBD); Control, NPK fertilizer, Moringa leaf powder (MLP), and NPK fertilizer+Moringa leaf powder. Soil samples were collected before and after the experiment to determine pH, organic carbon, organic matter, total nitrogen, available phosphorus, calcium, magnesium, potassium, and cation exchange capacity (CEC). The results showed that the combination of NPK+MLP treatment had the highest mean values for most of these parameters, indicating a synergistic effect between these inputs compared to the Control. Highest pH mean value of 6.21 compared to control 6.10, soil organic carbon (SOC) 6.47gkg^{-1} as compared to the control 4.33gkg^{-1}, Total nitrogen(TN) 0.51 gkg^{-1} against control 0.36 gkg^{-1}, available phosphorus 0.58 gkg^{-1} against control 0.42 gkg^{-1} and potassium 0.08 gkg^{-1} compared to control 0.04 gkg^{-1}. These increases were significant ($P \leq 0.05$). Therefore, the combined application of NPK fertilizer and Moringa leaf powder significantly enhanced soil fertility than applying NPK or MLP alone and therefore Moringa leaf powder is recommended for use in amending soils for enhanced soil fertility.
Keywords: Moringa, NPK fertilizer, Total nitrogen, available phosphorous

Introduction
Moringa leaf powder is a nutrient-rich fertilizer that is derived from the leaves of the *Moringa oleifera* tree. This tree is also known as the drumstick tree or the miracle tree because of its numerous beneficial properties. Moringa leaf powder contains essential plant nutrients such as nitrogen, phosphorus, potassium, and calcium, making it a valuable organic fertilizer for plants (Leone *et al.,* 2016). According to (Adebayo *et al.,* 2021) Moringa leaf powder as an organic fertilizer has its ability to improve soil health. Study by (Adekiya *et al.,* 2021) have shown that the powder contains high levels of organic matter, which helps to improve soil structure, texture, and water-holding capacity, it also contains beneficial microorganisms that help to break down organic matter and release nutrients in the soil, making them available for plant uptake Moringa leaf powder has been found to increase plant growth and productivity. Studies by (Ogunlaja *et al.,* 2021) have shown that the nutrients in the powder are readily available for plant uptake, which promotes healthy plant growth, increases crop yields, and improves the quality of fruits and vegetables. Moringa leaf powder is also an environmentally friendly alternative to chemical fertilizers.

Moringa leaf powder and NPK fertilizer play a crucial role in promoting plant growth and supporting soil nutrition. Moringa leaf powder, which is made from the dried leaves of the *Moringa oleifera* tree, is a nutrient-dense powder that is rich in vitamins, minerals, and antioxidants that are crucial for plant growth and development (Asif, 2012). It is commonly used as a soil supplement and organic fertilizer to improve crop yield, boost soil fertility, and enhance plant health. NPK fertilizer, on the other hand, is a chemically produced synthetic fertilizer that contains nitrogen, phosphorus, and potassium as its primary nutrients. These nutrients are crucial for plants' growth and are commonly lacking in soil. NPK fertilizer provides essential nutrients to plants and promotes their growth, increasing crop yields and improving soil fertility (Garden, 2021).

The Sudan savannah soil of Nigeria is characterized by low soil fertility and poor agricultural productivity, which pose challenges for sustainable agriculture and food security. Farmers in this region rely heavily on chemical fertilizers to improve soil fertility and crop yield, which are expensive and have negative environmental consequences. *Moringa oleifera* leaf powder may serve as a promising alternative to chemical fertilizers due to its nutrient-rich composition and ability to improve soil health. Farmers in this region spend a lot of capital resources in purchasing (synthetic) inorganic fertilizer for the growth and development of their crops, which in the long run reduce the profit margin at the end of cultivation season, thereby neglecting the use of local available organic source of fertilizers which is relatively in-expensive, improve soil physical and chemical soil properties and has negative environmental effect. The use of NPK fertilizer has been associated with soil acidity, salinization, and compaction, leading to soil degradation and environmental pollution (Pahalvi *et al.,* 2021). Synthetic NPK fertilizer is relatively expensive and at times not readily available in the market. Moringa leaves powder can serve as a better option than synthetic NPK fertilizer because of its nutritional effect on soil properties. NPK fertilizer, although widely used, supplies only three essential nutrients to the soil; N, P and K. In contrast, Moringa leaf powder contains not only these essential nutrients but also other micro and macro nutrients like calcium, magnesium, iron, zinc, and copper, and can improve soil water retention, increase soil organic matter, and enhance soil fertility, which are all vital for plant growth. Adequate knowledge and proper understanding of the influence of organic fertilizer (Moringa leave powder) on soil and performance of millet will greatly reduce the cost e.g. farm operations and increase or improve the farmer livelihood. The objective of this research is to determine the effect of Moringa leaf powder and NPK fertilizer on some selected soil properties.

Material and Methods

The field experiment was conducted during the 2023 rainy season at Dry land, Teaching and Research farm of Usmanu Danfodiyo University Sokoto State Nigeria. Sokoto State is Located at Latitude $13^{0}1'$ North, Longitude $5^{0}15'$ East, and elevation of 350m above sea level of the Sudan savanna agro-ecological zone characterized by three months of rainfall (NIMET, 2022). The vegetation of the area is semi-arid with average annual rainfall of 655mm, with relative humidity of 48.0 and average temperature of 36°C (NIMET, 2022). Soil samples were collected using soil auger at a depth of 0-30cm using simple random sampling across the area to make a composite sample before and after experiment. The representative soil samples collected were labelled, air dried and store in laboratory for physical and chemical analysis.

Particle size distribution was determined using Bouyoucos hydrometer methods as described by (Gee and Bauder, 1986). The soil textural classes were established using

USDA textural triangle.Soil pH was determined in distilled water, with soil-water ratio of (1:1) using pH meter as described by (Thomas, 1996). Organic carbon was determined using Walkey and Black wet oxidation method as described by Nelson and Sommers, (1975). Total nitrogen was determined using micro Kjehdahl digestion distillation methods as described by (Bremner, and Mulvaney, 1982). Available phosphorus was determined by Bray-P No 1 method as described by (Kuo, 1996). Ca and Mg was determined using atomic absorption spectrophotometer (AAS) while K and Na was determined using flame photometer (Devis and Freitas, 1970).Cation exchange capacity was determined by ammonium acetate saturation method in pH 7 as described by (Chapman, 1965). The treatment consist of NPK Fertilizer (60Kg N, 30 Kg P_2O_5, 30Kg K_2O ha^{-1}), Moringa leaves powder (2.5 $Kgha^{-1}$) alone, combination of NPK Fertilizer (30Kg N, 15Kg P_2O_5, 15Kg K_20 ha^{-1}) and Moringa leaf powder (1.25 $Kgha^{-1}$) and control (where no Fertilizer or Moringa leaf powder). The treatment was laid in the field for 60 days incubation period in a Randomized Complete Block Design (RCBD), replicated three times. For Moringa leaf powder a representative sample of Moringa leaves were collected from a well-mixed batch Moringa Plantation, the samples were dried to a constant weight in a hot air oven at 50-60°C after which the samples were grind into a fine powder using a grinder and sieved through a 0.5 mm mesh to ensure uniform particle size. The mineral analysis were determined as the procedure describe above. The data collected was statistically analyzed using the analysis of variance (ANOVA) and the treatment means were separated using LSD (least significance difference) at 5% level of significance.

Results and Discussion

Physical and Chemical Properties of soil before the experiments

The result of the physical and chemical properties of the soil before the experiment is presented in Table 1. The result shows that, the soil was slightly acidic with a pH value of 6.02, low in organic carbon with a value of 4.0 g/kg, low in organic matter 6.9 g/kg, low in total nitrogen 0.4 g/kg, low in available phosphorus 0.44 g/kg, low in exchangeable calcium 0.5 cmol/kg, medium in exchangeable magnesium 0.57 cmol/kg, low in exchangeable sodium 0.06 cmol/kg, low in exchangeable potassium 0.06 cmol/kg, and low in CEC 2.40 cmol/kg based on the ratings by Esu (1991). The particle size distribution showed that, the soil was dominated by sand separates (92.75%) followed by clay (5.29%) and silt (1.96%), while the textural classification indicated that the soil was sand in nature. This is in agreement with finding reported by Bationo and Mokwunye (2003) that, Entisols and Alfisols predominate most of the soils of Sudano-Sahelian zones of West Africa which are mainly composed of quartz sand, with low water and nutrient holding capacity. Like-wise the values are in agreed with the finding of Sharu *et al*., (2013) during their studies at Dryland teaching and research farm, Usmanu Danfodiyo University Sokoto who, reported the soil were predominantly of colluvial-alluvial origin and low in inherent fertility as evidenced by low organic matter, base saturation and low CEC.

Table 1: Some selected chemical properties of soil and Moringa leaves powder before the experiment

Parameter	Soil	Moringa leaves powder
pH (H_2O) 1:1	6.02	6.4
Organic Carbon (g/kg)	4.00	46.0
Organic Matter (g/kg)	6.89	79.3
Total Nitrogen (g/kg)	0.40	19.0
Available Phosphorus (g/kg)	0.44	5.0
Exchangeable Calcium (cmol/kg)	0.52	19.0
Exchangeable Magnesium (cmol/kg)	0.57	24.0
Exchangeable Sodium (cmol/kg)	0.06	0.25
Exchangeable Potassium (cmol/kg)	0.06	11.0
Cation Exchange Capacity (cmol/kg)	2.40	59.0

Effect of Moringa Leaves Powder and NPK Fertilizer on Soil Physical Properties

The result indicated that application of NPK fertilizer, Moringa leaf powder (MLP) and combination of NPK+MLP are similar with the control in terms of textural classes and statistically not significant (P > 0.05) (Table 2). According to Foth (1990), sand and silt will require considerable weathering for the texture of a soil to be converted to another form and recombined to form or changed the textural class. However application of Moringa leaf powder has slightly reduced the percentage sand and slightly increased the percentage clay and silt before and after the experiment. Adding Moringa leaf powder to sandy soil improved its structure, increasing the water-holding capacity, reducing soil erosion and increased levels of nitrogen, phosphorus, and potassium (Bopape-Mabapa *et al.,* 2021; Abdissa *et al.,* 2024).

Table 2: Effect of Moringa Leaves Powder and NPK Fertilizer on soil textural class before and after the experiment

Treatment	Sand (%)	Clay (%)	Silt (%)	Textural class
Before	93.0	5.00	2.00	Sand
After				
CK	92.0	5.50	2.50	Sand
NPK	91.0	7.50	1.50	Sand
MLP	91.0	6.00	3.00	Sand
NPK+MLP	90.5	5.50	4.50	Sand
	NS	NS	NS	

CK= Control, NPK= NPK fertilizer, MLP= Moringa leaves powder, NPK + MLP= NPK fertilizer + Moringa leaves powder and NS = Not significant at 5% level of significance.

Effect of Moringa Leaves Powder and NPK Fertilizer Application on Soil Chemical Properties

The result on soil pH as influenced by treatment before and after the experiment is presented in Table 3. The result shows that there was an increase in pH at the different treatment compared to the mean value obtained before the experiment. There was a significant difference ($P \leq 0.05$) on the soil pH between the treatments. Combination of NPK+MLP recorded the highest pH mean value of 6.21, followed by NPK and MLP with same mean value of 6.13, CK recorded the least mean value of 6.10. The mean values obtained for CK, NPK, MLP and NPK+MLP are slightly acidic based on the rating by (Esu 1991). The report in this study is in agreement with the finding of Mengistu and Fekadu (2019), who reported that the combined application of NPK fertilizer and Moringa leaf powder resulted in increase in soil pH compared to the individual applications, indicating potential synergistic effects between these treatments.

The result shows an increase in soil organic carbon in the combined treatment, NPK+MLP (6.47g/kg) as compared to the control (4.33g/kg) and also than applying NPK or MLP alone. However, the increase was not significant ($P \geq 0.05$) among the treatments. The values obtained for CK, NPK, MLP and NPK+MLP were low (<10) based on the rating by Esu (1991). The outcome of this study is in agreement with the finding of Nguyen *et al.,* (2018) who reported that the use of NPK fertilizer significantly decreased soil organic carbon (SOC) levels compared to the control (no fertilizer) and Moringa leaf powder treatments.

The result of soil total nitrogen (TN) is presented in Table 3. The result shows that there was increase in total nitrogen at the different treatment compared to the mean value obtained before and after the experiment. It was found that the treatments had significant difference ($P \leq 0.05$) on the soil total nitrogen. Combination of NPK+MLP has the highest value of 0.51g/kg, MLP 0.48g/kg and NPK 0.47g/kg, while control (CK) recorded the least mean value of 0.36g/kg. All the values obtained for CK, NPK, MLP and NPK+MLP were low based on the rating by (Esu, 1991).This result was in line with study Olatunji *et al.,* (2012) who reported that combining NPK and Moringa leaf powder tends to increase soil Nitrogen. This could be due to enhanced release and mineralization of nutrients from added organic amendment due to increase in the C:N ratio as well as synergistic effect of the NPK on organic manure as noted by Adeniyan and Ojeniyi, (2005). Agber and Obi (2012) noted that organic matter (such as leaf and manure addition) contain reasonable amount of N that will raise the productivity of the soil and increase the yield of crops.

The result of soil available phosphorus as influenced by treatment before and after the experiment is presented in Table 3. The result shows that there were increases in available phosphorus at the different treatment compared to the control mean value obtained before the experiment. The increase was significant ($P \leq 0.05$), combination of NPK+MLP gave highest mean value of 0.58g/kg, followed by MLP 0.54g/kg, NPK 0.46g/kg, and CK recorded the least mean value of 0.42g/kg. The values obtained for CK, NPK, MLP and NPK+MLP were low based on the rating by (Esu 1991).This result finding of the research was in line with the study conducted by Rai *et al*. (2019) who reported that the application of NPK+MLP significantly increased the available phosphorus in soil compared to the control treatment.

The result revealed an increase in exchangeable calcium in the MLP treatment, (0.60 cmol/kg) as compared to the control (0.45 cmol/kg) and where applying NPK or NPK+MLP. However, this increase is not significant difference ($P \geq 0.05$) among the treatments on calcium. The value obtained for CR, NPK, MLP and NPK+MLP are low based on the standard rating (Esu 1991).Although calcium is an essential nutrient for plant growth and development, it is not typically limiting in most agricultural soils. This is because calcium is widely available in most agricultural soils and many natural sources, such as limestone and gypsum, which are commonly used to adjust soil pH levels (Singh and Singh, 2019).

The result of soil exchangeable magnesium as influenced by treatment before and after the experiment is presented in table 3. The result shows that there was increase in exchangeable magnesium at the different treatment compared to the mean value obtained before the experiment. It was found out the treatments had significant difference ($P \leq 0.05$) on the soil exchangeable magnesium, thus NPK+MLP had the highest mean value of 0.88 cmol/kg, followed by NKP with mean value of 0.63 cmol/kg and MLP with mean value of 0.68cmol/kg, and CK mean value of 0.65cmol/kg. The values obtained for CK, NPK, MLP and NPK+MLP were medium based on the standard rating (Esu 1991).The result of this research was in line with study conducted by Singh and Singh (2018) who reported that the use of NPK fertilizers and Moringa leaf powder can enhance Magnesium availability and uptake by plants, leading to improved plant health and productivity. However soil exchangeable sodium result showed an increase in exchangeable sodium in the NPK treatment, (0.16 cmol/kg) as compared to the control (0.13 cmol/kg) . However, this increase is not significant ($P \geq 0.05$) among the treatments on soil exchangeable sodium. The value obtained for CK, NPK, MLP and NPK+MLP are medium based on the standard rating (Esu 1991).High sodium levels in soils can temper with the negative impacts on plant productivity and soil health (Kutmanoglu and Yildirimoglu, 2019).

The result showed that there was increase in exchangeable potassium at the different treatment compared to the mean value obtained before the experiment. The increase was significant ($P \leq 0.05$) NPK+MLP had the highest mean value of 0.08 cmol/kg, followed by NPK and CK with mean value of 0.06 cmol/kg, 0.04 cmol/kg, respectively. All the values obtained are low based on the standard rating (Esu 1991). The result in this study was in agreement with the work of Rai *et al.,* (2019) who reported that NPK fertilizers and Moringa leaf powder increase available K in the soil compared to NPK fertilizers alone, indicating a synergistic effect between these sources on soil Potassium availability.

The result of soil exchangeable cation exchange capacity as influenced by treatment before and after the experiment is presented in Table 3. The result shows that there was increase in exchangeable cation exchange capacity at the different treatment compared to the mean value obtained before the experiment. The increase was significant ($P \leq 0.05$) on the soil exchangeable cation exchange capacity, NPK+MLP have the highest mean value of 7.20 cmol/kg, followed by NPK and MLP with mean value of 4.60 cmol/kg and 6.53 and CK 4.07 cmol/kg. The values obtained falls within low to medium fertility class (Esu 1991). Tropical soils as described by Titzpatrick (1980) are characterized by low to medium CEC values because of the abundance of kaolinite clay, which contribute barely to the CEC of the soils. The organic matter of the soil was also low and may have effect on the overall CEC of the soil (Brady and Weil, 2016).

Table 3: Effect of Moringa Leaves Powder and NPK Fertilizer Application on Selected Chemical Properties of soil before and after the experiment. Mean in a column followed by similar letter (s) are not significantly different at 5% level of significance using least significant difference (LSD). * = Significant, NS = Not significant. CK= Control, NPK= NPK fertilizer, MLP= Moringa leaf powder, NPK + MLP= NPK fertilizer + Moringa leaf powder.

Treatment	Soil pH	OC (g/kg)	OM (g/kg)	TN (g/kg)	AP (g/kg)	Ca (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)	K (cmol/kg)	CEC (cmol/kg)
Before	6.02	4.00	6.90	0.40	0.44	0.52	0.57	0.06	0.06	2.40
After										
CK	6.10^{c}	4.33	7.53	0.36^{b}	0.42^{b}	0.45	0.65^{b}	0.13	0.04^{b}	4.07^{b}
NPK	6.13^{b}	4.60	7.67	0.47^{a}	0.46^{ab}	0.48	0.63^{b}	0.16	0.06^{ab}	4.60^{b}
MLP	6.13^{b}	4.67	8.53	0.48^{a}	0.54^{ab}	0.60	0.68^{b}	0.12	0.04^{b}	6.53^{a}
NPK+MLP	6.21^{a}	6.47	11.17	0.51^{a}	0.58^{a}	0.33	0.88^{a}	0.09	0.08^{a}	7.20^{a}
S.E±	0.02	0.54	0.88	0.20	0.03	0.06	0.04	0.01	0.01	0.41
P. Value	0.01	0.54	0.48	0.02	0.01	0.49	0.05	0.26	0.01	0.00
Significance	*	NS	NS	*	*	NS	*	NS	*	*

Conclusion

Combination of MLP+NPK significantly increases soil pH, total nitrogen, available phosphorus, exchangeable magnesium, exchangeable potassium, and cation exchange capacity compared to the control and sole application of NPK fertilizer or moringa leaves powder alone. Farmers should consider incorporating NPK fertilizer and Moringa leaves powder as soil amendments to improve soil fertility.

References

Abdissa, B. A., Dereje, D., Feyisa, A., Gebiyaw, F., & Daba, G. (2024). Application Rates of Moringa (Moringa stenopetala) Leaf Powder Enhanced Maize Growth, Yield Components, and Soil Chemical Properties. *Journal of Agriculture, Food and Natural Resources*, 2(2), 34-42.

Adebayo-Tayo B.C., Oyedeji O (2018). Effect of *Moringa oleifera* on the Physio-Chemical Properties of Soil. *Asian J Agric Rural Dev*, 8(1):18-24.

Adekiya A.O., Agbede T.M., Ojeniyi S.O., Ogunniyi J.E., Dunsin O, Eniola O.O (2021). Soil Nutrient Changes and Growth Response of Maize (*Zea mays* L.) to *Moringaoleifera* Leaf and Stem-Derived Compost as Soil Amendments in Nigeria. *Agronomy,* 11(8):1560. doi: 10.3390/agronomy11081560.

Adeniyan, O.N and Ojeniyi, S.O. (2005). Effect of poultry manure, NPK 15-15-15 and combination of their reduced levels on maize growth and soil chemical propertices. *Nigerian Journal of Soil Science,* 15:34-41.

Agber, P.I and M.E. Obi. (2012). Evaluation of Nutrient Restorative Ability of some Selected Crop and Soil Management Practice in Makurdi, Southern Guinea Savanna, Nigeria.

Asif, M. (2012). *Moringa oleifera*: A review on nutritive importance and its medicinal application. Food Science and Human Wellness, 1(2), 69–79. *https://doi.org/10.1016/j.fshw.2012.06.005*

Bopape-Mabapa, M. P., Ayisi, K. K., Mariga, I. K., & Mashao, F. M. (2021). Moringa (Moringa oleifera) Leaf Nutritional Composition as Influenced by Soil Physical and Chemical Properties and Tree Age under Diverse Agro-Ecological Conditions. *Applied Ecology and Environmental Research,* 19(2), 953-970.

Botiano, A and Mokwunye, A. (2003). Soil fertility management for sustainable land use in the west African Sudano-Sahelian zone. *Academy Science Publishers* (ASP). Pp. 253-292.

Brady, N.C and Weil, R.R. (2016*). The Nature and Properties of soils* (15th ed.). *Soil Science*, P. 1082.

Bray, R. H. and Kurtz L. T. (1945). Determination of total organic matter and available form of phosphorus in soils. *Soil Science*, 591 :39_45.

Bremner, J. M. and Mulvaney, C.S. (1982). Nitrogen-total. In: A.L. page, R.H. Miller, and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2; Chemical and Microbiological Properties. American Society of Agronomy, Inc., Madison, WI, pp. 595-624.

Chapman, H.D. (1965). Cation Exchange Capacity. In: Black, C.A., Ed., Methods of Soil Analysis, *American Society of Agronomy*, Madison, 891-901.

Devis J. and Freitas F. (1970). Physical and Chemical Method of Soil and Water Analysis. *Soil Science Bulletin* No..10 FAO.

Esu, I.E. (1991). Detailed soil survey of NIHORT farm at Bunkure, Kano state, Nigeria. Institute for

Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.
Foth, H.D. (1990). *Fundamentals of Soil Science* (8th Edition). Arcata Graphics Company, USA. 232.
Garden Myths. (2021). Understanding NPK fertilizer numbers. NPK Fertilizer: A Comprehensive Guide. Retrieved from *https://www.gardenmyths.com/understanding-npk-fertilizer-labels/*
Gee, G.W. and Bauder, J.W. (1986). Particle-Size Analysis. In: Klute, A., Ed., Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods, Agronomy Monograph No. 9, 2nd Edition, *American Society of Agronomy/Soil Science Society of America*, Madison, WI, 383-411.
Kuo, S. (1996). Phosphorus. In: Sparks, D.L., Ed., Methods of Soil Analysis: Part 3, SSSA Book Series No. 5, SSSA and ASA, Madison, 869-919.
Kutmanoglu, M., and Yildirimoglu, H. (2019). Effects of different levels of nitrogen, phosphorus, potassium and sodium on growth parameters of lettuce (*Lactuca sativa* L.*). Journal of Plant Nutrition and Soil Science,* 182(3), 447-455. Doi: 10.1007/s11104-018-1364
Nelson D. W. Sommers, L. E. (1975). Total organic carbon and organic matter. In: L. A. Page, R. H. Miller, D R. Keeney, Eds., Methods of Soil Analysis, Part 2. Chemical and Microbiological Methods, American Society of Agronomy, Madison, 1982, pp 539-579.
Nguyen, T. T., Le, H. T., and Pham, H. T. (2018). Effects of organic and inorganic fertilizers on soil organic carbon sequestration under rice-based farming systems in Vietnam's Mekong Delta. *Journal of Soils and Sediments*, 18(7), 1869-1881. Doi: 10.1007/s11368-018-1934-5
NIMET (2022). Rainfall data of Nigeria Metrological Station. Airport, Sokoto.
Ogunlaja O.O., Bamikole M.A., Arowosegbe S. (2021). Performance of Lettuce (*Lactuca sativa)* under Different Rate and Time of Application of *Moringa oleifera* Leaf Powder Fertilizer. *Sci World J.*
Olatunji, O., Ayuba, S. A., Anjembe, B.C and Ojeniyi, S.O. (2012). Effect of NPK and organic manure on cowpea and soil composition. *Nigeria Journal of Soil Science,* 22(1): 108-114.
Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. *Microbiota and Biofertilizers*, Vol 2: Ecofriendly tools for reclamation of degraded soil environs, 1-20.
Sharu, M.B., Yakubu M., Noma S.S., and Tsafe A.I (2013). Characterization and Classification on soil on an agricultural land scape in Dingyadi District, Sokoto State, Nigeria. *Nigerian Journal of Basic and Applied Science*. 21(29) 137-147.
Singh, S., & Singh, R. (2019). Role of Calcium in Plant Growth and Development: A Review. *Journal of Agricultural Science and Technology*, 14(2), 237-246. Doi: 10.553
Singh, S.K and Singh R. P (2018) *Moringa oleifera* Lam.: A Review on its Nutritional Profile and Health Promoting Properties with Special Emphasis on its Antioxidant Activity and Anti-inflammatory Potential: A Mini Review. *Journal of Food Science and Technology Research*, 5(4), 57-69. Doi: 10.3644
Solanki, S., Sharma, S., Singh, B., and Singh, R. (2018). Effect of Moringa leaf powder and NPK on growth and yield of soybean. *International*

Journal of Chemical Studies, 6(3), 2836-2840.

Thomas, G.W. (1996). Soil pH and Soil Acidity. In: Sparks, D.L., Ed., Methods of Soil Analysis: Part 3—Chemical Methods, Book Series No. 5, SSSA and ASA, Madison, WI, 475-489.

THE EFFECTS OF TILLAGE, CROP ROTATION AND NITROGEN FERTILIZATION ON SELECTED SOIL PHYSICAL PROPERTIES

N.I. Usman[1], A. A Yusuf[2] and A. Abdulkadir[2]

[1] Department of Crop Production Technology, College of Agriculture, Science and Technology Lafia, P.M.B 33, Lafia, Nasarawa State, Nigeria.

[2] Soil Science Department, Faculty of Agriculture / Institute for Agricultural Research, Ahmadu Bello University, P.M.B. 1044, Zaria, Kaduna state, Nigeria.

Corresponding author email:nasiriusman@yahoo.com

ABSTRACT

The study was carried out in the year 2017 to determine the effects of tillage, crop rotation, and N fertilization on soil physical properties, moisture content, bulk density, and hydraulic conductivity. The treatments of the experiments on crop rotation are maize grown in rotation with maize, maize in rotation with soybean and maize in rotation with cowpea, under conventional and reduced tillage, with N fertilization of 0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1}. The trial was arranged in a split plot design, replicated three times. The results showed that tillage had a significant effect on all the soil physical properties across the three soil depths, while the effects of crop rotation and N fertilization were not significant. The soil hydraulic conductivity was increased by conventional tillage, but was reduced by reduced tillage. The conventional tillage had the highest content of sand, and silt, while the reduced tillage had the highest clay, and soil moisture contents and soil bulk density. To improve the soil physical property of soils in the northern Guinea savanna of Nigeria over a long period of time, farmers are recommended to practice reduced tillage (conservation) to improve the soil structure and enhance crop productivity.

Keywords: *Soil Physical Properties, Tillage, Crop rotation and Nitrogen fertilization*

INTRODUCTION

Long-term field experiments are expected to provide important information regarding soil properties as affected by cropping system and soil management practices. Legumes such as cowpea and soybean add both organic matter and nitrogen (N) to the soil (Sainju *et al*., 2003) and increase soil fertility. Studies have shown that legume-cereal rotation produce relatively higher grain yields than either crop grown alone (Dapaah *et al*., 2003). Long-term field experiments with N fertilization can give valuable information about how those changes occur and indicate the trends of the changes (Dragan *et al.,* 2010).

Nitrogen (N) is most often the yield limiting nutrient with respect to crop production (Factsheet, 2014). Nitrogen contributes firstly to grain yield and forage biomass production, and at the same time to protein content of the yield (Eche, 2011). Therefore proper management of soil in terms of method of tillage practice and cropping system is very important in determining the amount of N in the soil (Veenstra *et al*., 2006).

Tillage is any physical, chemical or biological soil manipulation to optimize conditions for germination, seedling establishment and crop growth. Tillage helps in loosening and aerating the top layer of the soil, in destroying weed mechanically and in mixing crop residue, organic matter (humus), and nutrients evenly into the soil (Ray, 2013).

In Africa, three quarter of farmland is severely degraded due to poor soil quality. Agricultural production in Nigeria is mainly constrained by low levels of soil organic matter, low nutrient status and water holding capacity. Due to the fragile nature of the soils, they degrade rapidly under continuous and intensive cultivation (Abu and Abubakar 2013).

Crop rotation with grain legumes helps to improve soil fertility, through biological nitrogen fixation while tillage helps in soil aeration and soil aggregation thereby improving the soil physical properties (soil structure). Tillage practices also affect soil organic matter in surface soils. Studies have also shown the effects of different tillage management systems on soil quality under different climatic conditions and fertilization (Melero *et al*., 2009). However, information on changes produced by the interaction of tillage system, crop rotation, rate of N fertilization soil soil physical property over a long time is very scarce. Therefore in an effort to reduce land degradation and soil nutrient depletion problems in the northern Guinea savanna of Nigeria, the contributions of crop rotation, tillage and N fertilization on soil physical properties were investigated. The main objective of this research was to determine the effect of long term rotation, nitrogen fertilizer and tillage on some selected soil physical properties in the northern Guinea savanna of Nigeria.

MATERIALS AND METHODS

Experimental Site

A long-term field experiment begun in 2002 at the Institute for Agricultural Research, (I.A.R) farm in Samaru, to evaluate the effect of long term N fertilization on crop rotation, the site was later modified to accommodate tillage as an additional experimental factor in 2009. Now the experimental field has N fertilization, crop rotation and tillage practices.

The study was carried out at the Institute for Agricultural Research (IAR) farm in Samaru, with coordinates 11° 09, 943N', 007° 37. 956E' and 686 m above the sea level in the northern Guinea savanna (NGS) of Nigeria. The soil type is an Alfisol derived from Pre-Cambrian Crystalline basement complex rocks with some quaternary Aeolian deposits. The main sub-group is Typic Haplustalf (Usman, 2017). The experimental field was relatively flat with a mono modal rainfall pattern and a mean annual rainfall of 1011 ± 161 mm concentrated almost entirely from May to October. Samaru has minimum and maximum temperatures of 21°C and 33.5 °C, with a mean daily temperature of 24 °C and relative humidity of 55.23 %. This study was carried out in the wet season of 2013.

Treatment and Experimental Design

The treatments were factorial combination of three crop rotations (Maize - Maize, Maize – Cowpea and Maize – Soybean), two tillage practices Conventional (plots were manually ridged and remoulded) and Reduced (plots were not ridged and remoulded) and four N levels (0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1}), arranged in split plot design replicated three times. The main plot consisted of combinations of crop rotation and tillage, while the sub-plot consisted of N rate. Maize was sown on all the plots during this experiment.

Soil Sampling

Soil samples were collected from plots that received 0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1} and 90 kg N ha^{-1} during this experiment. Disturbed soil samples (using an auger) and undisturbed soil samples (using a core sampler) was collected at three depths; 0 – 5 cm, 5 – 15 cm and 15 – 25 cm before sowing and after harvesting and then composited for further analysis (Usman, 2017).

Measurement of soil physical properties

a. Soil particle size determination

Bouyocous hydrometer method was used to determine soil particle size (Agbenin, 1995 and Girei, 2015). Saturated hydraulic conductivity (Ks) was determined using the constant head permeameter method as described by Dipak and Abhijit. (2005). Bulk density was determined by the core method as described by Blake and Hartge. (1986).

Statistical Analyses

The data obtained was analyzed using the standard ANOVA procedures for a Split plot design. Analysis of variance was performed using the General Linear Model Proc. of SAS version 9.4 (SAS, 2013). Treatment means were compared using Duncan's Multiple Range Test at 5% level of significance ($p < 0.05$).

RESULT AND DISCUSSION

Particle size distribution

The effects of crop rotation, tillage and N rates on particle size distribution (PSD) are shown in Table 1.1. Crop rotation had no significant (*P>0.05*) effect on PSD. However, there was a significant difference (*P<0.05*) in PSD between tillage practices. The conventional tillage had more sand and silt separates and less clay than the reduced tillage. This result conforms to the work of Lawal (2015) who reported that silt plus clay associated carbon was significantly higher by 9.82 % in conventional tillage plots than in reduced or no till system. The result also shows that there was no significant difference (*P>0.05*) in N rates of clay, silt and sand particles. There was also no significant interaction (*P>0.05*) between tillage type and N rate in terms of the particle size distribution. This indicates that N rate had no contribution to PSD

.

Table 1.1: Effect of tillage and N rate on soil particle size distribution at 0 – 5 cm depth

Treatment	Particle Size Distribution		
	Clay (%)	Silt (%)	Sand (g/kg)
Rotation			
Maize	2.91	15.48	65.25
Cowpea	3.39	16.42	66.14
Soybean	3.15	16.08	66.10
SE±	0.16	0.36	5.13
Tillage			
Reduced	5.22^a	18.11^b	76.11^b
Conventional	4.44^b	19.67^a	77.11^a
SE±	0.19	0.38	0.34
Nitrogen rate (kg Nha^{-1})			
0	5.13	19.00	7.61
30	5.15	18.79	7.63
60	5.11	18.81	7.62
90	5.00	18.78	7.61
SE±	0.19	0.38	0.03
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

Saturated hydraulic conductivity (Ks)

The Ks was not significantly (*P>0.05*) influenced by crop rotation or nitrogen rate in all the three soil depths (0 – 5 cm, 5 – 15 cm, 15 – 25 cm), but it was significantly (*P>0.05*) affected by tillage practices

(Table 1.2). The highest mean Ks was observed under conventional tillage across all the three soil depths and the reduced tillage had the lowest Ks across all the three soil depths. The interaction was not significant (*P>0.05*) at any of the studied soil depths. Saturated hydraulic conductivity was found to be significantly influenced by tillage with higher soil water conductivity under conventional tillage than under reduced tillage. This is because conventional tillage helps to improve water conductivity (Ahn and Hintze, 1990); also the presence of roots and plant materials after harvesting of the maize crop could also affect the Ks value (Girei, 2015), hence its influence on the conventional tillage practices.

Table 1.2: Long term effect of crop rotation, tillage and nitrogen rate on saturated hydraulic conductivity Ks (cm hr^{-1})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	0.37	0.37	0.48
Cowpea	0.38	0.36	0.48
Soybean	0.37	0.40	0.44
SE±	0.02	0.03	0.02
Tillage			
Reduced	0.33^{b}	0.32^{b}	0.37^{b}
Conventional	0.43^{a}	0.43^{a}	0.56^{a}
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	0.37	0.36	0.45
30	0.37	0.38	0.45
60	0.38	0.38	0.47
90	0.37	0.38	0.47
SE±	0.02	0.02	0.09
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at *P<0.05* level of probability. NS = Not Significant.

Bulk density

The effects of crop rotation, tillage and nitrogen rates on maize bulk density are shown in Table 1.3. Crop rotation and N rate had no statistical difference on soil bulk density. However, tillage influenced soil bulk density, with the reduced tillage giving higher means at all soil depths than the conventional tillage. The Interactions between the various factors were not significant in all the soil depths.

Bulk density is influenced by vegetation and aggregation; high bulk density is an indication of low soil porosity and high compaction which may cause restriction of root growth and poor movement of air and water through the soil. In this study, high bulk density values were observed at the soil depth of 15 – 25 cm and lower bulk density values were obtained at 0 – 5 cm and 5 – 15 cm soil depths. Reduced tillage was found to give higher BD values than conventional tillage due to compaction and aggregation of the soil particles. This result corroborates with the findings of Dhiman *et al*. (2001) who reported an increase in bulk density of a soil from 1.5 Mg m^{-3} in conventional to 1.58 Mg m^{-3} in no-tillage plots. This indicates that bulk density is influenced by tillage activities.

Table 1.3: Long term effect of crop rotation, tillage and nitrogen rate on bulk density (Mgm^{-3})

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	1.43	1.43	1.50
Cowpea	1.48	1.48	1.52
Soybean	1.46	1.46	1.51
SE±	0.02	0.02	0.02
Tillage			
Reduced	1.83[a]	1.83[a]	1.90[a]
Conventional	1.53[b]	1.54[b]	1.66[b]
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	1.48	1.47	1.51
30	1.48	1.47	1.51
60	1.48	1.48	1.51
90	1.43	1.43	1.51
SE±	0.02	0.02	0.02
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P<0.05$ level of probability. NS = Not Significant.

Moisture content

Moisture content (MC) at field capacity was not statistically affected ($P>0.05$) by crop rotation or nitrogen rate across all soil depths, but it was statistically ($P<0.05$) affected by tillage practices in all the soil depths (Table 1.4), with the reduced tillage having the higher moisture content than conventional tillage at all the soil depths. The Interactions between factors were not significant ($P>0.05$) in all the soil depths. The presence of plant residue left on the soil surface under reduced tillage will favor more water retention in the soil than the conventional tillage. This agrees with the findings of Melero *et al.* (2009) that conservation or reduced tillage are based on the principle of mulch farming and they usually conserve soil and water simultaneously by controlling runoff.

Table 1.4: Long term effect of crop rotation, tillage and nitrogen rate on moisture content (cm^3/cm^3) at field capacity

Treatment	Depth (cm)		
	0 – 5	5 – 15	15 – 25
Rotation			
Maize	0.15	0.15	0.18
Cowpea	0.18	0.19	0.17
Soybean	0.15	0.17	0.17
SE±	0.02	0.02	0.02
Tillage			
Reduced	0.23^a	0.24^a	0.23^a
Conventional	0.10^b	0.10^b	0.12^b
SE±	0.02	0.02	0.02
Nitrogen rate (kg N ha^{-1})			
0	0.16	0.17	0.19
90	0.17	0.17	0.16
SE±	0.02	0.02	0.02
Interaction			
Tillage*Rotation	NS	NS	NS
Tillage*N rate	NS	NS	NS
Rotation*N rate	NS	NS	NS
Tillage*Rotation*N rate	NS	NS	NS

Means in the same column and under the same factor, followed by different letters are significantly different at $P<0.05$ level of probability. NS = Not Significant.

Conclusion

The study showed that reduced tillage improved the soil physical properties for adequate air and water circulation in the soil that will enhance root growth and development with consequent overall growth and development and optimal yield and sustainable of crops.

References

Abu, S. T. and Abubakar, I. U. (2013). Evaluating the effects of tillage techniques on soil hydro-physical properties in Guinea Savanna of Nigeria. *Soil and Tillage Research.* **126:** 159–168.

Agbenin, J. O. (1995). *Laboratory Manual for Soil and Plant Analysis,* Department of Soil Science, Faculty of Agriculture / Institute for Agricultural Research, Ahmadu Bello University, Zaria. Pp. 1-80.

Ahn, P. M. and Hintze, B. (1990). No tillage, minimum tillage and their influence on soil properties. In; organic matter management and tillage in Humid and sub-humid Africa. IBSRAM proceedings No. 10. Bangkok: Pp. 341-349.

Dapaah, H. K., Asafu-Agyei, J. N., Ennin, S. A. and Yamoah, C. (2003). Yield stability of cassava, maize, soya bean and cowpea intercrops. *Journal of Agricultural Science.* **140**: 73-82.

Dhiman, S. D., Om, H. M. and Kumar, H. (2001). Advantages and limitation of no tillage in wheat. *Indian Framing*, **51**(6): 8 - 10.

Dipak, S. and Abhijit, H. (2005). Physical and chemical methods in soil analysis; New Age International Publisher. Pp. 27–30.

Dragan, C., Elmira, S., Veljko, P., Darko, J. and Vesna M. (2010). Effect of Long-Term Nitrogen Fertilization on Main Soil Chemical Properties in CambisolInstitute of Soil Science, Teodora Drajzera 7, 11000 Belgrade, Serbia. Pp. 1-6.

Duncan, D. B. (1955). Multiple Ranges and Multiple ,*"F" Test, Biometrics*. Vol **11**: 1- 42.

Eche, N. M. (2011). Soil Properties affecting maize yield decline under long-term application of organic and inorganic fertilizers. Ph.D Thesis. Ahmadu Bello University, Zaria, Nigeria. Pp. 1-99.

Factsheet (2014). Nitrogen fertilization in crop production, Crops and Irrigation. Agriculture. Government of Saskatchewan, Ministry of Agriculture. Pp. 1-8.

Girei, H. A. (2015). Hydraulic characteristics and temporal variability of soil properties under a long term trial in Samaru, Northern Guinea Savanna of Nigeria. M.Sc Thesis, Ahmadu Bello University, Zaria, Nigeria. Pp. 21-76.

Lawal, H. F. M. (2015). Tillage and cover crop effects on soil quality and maize growth at Samaru, northern Nigeria. Ph.D thesis, Ahmadu Bello University Zaria. Pp 1-150.

Melero, S., Lo´ pez-Garrido, R., Madejo´ n, E., Murillo, J. M., Vanderlinden, K., Ordo´n˜ez, R. and Moreno, F. (2009). Long-term effects of conservation tillage on organic fractions in two soils in southwest of Spain. *Agriculture, Ecosystem and the Environment.* **133:** 68–74.

Ray, H. (2013). Soils in Agriculture. University of Washington. Retrieved 2013-08-28.

Sainju, U. M., Whitehead, W. F. and Singh, B. P., (2003). Agricultural management practices to sustain crop yields and improve soil and environmental qualities. *Science World Journal.* **3:** 768–789.

SAS Institute. (2013). *SAS system for mixed models*. Version 9.4 by The SAS Institute, Cary, NC.

Usman, Nasir. Ibrahim. (2017). *Effect of long term rotation, nitrogen fertilizer and tillage on soil quality and maize yield in the Northern guinea Savanna of Nigeria*. Published M.Sc Thesis, Soil Science Department, Ahmadu Bello Univerity Zaria.. https://kubanni.abu.edu.ng/items/c9eabdda-8da7-4635-ad62-91ab58a1988a

Veenstra J. J., Horthwith, W. R.., Mitchell, J. P. and Munk, D. S. (2006). Conservation tillage and cover cropping influence on soil properties in San Joanquin Valley cotton-tomato crop. http//californisagriculture.ucop.edu. Accessed in June, 2014.

EFFECTS OF SOIL AMENDMENTS AND IRRIGATION ON SOIL PROPERTIES AND PERFORMANCE OF IRISH POTATO IN KURU, JOS, PLATEAU STATE

[1]Daboro, P.C., [2]Ali, A., [2]Agbe, P. and [3]Kuberi, J.
[1]Plateau State College of Agriculture Garkawa, Dept. of Agric Technology.
[2]Federal University of Agriculture, Dept. of Soil Science, Makurdi,
[3]Government Science Secondary School, Kuru
Corresponding author email:pdaboro1234@gmail.com

ABSTRACT
This study investigated the effects of soil amendments and irrigation on soil properties and performance of Irish potato in Kuru, Jos, Plateau State during the 2017 and 2018 dry season. Five soil amendments were the control, goat dung (5 t/ha), cow dung (5 t/ha), poultry manure (5 t/ha) and NPK 15:15:15(400 kg/ha) and three irrigation frequency (3, 6 and 9 days). The experimental treatments were arranged in a randomized complete Block design (RCBD) and replicated three times. Poultry manure, cow dung and goat dung were applied two weeks before planting. Soil samples were collected from the depth of 0—20cm and 20—40cm from each of the plots and analyzed in the laboratory for physical and chemical properties. Crop data collected were number of leaves, leaf area, number of branches, plant height, number of tubers, number of seeds, diameter of tuber and weight of tubers. Analysis of variance was used to analyze data generated from the experimental fields at the depth of 0-20cm. Soil pH was strongly acidic (pH 5.0) and organic carbon was very low (0.00331g/kg) and clay loam. Poultry manure and 3 days irrigation interval had significant ($p<0.05$) effect on the soil properties growth and yield of Irish potato for both early and late planting seasons. Poultry manure amendment gave significantly higher leaf area and number of branches compared to the control for both early and late planting seasons. Irrigation intervals significantly affected leaf area with 6 days giving the highest ($51cm^2$). Poultry manure significantly gave higher number of leaves, plant height and compared to other amendments for both seasons. On yield it showed that NPK and poultry manure at 3 days irrigation interval had higher yield (46kg) of Irish potato. It is therefore recommended that 5 t/ha of poultry manure be used for Irish potato in the area with 3 days irrigation interval.

Keywords: Soil Amendment, Irrigation and Potato

1.0 INTRODUCTION
Irish potato (*solanum tuberosum L*) is said to have originated from the highlands of Bolivia in South America (Ifenkwe and Nwakocha, 1987). The spread of the crop outside its center of origin was mainly by deliberate introduction. The introduction of the crop spread from South America to Spain in 1579 and then to England in 1585, and Ireland by Spanish explorers in 1963. It was grown on a large scale in Ireland and became so popular that it is not surprising that it acquired the name of Irish potato. Potato production was first

introduced into Nigeria in the later part of the 19th century and early 20th century by the Europeans (Ifenkwe, 1981).

Irish potatoes are exceeding rich in vitamin B needing for the renewal of cell and maintenance of a healthy nervous system and a balanced mood. It also important to note that skin of the potatoes contains a great amount of vitamins and minerals. Potato contains iron, phosphorus, calcium, magnesium and zinc which helps the body to build and maintain bone structure and strength (Karphuin & Keita 2020). The carbohydrates present in Irish potatoes help in quick and easy digestion. This makes the crop a good choice for babies and patients who face difficulty in digesting foods (Karphuin & Keita 2020).

Fertilization provides necessary nutrients elements required for plant growth and are therefore regarded as important factors required to improve plant growth and production of potato plants (Westerman, 2005). Addition of animal manure (the remnants of sheep, cattle and poultry) at the rate of 20% of the soil weight to the potato plant led to a significant increase in plant (Al-kafagy, 2009). Potato plants are sensitive to the alteration in the soil moisture content and any decline or un-uniformity in irrigation (water stress), especially during initiation and growth phases of tubers result in a significant damage to plants and decrease to quantity and quality of tuber yield (Boa-Zhong *et al.*, 2003; Al-Aubiady, 2005). Plants are sensitive to water stress and that soil moisture is one of the important factors affecting the quality of tuber yield. They found that plant height, total water content of the leaves number of tubers, average weight and total tuber yield increase with increasing the amount of irrigation water, while the specific weight of tuber drops (Bao-Zhong *et al.*, 2003). Wang *et al.* (2006) use six irrigation frequencies in potato which irrigate one time every 1, 2, 3, 4, 6 and 8days with uniform water amount per treatment and noted that the greater the frequency of irrigation the greater the length and density of roots and stimulate growth with increase water efficiency.

Therefore, this study was designed to evaluate the effects of soil amendments (cow dung, goat dung, poultry manure and inorganic NPK 15:15:15 compound fertilizer) and irrigation intervals on soil physical and chemical properties and performance of early and late planted Irish potato in Kuru, Jos Plateau State Nigeria.

MATERIALS AND METHODS

3.1Description of the Study Site

The study was carried out at the National Root Crops Research Institute, Kuru in Jos South Local Government Area of Plateau State. Kuru is geographically located between Longitude 9° 44'E and Latitude 8° 47'N. The soil is predominantly sandy loam. The mean annual rainfall of the area ranges between 1105-1273.04 mm starting from April to September; reaching its peak between July/August of each year. The wet season start from April and last till October and the dry season from November to March, two principal air masses influence the climate of the area (Aniedu, 2015). The south west maritime wind which originate from the Atlantic Ocean blows across Jos

Plateau between April and October and is associated with the wet season, while the dry season is brought about by the north easterly wind from Sahara desert, locally called the Harmatan. The mean monthly maximum temperature is highest (24.5ºC) in March prior to the onset of rains, and lowest (19.4ºC) during the period of heavy rain fall in July and August (Aniedu, 2015). The relative humidity of the area is dependent on the seasons; it ranges from 40-62% being lowest during the dry season months of December to February and highest during the rainy season months of June to September.

The treatments consisted of five levels of soil amendments; poultry manure 5 t/ha, goat manure (droppings/pellets) 5 t/ha, cow manure at 5 t/ha NPK 15:15:15 400 kg/ha and control with three levels of irrigation frequency; 3 days, 6 days and 9 days. The factors were combined to give a total of fifteen treatments and laid out in a randomized complete block design (RCBD) with three replications. Soil samples were collected from the site before planting. These samples were collected at soil depths of 0-20, 20-40 cm respectively. Soil samples were collected in each plot after harvest based on the treatments. Crop data collected were plant height, number of leaves, leaf area, number of branches, at 3 weeks intervals i.e. 3, 6 and 9 weeks after planting while number of tubers and weight of tubers were collected during harvest. The plant height was recorded by taking measurement of tagged plants from the ground level to the upper leaf using meter rule then number of leaves was by counting the leaves on the potato plants.

Results and Discussion

Effects of soil amendment and irrigation frequency on plant height and number of leaves

The effect of soil amendment and irrigation frequency on number of leaves and plant heights are presented in Table 2. The results of the effects of soil amendments on plant height was significant ($p<0.05$) at early and late planting opportunity with poultry manure having the highest number of leaves 10.40, 39.58 and 30.89 at 3, 6 and 9 WAP respectively. Late planting opportunity 2018 followed the same pattern with poultry manure having the highest number of leaves (9.43, 27.78 and 31.66) at 3, 6 and 9 WAP. The shortest plant heights were obtained from the control plots where no amendment was applied during the early and late planting seasons while the tallest plant heights were obtained in plots amended with poultry manure which is in agree with the report of Errebbi *et al.* (1998) that says, organic nitrogen obtained from poultry manure plays an important role in the balance between vegetative and reproductive growth of potato and final stem count. This is also in agreement with the finding of Leyterm and Westerman (2006) who reported that potato is highly responsive to N fertilizers.

Results also showed that soil amendments significantly ($p<0.05$) affected number of leaves at both early and late planting in 2017 and 2018 dry seasons farming. Poultry manure produced more number of leaves, 14, 36 and 37 at 3, 6 and 9 WAP respectively while the control had the least (9, 16 and 18) for the early planting. Amendments had a significant ($p<0.05$)

effect on number of leaves during the late planting opportunity with poultry manure having the highest number (14, 40, 42) at 3, 6 and 9 WAP respectively. This is also in agreement with report of Eliot (2005) who report that chicken manure has long been recognized as the most desirable of natural fertilizer because of its high organic nitrogen content.

Effects of irrigation frequency on number of leaves was significant ($p<0.05$) during the early and late planting opportunities in 2017 and 2018 planting season. During the early planting opportunity the 3 days irrigation frequency gave the highest number of leaves (13, 28 and 37) at 3, 6 and 9 WAP while the 9 days irrigation frequency had the lowest (9, 18 and 22 within the same period. While during the late planting opportunity the 3 days irrigation frequency significant ($p<0.05$) affected the number of leaves with the following values 11.95, 31.40 and 32.40 while 9 days irrigation frequency had the lowest (9.60, 25.90 and 26.10). The effect of irrigation on plant height indicated that irrigation had significant ($p<0.05$) effect on plant height at the early and late planting opportunities in 2017 and 2018 planting seasons. At the early planting, results showed that 3 days irrigation frequencies produce higher plant height (11.64 cm, 23.83 cm and 23.66 cm) at 3, 6 and 9 WAP respectively. While 9 days irrigation frequency produced the least (6.21 cm, 16.97 cm and 20.30 cm) within the same period. The results of the effect of late planting showed that irrigation had significant ($p<0.05$) effect on plant height with the 3 days irrigation frequency producing higher plant height (9.41 cm, 22.53 cm and 28.15 cm) at 3, 6 and 9 WAP while the 9 days irrigation frequency gave the least plant height (5.18 cm, 14.45 cm and 20.88 cm) at 3, 6 and 9 WAP. This is in agreement with the finding of Dowgert (2010), who observed that there is an increase in productivity of plant as a result of irrigation frequencies.

Table 2: Main Effect of Soil Amendments and Irrigation Frequency on Number of Leaves and Plant Height of Irish Potato

	Number of Leaves						**Plant Height (cm)**					
	Early			**Late**			**Early**			**Late**		
Amendment	**3**	**6**	**9**	**3**	**6**	**9**	**3**	**6**	**9**	**3**	**6**	**9**
	← (WAP) →			← (WAP) →			← (WAP) →			← (WAP) →		
Control	8.78	[illegible]	17.80	9.69	[illegible]	23.10	6.46	[illegible]	19.28	5.82	[illegible]	13.93
Cow dung	10.44	19.13	118.90	10.24	24.00	24.40	9.83	16.62	22.27	6.13	13.27	17.23
Goat dung	12.22	22.31	22.20	12.24	33.00	31.50	9.11	24.70	27.43	7.83	19.22	22.76
P/manure	13.78	35.51	37.40	13.68	40.40	42.40	10.40	31.58	30.89	9.43	27.78	31.66
NPK 15 : 15:15	10.00	25.78	47.70	10.34	30.60	27.90	7.10	20.78	21.48	7.0	18.78	35.69
LSD(P ≤ 0.05)	1.88	6.26	9.23	2.31	7.17	6.76	1.46	1.89	5.91	1.19	3.12	5.17
Irrigation Frequencies												
3	12.73	27.93	37.10	11.95	31.40	32.90	11.64	23.87	27.66	9.41	22.53	28.15
6	10.93	24.28	27.80	12.16	33.00	30.50	7.89	23.36	24.85	6.89	18.21	23.73
9	9.47	18.19	21.50	9.60	25.90	26.10	6.21	16.97	20.30	5.18	14.45	20.88
LSD(P ≤ 0.05)	1.46	4.85	7.27	1.79	5.54	5.23	1.15	1.47	4.62	0.93	2.42	4.00

LSD = Least Significant Difference

Effect of Soil Amendments and Irrigation Frequency on the Growth of Potato

The main effects of amendment on leaf area and number of branches are presented in Table 1. Results showed that amendments significantly ($p<0.05$) affected leaf area at both the early and late planting season in 2017 and 2018. Poultry manure gave the largest leaf areas of 39.90 cm, 60.40 cm and 61.30 cm at 3, 6 and 9 WAP respectively during early planting season, while the leaf area was not significantly different from the control 20.02 cm, 27.90 cm and 37.20 cm at 3, 6 and 9 WAP, respectively.

The results on number of branches as presented in Table 1 showed that there was significant ($p<0.05$) effect of amendment on number of branches during the early planting opportunity at 6, and 9 WAP with poultry manure having the largest leaf area of 2.11 cm, 3.44 cm and 4.78 cm at 3, 6 and 9 WAP respectively while during the late planting there was no significant effect of amendment on number of branches. The highest number of branches at 6 WAP and 9 WAP were obtained in plots amended with poultry manure. This is in agreement with the findings of Wang *et al.,* (2006) who reported that application of poultry manure was found to improved structural stability and lowered bulk density of the soil, improves moisture retention, water infiltration rate and hydraulic conductivity properties and soil fertility which lead to increase in crop yield. Vegetative growth such as plant height and number of leaves increases due to higher organic nitrogen in poultry manure (El-Sawy et al, 2012). Therefore, poultry manure is beneficial to soil biological properties and tuber yield of potato (Rees et al 2013.

The effect of irrigation frequency on leaf area was significant ($p<0.05$) at 3, and 6 WAP during the early planting season with 3 day irrigation frequency having the largest leaf area of 29.54 cm^2, 40.10 cm and 51.40 cm are at 3, 6 and 9 WAP respectively while 9 day irrigation frequency had the lowest leaf area (21.68 cm, 34.10 cm and 42.80 cm). Results also showed that the irrigation frequency significantly ($p<0.05$) affected leaf area during the late planting season with 3 days irrigation frequency having the largest leaf area of 31.11 cm, 36.50 cm and 47.40 cm at 3, 6 and 9 WAP while the least was obtained at 9 days irrigating frequency, (24.08 cm, 26.70 cm and 37.80 cm). Irrigation had no significant effects on the number of branches during the early and late planting opportunities. This is in agreement with the findings of Wang *et al.* (2006) who noted that change in the frequency of irrigation can affect the growth of potato and as well its yield. Also, irrigation frequencies can modify plant physiological processes, growth, yield and water use efficiency.

Table 1: Main Effect of Soil Amendments and Irrigation Frequency on Leaf Area and Number of Branches of Irish Potato

	Leaf Area (cm²)						Number of Branches					
	Early			Late			Early			Late		
Amendment	3	6 (WAP)	9	3	6 (WAP)	9	3	6 (WAP)	9	3	6 (WAP)	9
Control	20.02	27.90	37.20	24.23	27.90	29.80	1	2	3	2	3	3
Cow dung	20.56	28.30	39.00	27.26	29.10	34.90	1	[illegible]	3	[illegible]	[illegible]	
Goat pellets	28.20	36.10	49.40	28.10	31.50	44.10	[illegible]	2		[illegible]	2	3
Poultry manure	39.90	60.40	61.30	38.72	41.50	55.20	2	3	3	2	3.60	3.60
NPK 15 : 15 : 15	19.84	44.30	54.10	27.98	32.10	51.60	1.67	2.78	5	1.67	4	4
LSD(P ≤ 0.05)	4.68	6.52	8.63	5.86	6.76	7.20	2	3	4	2	NS	3
Irrigation Frequencies												
3	29.54	40.10	51.40	31.11	36.50	47.40	[illegible]	3	4	1	3	3
6	27.09	39.10	49.80	32.59	34.00	44.20	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]
9	21.68	34.10	42.80	24.08	26.70	37.80	2	[illegible]	3	2		3
LSD(P ≤ 0.05)	3.63	NS	6.68	4.54	5.23	5.57	NS	3	NS	NS	NS	[illegible]

KEYS: WAP = Weeks after Planting;

4.5.5 Effect of soil amendments and irrigation frequencies on yield and components of Irish potato

The effect of soil amendments and irrigation frequencies on number of seeds, number of tubers, tuber length, tuber diameter, weight of seeds (kg) and weight of tuber (kg) is presented in Table 3. The results showed that soil amendments did not significantly affect number of seeds in both the early (October to December) and late (January to March) planting season of 2017 and 2018 dry season farming. However, soil amendments significantly (P<0.05) affected the number of tubers in early (October to December) and late (January to March) planting season of 2017 and 2018 dry seasons farming. N:P:K 15:15:15 significantly (P<0.05) increased the number of tubers during the early planting season with the highest number of tubers (46) while control had the least (13) during the late planting seasons. For tuber diameter, results showed that soil amendments significantly (P<0.05) affected tuber diameter during the early and late planting opportunity of 2017 and 2018 dry season. During the early planting opportunity poultry manure had the highest tuber diameter (14.84 cm) while control had the least (12.90 cm).

The same trend followed during the late planting opportunity with poultry manure having the highest tuber diameter (15.09 cm) and the least was obtained from the control (12.95 cm). For tuber length, soil amendment did not show any significant effect on tuber length at the early and late planting opportunity of 2017 and 2018 dry season farming. Soil amendments significantly ((P<0.05) affected weight of seed at both the early and late planting opportunity of 2017 and 2018 dry season farming. During the early planting opportunity poultry manure and goat droppings had the highest weight of seed (1.61 t/ha) while the least was obtained from control (1.20 t/ha), the result also showed that during the late planting opportunity, poultry manure gave the highest seed weight (1.80 t/ha) while control produced the least (1.22 t/ha). Soil amended with poultry manure significantly (P<0.05) increased the weight of potato tubers at both the early and late planting opportunities of 2017 and 2018 dry season farming. The result showed that during the early planting opportunity, soils treated with poultry amendment produced the highest (4.23 t/ha) while the control produced the least (0.80 t/ha). The same trend followed during the late planting opportunity which showed that plots amended with poultry manure gave the highest tuber (4.58 t/ha) while the least was obtained from the control. This is in agreement with the report of Kandil (2011) and Rulz *et al.* (1999) and Samiha, (2009), who reported that nitrogen fertilization increased the average fresh tuber, plant height, leaf number and tuber weight per plant.

The effects of irrigation frequency on yield parameters of potato are presented in Table 3. The results showed a significant (P<0.05) effect of irrigation frequency on number of seeds at 3, 6 and 9 days irrigation frequencies. The 3 days irrigation frequency had greater effect on number of seeds than other irrigation days both at early and late planting opportunities during the 2017 and 2018 dry season farming. The 3 days irrigation frequency had the highest number seeds (69) followed by 6 days with (54) and the least was from 9 days irrigation frequency (45). Irrigation frequency significantly (P<0.05) affected number of tubers in both early and late planting opportunity. The 3 days irrigation frequency had greater effect on potato tubers (40, 30 and 16 at 3, 6 and 9 days irrigation frequencies during the early planting opportunity. The same trend followed during the late planting opportunity (42.80, 30.90 and 15.80) at 3, 6 and 9 days frequency respectively. Irrigation frequency had a significant effect on tuber diameter. The 3 days irrigation frequency had greater effect on tuber diameter, while 9 days irrigation frequency had the least. The values obtained for the irrigation frequency were 13.93, 12.80 and 13.07 cm at 3, 6 and 9 day irrigation frequency respectively, during the early planting opportunity while 14.80, 14.21 and 13.15 at 3, 6 and 9 days irrigation frequency were obtained during the late planting opportunity of 2017 and 2018 dry season farming. Irrigation frequencies significantly affected tuber length for both early and late planting opportunities of 2017 and 2018 dry season farming. Irrigation frequency significantly (P<0.05) affected the weight of potato seed during the early and late planting opportunity of 2017 and 2018 dry season farming. Three days irrigation frequency had greater weight than other irrigation days. The values obtained were 1.86 t/ha, 1.41 t/ha and 1.03 t/ha for 3, 6 and 9 days irrigation frequencies. The same trend was observed during the late planting opportunity with 3 days irrigation frequency having the highest value (1.98 t/ha) followed by 6 days (1.62 t/ha) and 9 days (0.95 t/ha) in that order. Irrigation frequency had a significant (P<0.05) effect on weight of ware during the early and late planting opportunity in the 2017 and 2018 dry season farming with 3 days irrigation interval having a greater weight while 9 days had the least. The same pattern followed during the late planting season with the values of 3.95 t/ha, 2.47 t/ha and 0.99 t/ha at 3, 6 and 9 days irrigation frequencies, respectively. This is in agreement with the findings of Bao-Zhong *et al.,* (2003) who noted that potato plants are sensitive to water stress Wang *et al.,* (2006) also used six irrigation frequencies in potato which irrigate one time everyday 1,2,3,4,6 and 8days uniform water amount per treatment and noted that the greater the frequency of irrigation the greater the length and density of roots and stimulate tuber growth with increased water use efficiency.

Table 3: Effect of Soil Amendments and Irrigation Frequencies on Yield Parameters of Irish Potato

	EARLY						LATE					
Amendment	**No. Of Seed**	**No. of Ware**	**TD**	**TL**	**Weight of Seed (kg)**	**Weight of Ware (kg)**	**No. Of Seed**	**No. of Ware**	**TD**	**TL**	**Weight of Seed (kg)**	**Weight of Ware (kg)**
Control	48.40	12.70	12.90	6.69	1.20	0.80	48.80	14.00	12.95	6.70	1.22	0.86
Cow dung	54.40	14.40	13.21	6.76	1.26	0.98	51.70	14.80	12.95	6.94	1.36	1.16
Goat dung	64.20	27.00	13.21	6.76	1.61	1.82	64.00	28.00	14.55	6.81	1.80	2.03
P/manure	57.60	43.40	14.84	7.61	1.61	4.23	57.40	46.10	15.09	7.64	1.70	4.58
NPK 15 : 15	56.00	45.70	14.61	7.31	1.50	3.83	56.30	46.20	14.71	7.21	1.49	3.73
LSD	NS	7.67	1.13		NS	0.34	NS	8.22	1.36	NS	0.35	0.95
	0.86											
Irrigation Frequencies												
3	69.00	40.10	13.93	7.13	1.86	3.64	69.70	42.80	14.80	7.35	1.98	3.95
6	54.00	30.00	12.80	7.23	1.41	2.30	52.10	30.90	14.21	7.16	1.62	2.47
9	45.00	16.00	13.07	6.67	1.03	1.06	45.10	15.80	13.15	6.67	0.95	0.99
LSD	10.35	5.94	0.88	NS	0.26	0.67	10.86	6.33	1.05	NS	0.27	0.73

Key: TD = Tuber Diameter; TL = Tuber Length; WAP = Weeks after Planting; LSD = Least Significant Difference

Same comments as earlier made under Table 1

REFERENCES

Al-Aubiady. A.M.S, (2005). Physiological studies to improve growth, yield, tuber seed production and decrease the water stress in potato (Solanum tuberosum L). Unpublished PhD Thesis, College of Agriculture and Forestry-Mosul University. 163 pp.

Al-Kafagy, H.A.F. (2009). Effect of organic and phosphate fertilizer on the growth and yield of potato var. Dazari. *Euphrates Journal of Agricultural Science*. 1(2); 50-58.

Aoyama, M.D.A., Anger, A.N., Deyegamiye and N. Bissonnelte, (1999). Protected organic matter in water stable aggregates as affected by fertilizer and manure application. *Canadian Journal of Social Sciences*, 79: 419-425.

Bao-Zhong, Y, Soich, M and Kang, Y. (2003). Effect of different irrigation regimes on the growth and yield of drip irrigated potato. Agricultural Water Management, 63:153-167.

Boyle, R.K., Mcainsh, M., Dodd (2016). Daily irrigation attenuates xylem abscisic acid concentration and increase leaf water potential of pelargonium x hortorun compared with infrequent irrigation. *Physical plant* 158(1), 23-33.

Dowgert, M.F. (2010). The impact of irrigated Agriculture on a stable food supply, Netafin irrigation incorporation Fresno proceedings of the Annual centralplains irrigation conference, Kearney, N.F. February 24-25. St. Pay, MN, USA 125-130pp

Eliot, F. (2005). Organic farming in Scotland http://www.alfredhartemink.nl/fertilizer.htm,(21/09/2009).

Errebi, M., Rosen, C.J., Gupta, S.C. and Birong, D.E. (1998). Potato yield Response and Nitrate leaching as influenced by Nitrogen management. *Agronomy Journal*, 90: 10-15.

Ifenkwe, O.P. (1981). A renew of the status of potato production in Plateau State of Nigeria Bulletin No 1 National Root Crop Research Istitute Umudike pp. 1-2

Ifenkwe, O.P. and Nwokocha, H.N. (1987). The most limiting factors from potato crop production in Nigeria, Nigeria-Netherlands Workshop paper. "Towards increase potato production in Nigeria, Vom Plataeu State, Nigeria, Feb 20-21, 1986, 27-32

Ifenkwe, O.P., (1986). Development of potato production in Nigeria. Nigeria Netherlands workshop paper. Towards increasing potato production in Nigeria, Vom Plateau State Nigeria February 20-21, (1986).

Kandil, A.A., Attia, A.N., Badawi, M.A., Sharief, A.E. and Abido, W.A.H.(2011), Effect of water stress and fertilization with Inorganic Nitrogen and organic chicken manure on yield and yield components of potato. And *Australian Journal of Basic Applied Science,* 5(9): 997-1005.

Leytem, A.B. and Westermann, D.T. (2006). Phosphorus availability to barely from manures and fertilizers on a calcareous soil. *Journal of Soil Science,* 170 (6):40-412

Olayinka, A. (1990). Effects of poultry manure, corn straw and saw dust on plant growth and soil chemical properties. *Ife Journal of Agriculture,* 12: 36-44.

Rees, W.H., Chow, L.T., Zebarth, B., Xing, Z., Toner, P., Lavoie, J. and Daigu J.L. (2013). Impact of supplemental poultry manure application on loam soil in North Western New Brunswick.

Canadian Journal of Soil Science, 94(1)

Singh, Dhyan, Chhonkar, P.K. and Pande, R.N; 1999. Soil testing, plant, water analysis. Methods manual IARI ICAR, New Delhi, 1. 6-11

Wang, F.X., Kang, Y. and Liu, S.P. (2006). Effect of drip irrigation frequency on soil wetting pattern and potato growth in North China Plain. *Journal of Agricultural Water Management,9* 79:248-264.

Wang, F.X., Kang, Y. and Liu, S.P. (2006). Effect of drip irrigation frequency on soil wetting pattern and potato growth in North China Plain. *Journal of Agricultural Water Management,9* 79:248-264.

Westerman, D.T. (2005). Nutritional requirements of potatoes. *American Journal of Potato Research,* 82:301-307.

Xue, Q., Weiss, A. and Beanziger, P.S. (2004). Predicting leaf appearance in field–grown winter wheat, evaluating linear and non-linear models, *Ecological Modeling* 175(3): 261-270.

BIOLOGICAL NITROGEN FIXATION BY FORAGE/GREEN MANURE LEGUMES FOR SUSTAINABLE SOIL FERTILITY. A REVIEW. PART I. BIOMASS YIELD, NUTRIENT CONCENTRATION AND NUTRIENTS UPTAKE.

[1]Bashir A. A
[1] Department of crop production technology, Federal Polytechnic Bali, Taraba State
Corresponding author email: bashirimran23@gmail.com

ABSTRACT
Nitrogen is the single most important soil-based element for plant growth. Except for water availability, it is nitrogen that limits plant growth frequently. Although the atmospheric air is 78% N_2, it is unavailable to higher plants unless reduced to ammonia. The demand for nitrogen to satisfy crop production requirements can only be fulfilled through the two major sources – Industrial N_2 fixation in fertilizers or biological nitrogen fixation (BNF) in legumes. Legumes are the most important hosts of BNF. This study reviewed and interpreted the vast research results accumulated in the period 1973-2023 by faculties/colleges of agriculture and research institutes on the biomass yield potentials of legumes species, to make the information available for agronomists, researchers, farm managers and farmers alike. The result showed that green manure legumes yield large quantities of fresh biomass in situ, which is rich in plant nutrients. The manuring species supply 40 to 120 kg Nha^{-1}, equivalent to the application of three to ten tonnes of farmyard manure on the basis of organic matter and its N contribution. The review further showed green manures with their deep taproot are more efficient in nutrients uptake than grasses. It was concluded that manuring legumes are potential biomass yielders with enhanced nutrients uptake making them the only important species for BNF. Forage/green manure legumes are recommended for use in cropping systems due to their high biomass yield for an enhanced BNF, a vital mechanism for replenishing the reservoirs of soil organic N to support crop growth.
Keywords: Biomass yield, Biological Nitrogen Fixation, Nutrients Uptake

INTRODUCTION

During the last half century (1973-2023), agriculture worldwide has experienced soil degradation, reduced agricultural biodiversity, increased dependence on scarce nonrenewable resources, reduced crop yields and vulnerability to climate change (Cherr *et al*, 2005; Bashir, 2009). Low and declining soil fertility has been recognized as a major threat to crop production and an impediment to intensifying agriculture in sub-Saharan Africa (IITA, 2017). Researchers, government agencies, farm managers and enlightened farmers have, therefore, expressed increasing interest in agro-ecologically and economically viable alternatives that harness biological processes and restoration of soil fertility (Cherr *et al*, 2005; Bashir, 2009).

Leguminous forage and green manure crops may provide such an alternative (Bashir, 2019; Cherr *et al*, 2005). High biomass yielding and nutrient-fixing forage legumes, utilized as green manure crops have been widely reported to play important roles in improving soil fertility and sustainability (Rani *et al*, 2021; Bashir, 2023). With deep root system Forage/Green Manure Legumes (FGML) have enhanced nutrient uptake and their tissue is rich in nutrient concentration (Sullivan, 2003). Biomass is the precursor of biological nitrogen fgixation (BNF).

This paper reviewed and interpreted the scientific literature on nutrient uptake by FGML within the period from 1973 to 2023 in order to make useful knowledge available to soil scientists, other agricultural scientists, farm managers and farmers alike.

The objectives were to:

i) review and interpret information on the biomass yield potential of some FGML and
ii) recommend some top biomass yielders for their potential BNF ability in the guinea and dry Savanna zone of Nigeria.

Biomass Yields in Forage/Green Manure Legumes

The most important aspect of green manuring is their ability to yield large quantities of green matter as fresh biomass in-situ within short period of time (Singh, 1984). The biomass yield of these legume plants as presented Table 1.1 vary with the species, climatic condition, age of the species and management practices (Meelu *et al*, 2007; Bashir, 2015). **Table 1.1** is a compilation of global biomass yields which range from 0.26 t/ha (Bashir, 2015) in the tropics to a high of 10 t/ha (Carsky, 1989) in the temperate region. Similar yields were reported by other authors in the temperate region of the world (Carsky, 1989; Sullivan 2003; Meelu *et al*., 2007). Meelu *et al*., (2007) reported that among summer legumes, pigeon pea and sunn hemp were the more productive with dry biomass reaching 13 t/ha for full season crops. This is in agreement with FAO (2011) that pigeon pea is a great producer of biomass even on extremely degraded soils.

Kusvuran *et al*. (2015) defined biomass in green manuring as the sum total weight 0f the plant components above and below the soil line; an important concept, which directly affects soil productivity. With their rapid biomass growth, green manuring species might probably provide an in-situ source of organic manures for tropical cropping systems (Bashir, 2023). Sullivan (2003) reported that the contribution of organic matter to the soil from the application of a green manure is comparable to the addition of 20 – 25 t/ha of Farmyard manure to a farm land. This report is supported by Rani *et al*., (2021) that green manure crops supply 40 to 120 kg Nha^{-1}, an amount of N equal to an application of three to ten tonnes of Farmyard manure on the basis of organic matter and its N contribution. Biomass yield in forage/green manure legumes is the precursor of biological nitrogen fixation, which remains an important concept in tropical cropping systems.

Table 1.1 Biomass Yields in Forage/Green Manure Legumes

S/N	Forage/Green Manure Legume	Age/Growth/Time (Day)	Biomass Yield (t/ha)	Reference *
1.	Crimson clover (*Trifolium incanatum*)	Annual	2.4	Meelu *et al.* (2007)
2.	Hairy vetch	Annual	6.7	Hargrove (1986)
3.	Sunnhemp (*Crotataria juncea*)	19 weeks	8.0	Cherr *et al.* (2005)

4.	Sunnhemp (*Crotataria juncea*)	10 weeks	3.32(17.5 F[1])	Rani *et al.* (2021)
5.	*Sesbania rostrata*	13 weeks	5.8	Becker *et al.* (1991)
6.	*Sesbania rostrata* (rainy season)	8 weeks	2.6 (10 F[2])	Bashir (2009)
7.	*Sesbania rostrata* (dry season)	6 weeks	0.368	Bashir (2015)
8.	*Sesbania rostrata* (rainy season)	6 weeks	3.7 (14.25 F[2])	Bashir (2019)
9.	*Lablab purpereus*	Season	4.0	FAO (2011)
10	*Lablab purpereus*	6 weeks	0.26	Bashir (2015)
11	Velvet bean (*Mucunna pruriens*)	13 weeks	4.0	Cherr *et al*. (2005)
12	*Mucuna Pruriens*	Season	6.6 (25.5F[2])	Adigbo and Okeleye (2006)
13	*Mucunna pruriens*	Season	5.5	FAO (2011)
14	*Mucunna pruriens* (dry season)	6 weeks	0.8	Bashir (2015)
15	*Mucunna pruriens* (rainy season)	6 weeks	3.7(14.25F[2])	Bashir (2019)
16	Pigeon Pea (*Cajanus cajan*) dry season	6 months	10.0	Carsky (1989)
17	Pigeon Pea (*Cajanus cajan*) dry season	6 weeks	0.4	Bashir (2015)
18	Cassia weed (*Cassia fistula*)	Season	3.4	Rakiya *et al.* (2019)
19	Cowpea (*Vigna unguiculata*)	60	4.4(23.2F[1])	TNAU (2016)
20	Cowpea (*Vigna unguiculata*)	6 weeks	2.3	Fabunmi and Balogun (2015)
21	*Stylosanthesis guianensis*	Season	4.3	Cherr *et al.* (2005)
22	*Stylosanthesis guianensis*	6 weeks	0.30	Basher (2015)
23	*Centrosema pubscens*	6 weeks	0.342	Bashir (2015)
24	Pearl Millet	6 weeks	0.143	Bashir (2015)
25	Sorghum	6 weeks	0.276	Bashir (2015)
26	Maize	Season	2.7	Randa *et al.* (2006)

Notes: *Figures estimated from original sources
1= 19% dry matter (Fabunmi and Balogun, 2015)
2= 26% dry matter (Bashir, 2019)

Nutrient contents in Forage/Green Manure Legumes

Nutrient content of forage/green manure legumes shown in Table 1.2. N content in the species ranged from 0.352% in sunn hemp (Randa *et al*, 2006) to a high of 4.2% in hairy vetch (Sullivan, 2003). Nutrient content in manuring legumes is influenced by age. For example, cowpea being mature at harvest, account for the lower nutrient content in the crop. The report was supported by Rani *et al,* (2021) that the nitrogen content of forage/green manure legumes is influenced by age of the plant.

Biomass along with N content determine nutrient uptake in plants, an important concept in soil fertility.

Table 1.2 Nutrient contents in Forage/Green Manure Legumes

S/N	Forage/Green Manure Legume	Nutrient content (%)			Reference
		N	P	K	
1.	Crimson clover (*Trifolium incanatum*)	2.71	0.377	3.37	Sallivan (2003)
2.	Hairy vetch	4.32	0.552	4.08	Sallivan (2003)
3.	Sunnhemp (*Crotataria juncea*)	2.30	0.50	1.80	TNAU (2016)
4.	Sunnhemp (*Crotataria juncea*)	0.352	0.031	0.282	Randa *et al*. (2006)
5.	*Sesbania rostrata*	2.71	0.53	2.21	TNAU (2016)
6.	*Sesbania rostrata* (rainy season)	0.210	0.02	0.9	Bashir (2009)
7.	*Sesbania rostrata* (dry season)	3.80	0.09	3.80	Bashir (2015)
8.	*Sesbania rostrata* (rainy season)	2.97	0.14	1.37	Bashir (2019)
9.	*Lablab purpereus*	3.34	0.09	3.46	Bashir (2015)
10.	*Lablab purpereus*	3.34	0.09	3.46	Bashir (2015)
11.	Velvet bean (*Mucunna pruriens*)	4.4	0.3	1.6	Nalivata *et al* (2017)
12.	*Mucuna Pruriens*	2.93	0.11	1.19	Bashir (2019)
13.	*Mucuna Pruriens*	2.93	0.11	1.19	Bashir (2019)
14.	*Mucunna pruriens (dry season)*	3.46	0.09	2.84	Bashir (2015)
15.	*Mucunna pruriens*(rainy season)	2.93	0.11	1.19	Bashir (2019)
16.	Pigeon Pea (*Cajanus cajan*)	3.0	0.30	1.99	Rani *et al* (2021)
17.	Pigeon Pea (*Cajanus cajan*) dry season	4.10	0.09	3.90	Bashir (2015)
18.	Cassia weed (*Cassia fistula*)	1.60	0.24	1.20	TNAU (2016)
19.	Cowpea (*Vigna unguiculata*)	0.412	0.045	0.429	Randa *et al.* (2006)
20.	Cowpea (*Vigna unguiculata*)	2.9	0.1	2.1	Nalivata *et al* (2017)
21.	*Stylosanthesis guiaensis*	4.28	0.08	2.62	Bashir (2015)
22.	*Stylosanthesis guiaensis*	4.28	0.08	2.62	Bashir (2015)
23.	*Centrosema pubscens*	2.85	0.09	3.67	Bashir (2015)
24.	Pearl Millet	1.75	0.01	4.48	Bashir (2015)
25.	Sorghum	1.96	0.09	3.14	Bashir (2015)
26.	Maize	0.148	0.027	0.256	Randa *et al* (2006)

Nutrient uptake by Forage/Green Manure Legumes

The nutrient uptake in the forage/green manure legumes as presented in Table 1.3 shows pigeon pea with a value of 410 kg/ha while the lowest value of 3.95 kg/ha was found in cereal crops. N uptake legumes by main factor determining biological nitrogen fixation. The highest N uptake were reported in the order of Pigeon Pea (*Cajanuscajan*) > Hairy vetch > *Mucuna Pruriens* > *Stylosanthesis guianensis* > Sunn hemp (*Crotataria juncea*) > Velvet bean (*Mucunna pruriens*) > *Sesbania rostrata* > *Lablab purpereus* >*Sesbania rostrata* > *Mucunna pruriens* > Cowpea (*Vigna unguiculata*) > Crimson clover (*Trifolium incanatum*). These high biomass yielders can provide the raw material for biological fixation if used as green manure improving soil fertility.

Table 1.3 Nutrient uptake by Forage/Green Manure Legumes

S/N	Forage/Green Manure Legume	Biomass yield (t/ha)	Nutrient uptake (kg/ha)			
			N	P	K	NPK
1.	Crimson clover (*Trifolium incarnatum*)	2.4	65.04	9.05	80.88	155
2.	Hairy vetch	6.7	289.44	38.98	273.36	602
3.	Sunnhemp (*Crotataria juncea*)	8.0	184.0	40.0	144.0	368
4.	Sunnhemp (*Crotataria juncea*)	3.32	11.69	1.03	9.36	22
5.	*Sesbania rostrata*	5.8	157.18	30.74	128.18	316
6.	*Sesbania rostrata* (rainy season)	2.6	5.46	0.52	23.4	29.38
7.	*Sesbania rostrata* (dry season)	0.368	13.98	0.33	13.98	28
8.	*Sesbania rostrata* (rainy season)	3.7	109.89	5.18	50.69	168
9.	*Lablab purpereus*	4.0	133.60	3.60	138.40	276
10	*Lablab purpereus*	0.26	8.68	0.23	9.0	18.0
11	Velvet bean (*Mucuna pruriens*)	4.0	176.0	12.0	56.0	244
12	*Mucuna Pruriens*	6.6	193.38	1.26	78.54	273
13	*Mucuna pruriens*	5.5	190.3	4.95	156.2	351
14	*Mucuna pruriens* (dry season)	0.8	23.44	0.88	9.52	34
15	*Mucuna pruriens* (rainy season)	3.7	108.41	4.07	44.03	157
16	Pigeon Pea (*Cajanus cajan*) dry season	10.0	410.0	9.0	390	809
17	Pigeon Pea (*Cajanu scajan*) dry season	0.4	16.40	0.36	15.6	32
18	Cassia weed (*Cassia fistula*)	3.4	54.40	8.16	40.8	103
19	Cowpea (*Vigna unguiculata*)	4.4	18.12	1.98	18.87	39
20	Cowpea (*Vigna unguiculata*)	2.3	66.70	2.30	48.30	117
21	*Stylosanthesis guiaensis*	4.3	184.04	3.44	112.66	300
22	*Stylosanthesis guiaensis*	0.30	12.84	0.24	7.86	20
23	*Centrosema pubscens*	0.342	9.75	0.31	12.55	22
24	Pearl Millet	0.143	2.50	0.02	6.41	9
25	Sorghum	0.276	5.40	0.24	8.66	14
26	Maize	2.7	3.99	0.72	0.91	11
27	Average N uptake in cereals	-	3.95	-	-	-

Conclusion: Researchers, government agencies, farm managers and enlightened farmers have expressed increasing interest in agro-ecologically and economically viable alternatives that harness biological processes and restoration of soil fertility. The review study showed that the highest N uptake were reported in the order of Pigeon Pea (*Cajanus cajan*) > Hairy vetch > *Mucuna pruriens*> *Stylosanthesis guianensis* > Sunn hemp (*Crotataria juncea*) > Velvet bean (> *Sesbania rostrata* > *Lablab purpereus* > Cowpea (*Vigna* *unguiculata*) > Crimson clover (*Trifolium incarnatum*).

Recommendation: These eleven forage/green manure species are recommended for use as green manure in the cropping systems of the guinea and dry Savanna of Nigeria. With their high biomass yield will promote biological nitrogen fixation to improve soil fertility.

References

Bashir A. A. (2009). Effects of Spacing and time of application of *Sesbania rostrata* green Manure on soil chemical properties and growth of Sorghum bicolour. M. Sc. Dissertations. Department of Soil Science, University of Maiduguri.

Bashir A. A. (2019). Influence of leguminous Green Manures on soil chemical properties and the yields of pearl Millet and Sorghum in a Semi-arid Environment Ph.D Thesis submitted at the University of Maiduguri.

Bashir A. A. (2015). Contribution of legumes to soil available Nitrogen. A Ph.D Non Thesis Seminar paper Department of Soil Science, University of Maiduguri December, 2015.

Carsky R. J. (1989). Estimating availability of nitrogen from green manure to subsequent maize crops using buried bag technique. Ph D. Thesis.Cornell Univ, Ithaca, New York.

Cherr C. M., Scholbery J.M.S., and McSorley R. (2005). Green Manure Approaches to Crop Production. A Synthesis. University of Florida, USA.

.

Fabunmi T.O and Balogun R.O (2015). Response of Maize to green manure from cowpea in a derived savannah of Nigeria, *Africa Journal of Food, Agriculture, Nutrition and Development*, Vol.15 (3) pp. 10138-10152.

Food and Agriculture organization FAO (2011).Green manure/cover crops and crop rotation on small farms. Integrated crop management Vol. 12. 2010. FAO, Rome.

Hargrove W.H. (1986), Winter Legumes as a nitrogen source for no-till grain Sorghum. *Agron. J.* 78:70-74

IITA (2017) International Institute of Tropical Africa, Ibadan. ~~Animal~~ Annual Report, 2017.

Kusvuran A., Parlak E.L. and Saglamtimur T. (2015).Biomass yield of Faba bean and its mixture with some grasses. *Turkish Journal of Agricultural and Natural Sciences* 2 (2): 178-184.

Meelu O.P, Singhy, and Singh B, (2007). Green Manuring for Soil productivity improvement, Daya Publishing House Delhi.

Nalivata P., Kibunja C., Mufegi J., Tetteh F. And Tarfa B. (2017).Integrated Soil Fertility Management in Sub-Saharan Africa.Wortmenn C.S. and Sones K. (eds). CABL

Rani T.S., Umaredy R., Ramulu Ch., and Kamar T.S, (2021). Green Manures and Green leaf Manures for Soil fertility improvement: *A review Journal of Pharmacognosy and Phytochemistry*. 10 (5): 190-196.

Singh N.T. (1984). Green Manure as a source of nutrients in rice production. International Rice Res. Inst. Los Barios, Philiplines

NUTRIENT LOSSES DUE TO LEACHING AS AFFECTED BY MULCHING AND INORGANIC FERTIIZER IN AN ULTISOL CULTIVATED WITH OIL PALM (*Elaeis guineensis* jacq)

[1]Ikyaahemba, P.T.,[2] Salako, F.K., [2]Azeez, J.O., [2]Busari, M.A., [3]Bada, B.S., [1]Oviasogie, P.O., [1]Ekebafe, M. O., [4]Wuese, S. T. and [5]Agaku, D.T.

[1]Nigerian Institute for Oil Palm Research (NIFOR), Benin City. Nigeria
[2]Department of Soil Science and Land Management,
Federal University of Agriculture Abeokuta, Nigeria,
[3]Department of Environmental Management and Toxicology,
Federal University of Agriculture Abeokuta, Nigeria
[4]Joseph Sarwuan Tarkaa University of Agriculture Makurdi –Nigeria,
[5]National Horticultural Research Institute, Ibadan-Nigeria
Corresponding author email:ptordue@gmail.com

ABSTRACT

The soils of the oil palm belt of Nigeria are leached soils with inherently low fertility status occasioned by low activity clays, low organic matter and high rainfall. Hence, this research was conducted to assess the effect of mulch (empty fruit bunch of oil palm) in mitigating leaching losses from application of NPKMg fertilizer on an Ultisol cultivated to oil palm. A mini-lysimeter was used in an open field condition. Factors were: NPKMg (12:12:17:2) at 0 and 250 g^{-1} palm and Empty oil palm Fruit Bunch (EFB) at 0, 35.4 and 71 t ha^{-1}. The experiment was a 2 x 3 factorial fitted into a Randomized Complete Block Design (RCBD) with three replicates. Pre-planting soil samples were collected at 0-20, 21-40 and 41-60 cm depths to determine physical and chemical properties. Leachates from individual mini-lysimeter were collected to determine the amount of nutrients leached every month for the period of five months. Results showed that application of 250 g NPKMg fertilizer increased the leaching of N, P, K and Mg. The increasing rate of EFB mulch 0 g > 35.4 g > 71 g under field condition caused a significant reduction in leaching of plant nutrient. The study concluded that, application of 71 g of EFB mulch significantly reduced the leaching of NPKMg compare to 35.4g and thus recommended for effective production of oil palm seedlings.

Key words: *Fertilizer, Mulching, Nutrient losses, Oil palm seedlings, Ultisols*

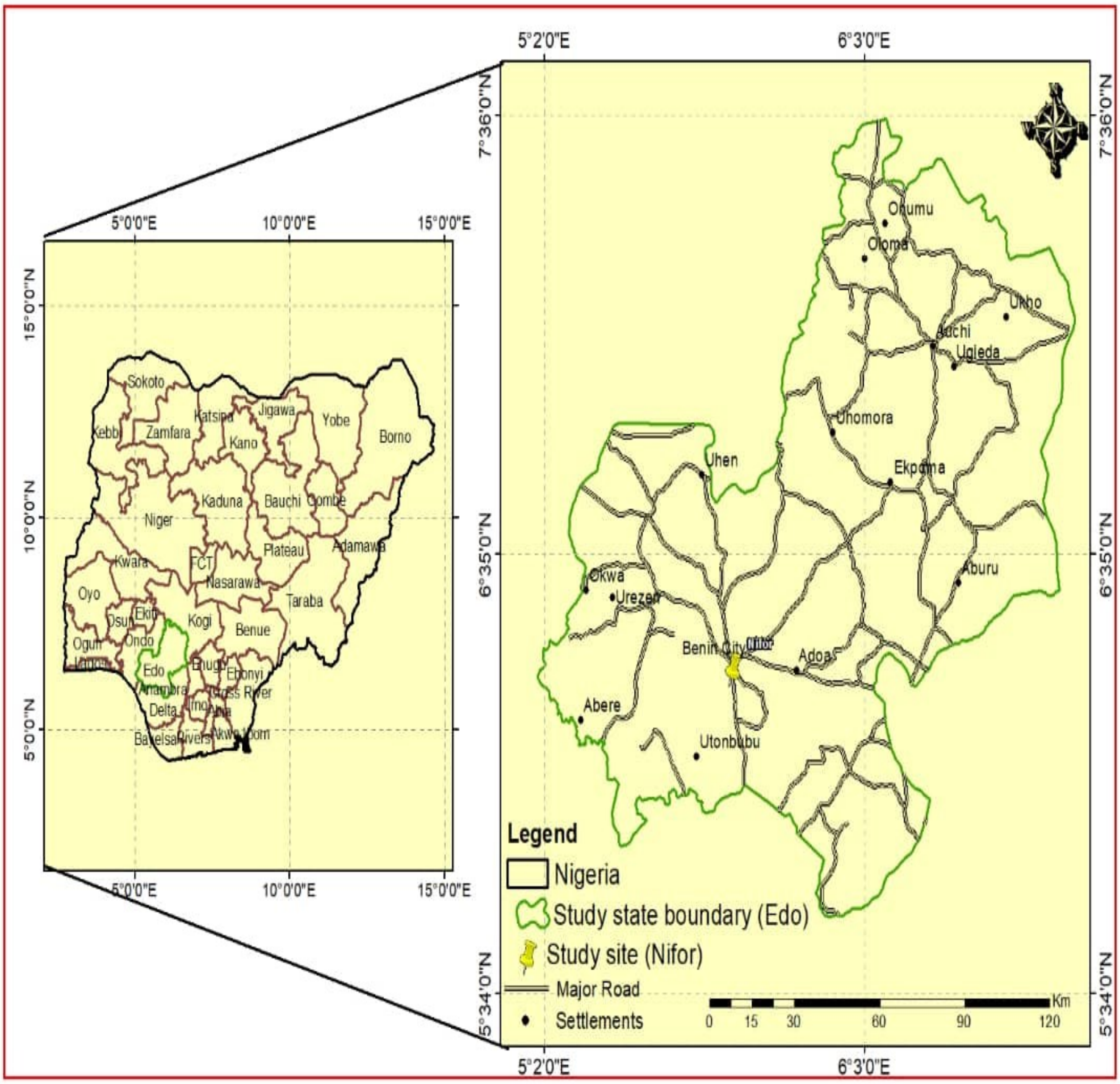
INTRODUCTION

The soils of the oil palm belt of Nigeria are leached soils with inherently low fertility status occasioned by low activity clays, low organic matter, high rainfall and nutrient losses due to leaching (Blombäck *et al.* 2011). The relatively high rainfall, temperatures and intense sunshine in this region makes the soil prone to nutrient loss. It is therefore a key bottleneck to achieving sustainable fertility management for tropical soils. Generally, these soils require high fertilizer input and special management to sustain agricultural production (ISRIC, 2012). The use of mulches, inorganic fertilizer (NPKMg) and organic amendments among others have long been used in ameliorating the poor soil conditions of sandy soils in the tropics (Busari *et al*., 2004). Oil palm yield in Nigeria and some part of West Africa hardly meet the genetic potential of the crop due to erratic rainfall, high leaching of nutrients and poor agronomic practices (Ikuenobe, 2016). Nutrients applied as fertilizers are subjected to losses in the dissolved form via surface run off, erosion, leaching and fixation in the soil. For example, high rate of NPKMg 12:12: 17:2 fertilizer application per unit area (within the palm circle) encourage nutrient losses through leaching in an oil palm ecosystem (Corley and Tinker, 2009). Fertilizer in oil palm production accounts for 50-70% of field operational cost and about 25% of the total cost of production (Calima *et al*., 2012). Several studies have documented the importance of organic mulches in crop production (Ashworth and Harrison, 1983; Agele *et al*. 2000). The oil palm empty fruit bunch (EFB) serves as a source of nutrients, improves soil moisture content, increases root development, reduces soil erosion and has a moderating effect on soil temperature (Singh, G. *et. al;* 1999) and is particularly useful for immature palms. Mulching is a viable strategy of manipulating the micro environment and reducing evaporation (Ghosh *et al.*, 2006 and Chakraborty *et al.*, 2008). Therefore, considering the importance of oil palm empty fruit bunch in the overall productivity of the palm, there is need to investigate the use of oil palm EFB as mulch in mitigating losses due to leaching arising from NPKMg fertilizer on an Ultisol cultivated to the oil palm using a mini-lysimeter.

MATERIALS AND METHODS

Location of the study area

The field experiment was conducted at the Nigerian Institute for Oil palm Research (NIFOR). The study site was located on latitude 6^0 33' 32.41" N and longitude 5^0 37'16.68" E with elevation of 156 m above sea level. The study site is in the rainforest agro-ecological zone of Nigeria. Humid tropical climate prevails with average annual rainfall of 2000 - 2500 mm (Ogeh and Adeoye, 2012). The rainy season starts in April and end in October. While the dry season is between November and April. The mean air temperatures ranged between 22 ºC and 31° C. This experiment was conducted between June to October, 2019. A hybrid *Tenera* variety of oil palm developed by NIFOR was used as a test crop.



Coordinates: Latitude 6^0 33' 32.41" N and Longitude 5^0 37'16.68" E
Figure 1: Map of Edo State, showing NIFOR and other major towns
Source: Edo State Ministry of Land and Survey (2016)

Soil sample collection and analysis
Representative soil samples were collected at the onset of the experiment using soil auger from 0-20, 21-40 and 41-60 cm depths respectively from NIFOR main station in Field 9 and bulked separately to form composite sample which were used for routine laboratory analysis. Soil physical properties such as particle size distribution were determined by hydrometer method (Gee and Or, 2002). Bulk density was determine from undisturbed soil sample by core sampling method in the field at (3) depths 0 - 20, 21 - 40 and 41 - 60 cm, oven dried for 24 hours at 105 º C and determined using the formula of (Jury and Gardner, 1991). Bulk density = $\frac{Wd}{Vc}$ ...

Where, pb is soil bulk density (g/cm^3), Wd is weight of dry soils (g) and Vc is volume of soil (cm^3); Total porosity ***(Pt)***: the percentage of bulk volume not occupied by solids was calculated from the bulk density value assuming a particle density (Pd) of 2.65 gcm^{-3}.
Total porosity (Pt) = 1- Bd., Where, Bd is the bulk density and (pd) is the

particle density = 2.65 g cm^3; Saturated hydraulic conductivity, K_{sat} was calculated using formula proposed by Rattan and Shukla (2005). $K_{sat} = \frac{Q}{At} \bullet \frac{L}{\Delta H}$. Where, K_{sat} = saturated hydraulic conductivity (cm/hr), Q= volume of water per unit time (cm^3/mins), L = length of soil column (cm), A = cross sectional area of the soil column (cm^2), ΔH = change in hydraulic head (dimensionless) and t = time of flow (mins). Soil pH was determined in 1:2 soil water suspensions using a pH meter (Hendershot *et al.*, 1993); Organic carbon was analyzed by the dichromate oxidation procedures (Walkley and Black, 1934) method. Total nitrogen was determined by Micro-kjeldah method (Brookes *et al.*, 1985); Available phosphorus was determined by Bray-1 method (Bray and Kurtz, 1945). Exchangeable cations were extracted using NH_4OAC buffered at pH 7.0 (Thomas, 1982), Potassium (K) and Sodium (Na) were determined with a flame photometer while Exchangeable calcium (Ca) and Magnesium (Mg) were determined using Atomic Absorption Spectrophotometer (AAS) Perkin Elmer 403. Leached mount of NPKMg were calculated by multiplying leachate volume by leachate concentrations for each individual lysimeter.

Treatments and Experimental Designs

Treatments consisted of 2 factors viz; NPKMg fertilizer, at two levels 0 g and 250 g per palm, while EFB was applied at 3 levels 0 g EFB, 35.5 g EFB and 71 g EFB (based on application rate of 75 kg ha^{-1} as recommended by Lim and

.

Zaharah (2000). The experimental design was 2 x 3 factorial fitted to a randomized complete block design to give a total of six treatment combinations with three replicates as follows:

1. C_T = 0 g NPKMg + 0 g EFB
2. T_1 = 0 g NPKMg + 35.4g EFB
3. T_2 = 0 g NPKMg + 71g EFB
4. T_3 = 250 g NPKMg + 0 g EFB
5. T_4 = 250 g NPKMg + 35.4g EFB
6. T_5 = 250 g NPKMg + 71g EFB

Lysimeter design and installation

Mini-lysimeter consisted of ¾ polyvinyl chloride PVC of 1 m in length; two plastic elbows that connect the polyvinyl chloride (PVC) pipe at the button and through the outlets at the collection point were used (Plate 1 and 2). Each ¾ PVC was attached to the 20 L emulsion paint plastic lysimeter (bucket type) of 48.5 cm height and a diameter of 29.0 cm filled with soil from the site of experiment (Plate 3 and 4); Abrasive glue was used for fastening the joint of the pipes and elbow to the lysimeters and the drainage outlets at the collection point. Leachates were collected from each lysimeter in a 1000 mls plastic containers which was connected through the ¾ PVC pipes to the drainage outlets at the basal (bottom) of each lysimeter. A 0.05 mm wire mesh was fitted into the lysimeter outlet to cover the drainage holes at the bottom of the lysimeter to prevent soil particle leaving with the water draining out of the lysimeter (Plate 1 to 4). A total of eighteen (18) lysimeters were assembled between March and April, 2019 and installed in the field on the 8th May, 2019 and the experiment began on the 1st June, 2019

Plate 1: Mini-lysimeter with attached elbow

Plate 2: Mini-lysimeter with drainage outlets

Plate 2: Mini-lysimeter with drainage outlets

Plate 3: Assembling of parts before installation

Plate 4: Mini-lysimeter installed on the field

In each plot a drainage passage was dug at a depth of 67.5 cm and a width of 60.4 cm using a digger, hoe and shovel. The drainage channel was created side by side in order to avoid accumulation of water and to prevent future erosion that might set in along the path of the drainage. The soil removed from the area in which the mini-

lysimeter was installed was back filled as it was removed, to mimic the natural soil profile. It was irrigated to facilitate soil settling before the commencement of the study (Plates 3 and 4).
Losses of N, P, K and Mg due to leaching were monitored every month for a period of five (5) months.

Planting
Oil palm seedlings of uniform growth used for this experiment were sourced from NIFOR main nursery and transplanted singly by hand into the mini-lysimeter installed on the field on the of 10th June, 2019; one stand of oil palm seedling was planted per lysimeter into the 18 mini-lysimeter. All the transplanted seedlings were watered to facilitate soil
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settling before treatments were applied**.** The NPKMg 12:12:17:2 compound a fertilizer was applied using the ring method i.e. 7 cm from the stand of seedlings was weeded regularly by rouging every fortnight to control weed.

Leachate collection and analysis
The leachate volume from lysimeter that captures percolating water was collected on monthly intervals for the period of five months between June to October, 2019 (Plate 5 to 7).The 100 ml subsample was retained for the analysis of NH_4-N, NO_2-N, PO_4-P, K and Mg. NH_4-N and NO_2-N were extracted using 2 M KCl solutions, PO_4 by Bray-1. K and Mg were measured by ICP-AES (Rowell, 1994)

PLATE 5: A unit of Mini-lysimeter showing Oil palm transplanted seedlings

PLATE 6: Field leachate collection

PLATE: 7 A cross section of the Mini-lysimeter showing leachate collection point on the field

Statistical analysis

Data collected were subjected to Aanalysis of Variance (ANOVA) using Genstat edition 2012 software.Treatments means were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability.

Results and Discussions

The textural class of soils in the study area is presented in Table 1. The texture of the soil was sandy clay loam with relative high proportion of sand fraction over the mineral particles and decreased with increasing soil depth. This may be due to the sandy nature of the soils as observed in this study. This observation corroborates the findings of Osayande *et al*. (2013) who reported that the parent material of the coastal plain soils of Nigerian Institute for Oil Palm Research (NIFOR) may have influence the texture of the soils in the study area. The clay content increased with increasing soil depth. This observation conformed to Chude *et al*., 2013 who reported that acid sand soils are low in fertility. Akanbi and Togun (2002) also confirmed that most tropical soils are low in nutrients content. The degraded characteristics of this soil may be connected to high rainfall, leaching loses and intense weathering which characterizes soils of the tropics (Parnes, 1990; Gordon *et al*., 1993). These soil properties may adversely affect plant growth by exhibiting low water and nutrient retention capacity. The soil reaction in the study area is extremely to moderately acid with pH values ranged from 4.2 to 4.6 between 0-20 and 40-60 cm depth. The low pH observed in the study area however, did not limit oil palm cultivation because Jacquemard *et al*. (1998) has reported that oil palm can cope with a pH as low as 4. The soils generally had a bulk density range of 1.5 to 1.7 g/cm^3 and this bulk density did not pose any restriction to root proliferation. However, this observation was contrary to the works of Brady and Weil (1999) who reported that growth of roots into most soils could generally be limited by bulk densities ranging from 1.45 g/cm^3 in clay to 1.85 g/cm^3 in loamy sand. The high leaching loss of N, P, K and Mg (Table 2, 3, 4 and 5) as observed on the field with the application of NPKMg fertilizer may be attributed to the ready availability of the mineral elements present in the fertilizer. This observation is consistent with Adeniyan *et al*. (2011) who reported that the nutrient in inorganic fertilizer are already in mineralized form and provides a ready source of nutrient to the soil. However, the low leaching of N, P, K and Mg observed with increasing rate of EFB mulch may be due to enhanced water-holding capacity of the EFB mulch thereby reducing the amount of nutrient loss. Previous studies by Aribe (2003) had established improvements of soil physical properties by the application of organic materials. The result of this study is in line with the findings of Liang and Wang, (2002) who observed that, mulch materials could have decomposed to release nutrient, enhanced soil microbial activity, improved soil water retention capacity and consequently reduce nutrient loss. The interaction of NPKMg fertilizer and EFB mulch were not significant on leached amount of plant nutrients N, P, K and Mg.

CONCLUSION

Generally, the result of this investigation has demonstrated that application of NPKMg fertilizer increased the leaching of N, P, K and Mg on the field while increasing rates of EFB mulch reduced the leaching loss of plant nutrients.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interest regarding the publication of this manuscript.

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Table 1: Some physical and chemical properties of soil used for the field experiment

Soil physical characteristics	Soil depth (cm) 0 – 20	21 – 40	41 -60
Sand (g/kg)	685	621	588
Silt (g/kg)	56	32	26
Clay (g/kg)	259	347	386
Textural class	Sandy clay	Sandy clay	Sandy clay
Bulk density (g/cm^3)	1.48	1.43	1.32
Total porosity (%)	44	46	50
K_{sat} (cm /hr)	1.42	1.39	0.21
Chemical characteristics			
Soil pH (H_2O) 1:2	4.6	4.4	4.2
Organic carbon (g/kg)	0.34	0.32	0.30
Total N (g/kg)	1.2	1.1	1.0
Available P (mg/kg)	27	23	22
Exch. acidity (cmol/kg)	0.4	0.2	0.2
Exchangeable Bases			
Calcium (cmol/kg)	0.33	0.32	0.32
Magnesium (cmol/kg)	0.39	0.37	0.34
Potassium (cmol/kg)	0.53	0.49	0.46
Sodium (cmol/kg)	0.25	0.24	0.22

Table 2: Effect of NPKMg and empty oil palm fruit bunch on leached nitrogen under oil palm seedlings on the field

Treatments rates (g)	Leached nitrogen (NO_3-N or NH_3-N a) (mg/L) 1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
NPKMg 0	20.61bc	20.82bc	19.36d	22.46d	21.08cd
NPKMg 250	36.54c	42.21c	38.25c	43.24c	41.56c
EFB 0	187.7a	172.7a	174.6a	179.5a	166.2a
EFB 35.4	81.78b	77.49b	54.26b	42.09b	46.46b
EFB 71	36.15c	31.79bc	22.58bc	22.24d	20.45cd

Means with the same letter (s) in the same column are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT), NPKMg = inorganic fertilizer (NPKMg 12:12:17;2), EFB = Oil palm empty fruit bunch, MAT = Month after treatment application

Table 3: Effect of NPKMg and empty oil palm fruit bunch on leached phosphorus under oil palm seedlings on the field

Treatments Rate (g)	Leached phosphorus (mg/L)				
	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
NPKMg 0	14.69e	16.77e	16.72e	16.22e	18.17e
NPKMg 250	50.78c	66.21c	68.47c	45.16c	32.83c
No EFB mulch	151.9a	142.9a	123.5a	112.0a	105.1a
EFB 35.4	81.14b	84.33b	83.44b	75.03b	65.42b
EFB 71	35.72d	38.24d	36.72d	35.45d	27.26d

Means with the same letter (s) in the same column are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT), NPKMg = inorganic fertilizer (NPKMg 12:12:17:2), EFB = Oil palm empty fruit bunch, MAT = Month after treatment application

Table 4: Effect of NPKMg and empty oil palm fruit bunch on leached potassium under oil palm seedlings on the field

Treatments Rate (g)	Leached potassium (mg/L)				
	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
NPKMg 0	20.66d	23.52d	23.76d	22.93d	23.27c
NPKMg 250	36.23c	37.32c	42.50b	54.13b	39.07b
No EFB mulch	144.8a	165.3a	145.3a	125.3a	116.3a
EFB 35.4	76.31b	72.07b	58.37b	36.82c	41.64b
EFB 71	38.65c	23.19d	28.49c	23.90d	21.26c

Means with the same letter (s) in the same column are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT), NPKMg = inorganic fertilizer (NPKMg 12:12:17:2), EFB = Oil palm empty fruit bunch, MAT = Month after treatment application

Table 5: Effect of NPKMg and empty oil palm fruit bunch on leached magnesium under oil palm seedlings on the field

Treatments Rate (g)	Leached magnesium (g/kg soil)				
	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
NPKMg 0	24.73d	27.26d	26.15c	26.15c	26.43c
NPKMg 25 0	34.54c	36.47c	39.61b	39.31b	37.26b
No EFB mulch	66.42a	68.32a	67.31a	65.42a	71.50a
EFB 35.4	43.82b	42.94b	41.54b	38.37b	40.46b
EFB 71	23.90d	28.42d	24.56c	26.94c	31.36c

Means with the same letter (s) in the same column are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT), NPKMg = inorganic fertilizer (NPKMg 12:12:17:2), EFB = Oil palm empty fruit bunch, MAT = Month after treatment application

REFERENCES

Adeniyan, O. N., Ojo A.O., Akinbode, O.A and Adediran, J.A. 2011.Comparative study of different organic manures and NPK fertilizer for improvement of soil chemical properties and dry matter yield of maize in two different soils. *Journal of soil science and Environmental Management,* 2 (1): 9-13.

Agele, S.O., Iremiren, G. K. and Ojeniyi, S.O. 2000. Effect of tillage and mulching on the growth, development and yield of late season tomato (Lycopersiconesculentum) in the humid South of Nigeria. *Journal of Agricultural Science,* 134, 55-59.

Akanbi, W. B. and Togun, A.O. 2002.The influence of maize stover compost and nitrogen fertilizer on growth, yield and nutrient uptake of Amaranth.*ScientiaHoriculture,* 93:1-9.

Aribe N.S. 2003. Effect of tillage practices and crop residues management on soil fertility and maize yield Soil Fertility. 15 (3): 21-26.

Ashworth, S. and Harrison, H. 1983. Evaluation of mulches for use in the home garden.*Horticultural Science,* 18 (2), 180-182.

Blombäck, K., Johnsson, H., Lindsjö, A., Mårtensson, K., Person, K and F. Schmieder. 2011. *Läckage av näringsämnen från svensk åkermark för år 2009 beräknad med PLC5- metodik*. (SMED Rapport, Nr 57, 2011).Norrkoping: Sveriges Meteorological och Hydrological Institute: www.smed.se. (in Swedish).

Brady, N.C. and Weil, R.R. 1999. The Nature and Properties of Soils. Twelfth Edition. *Prentice- Hall, Inc*. New Jersey. Pp.144.

Bray, R.H. and Kurtz, L.T., 1945. "Determination of total organic matter and available form of P in soils". *Soil Science. 59:39-45*.

Busari, M. A. Adekunle, I.O. and Azeez, J.O 2004. Effects of poultry manure and phosphorus application on the productivity and fodder quality of two centrocema species in an Alfisol. Proceedings of the 24th Annual Conference of the Soil Science Society of Nigeria, December, 6-10, 2004. University of Agriculture Abeokuta, Nigeria. Pp. 133- 142.

Brookes, P.C., Landman, A, Prudes, G and Jenkenson, D. S. 1985. Chloroform Fumigation and release of soil nitrogen; a rapid extraction method to measure microbial biomass and nitrogen in soil. *Soil Biology and Biochemistry*, 17: 837-842.

Calima, J. P., Carcasses, N. and Perel. 2012. Agriculture Environmental indicator for sustainable palm oil production "*Palmas*". 28: 434-445. View at google scholar.

Chakraborty, D., Nagarajan, A., Aggarwal, P., Gupta, V.K., Tomar, R.K., Garg, R.N., Sahoo, R.N., Sarkar, A., Chopra, U.K.,Sharma, K.S. and Kalra, N. 2008. Effect of mulching on soil and plant water status and the growth and yield of wheat in a semi-arid environment. Agricultural Water Management. 95: 1323-1334.

Chude, V. O., Olayiwola, S. O., Osho, A. O. and Daudu, C. K. 2011. Fertilizer Use and Management Practices in Nigeria (4th ed) *Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja,* 128-142.

Corley, R.H.V. and Tinker, P. B. 2009.The Oil Palm. Blackwell science Ltd (4th edition), London 592 pp.

Chude, V. O., Olayiwola, S. O., Osho, A. O. and Daudu, C. K. 2013. Fertilizer Use and Management Practices in Nigeria (4th ed) *Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja,* 128-142.

FAO, 1995. Tillage system in the tropics, *FAO Soils Bulletin*, 71 Food and Agricultural Organization, Rome, Italy. 45pp.

Gee, G. W. and Or, D. 2002. Particle size Analysis. Pp 255 – 293. In: J. H.Dane and G. C. Topp (eds). Methods of Soil Analysis, Part 4, Physical Methods *.Soil Science .Society. America.* No. 5. Madison, WI.

Ghosh, P.K., Dayal, D., Bandyopadhyay, K.K. and Mohanty, M. 2006. Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. Field Crops Research. 99 (2-3): 76-86.

Gordon, W.B.,Whitney, D.A. and Raney, R. A. 1993. Nitrogen management in furrow irrigated and ridge-tilled corn. *Journal of production Agriculture.*6:23-217.

Ikuenobe, C. E. 2016. Evaluation of controlled Released Fertilizer (Agromaster and Agroblend) in the oil palm in Nigeria.*NIFOR In-house Review 2016*, Pp. 60-79.

Hendershort, W.H., Lalande,H. and Duquette, M. 1993. Soils reaction and exchangeable acidity. In: Carter M.R. (ed). Soil Sampling and Methods of Soil Analysis. *Canadian Society of Soil Science*. Lewis Publishers, London, PP 141-145.

ISRIC, (2012). Htt://www.isric.nl/isric/webdocs/majors oils of the World/set3/ar/arenosol.pdf. 25/3/2019.

Jacquemard, J.C., Baudouin, L., Berthaud, A., Graille, J., Huquest, R., Mariau, D., Noel, J. M., Quencez, P. and Tailliez, B. 1998.Oil palm (*The Tropical Agriculturist*). London: Macmillian, Basingstoke. 647pp..

Jury, W. A. and Gardner, W. R. 1991. Soil physics. Fifth ed. John Wiley and Sons, New York.

Liang, Y. and Wang, Z. 2002. The benefits and prospects of no-till and cropland mulch on water conservation of Loess Plateau in China. Presented at the 12th *Conference of International Soil Conservation Organization* (ISCO), May 25-31, Beijing, China. Pp 56-58.

Lim, K. and Zaharah, A. R. 2000. Decomposition and n & k release by oil palm empty fruit bunches applied under mature palms. *Journal of Oil Palm Research,*.12: 55-62.

Walkley, A., and I, A. Black 1934.

Ogeh, J. S. and Adeoye, G.O. 2012. Used and performance of Sokoto rock phosphate and super phosphate on phosphorus fertility and crop yield in cassava-based cropping systems. *Nigeria Journal of Soil and Environmental Research*, 10: 35-45.

Osayande, P. E., Oviasogie, P.O., Aisueni, N.O., Ovie, S., Irhemu, P. and Ekebafe, M.O. 2013. Assessment of diotinite and oxalate extractable iron and aluminum oxides in soils supporting raphia palms at NIFOR main station. *Nigerian Journal of Soil Science,* 23 (2):1-9.

.

Parnes, R. 1990. Fertile soil. A Grower's Guide to Organic and Inorganic Fertilizer. Loss Angeles University of California Pres. 80.

Rattan, Lal.,Manoj, K. and Shukla. 2005. Principles of soil physics. The Ohio state University Combus, Ohio USA Mared Dekkar, *INC New York Basel*, 682pp.

Rowell, .D. L 1994. Soil Science: Methods and applications, *Longman Scientific,* London. (ed) Lewis publisher, 123-133.

Singh, G., Kow, D.L., Lee, K.H., Lim, K.C. and Loong, S.G. 1999. Empty fruit bunches as mulch. In: Oil palm and the environment. A. Malaysian perspective (ed: Singh, G. *et. al*). Publisher: Malaysian Oil Palm Grower's Council. Nov. 1999.

Thomas, G.W. 1982. Exchangeable cation , In Page, A.L *et al (eds) method of soil Analysis* . Part 2, Agron. Monograph, a Second edition, ASA and SSSA Madison. Pp 159-165.

Walkley, A. and Black, I. A., 1934. Determination of organic matter in soil. Soil science 37: 549- 556

USE OF ROCKDUST FOR SOIL FERTILITY AMENDMENT AND PERFORMANCE OF MAIZE GROWN ON DEGRADED SOIL

[1]Ndor, E*, [1]Usman, I.N and [2]Jayeoba O. J
[1]Department of Crop Production Technology, College of Agriculture, Science and Technology Lafia, Nasarawa State, Nigeria.
[2]Department of Agronomy, Faculty of Agriculture, Nasarawa State University, Shabu-Lafia, Nigeria
Corresponding author email:ndors12@yahoo.com

ABSTRACT
The experiment was conducted during 2023 rainy season at the Research and Teaching farm of the College of Agriculture, Science and Technology Lafia, Nasarawa state, Nigeria; to determine the effect of rock dust amended soil on the growth and yield of maize (Zea mays). The treatment consisted of five rates of rock dust: 0, 7.5, 15, and 30 t ha^{-1}). The experiment was laid in Randomized Complete Block Design (RCBD). The result showed that, there was significant ($P<0.05$) difference in application of rock dust on plant height of maize. Application of 30t/ha of rock dust produced the tallest maize plants (85.20cm) which is statistical at par with the application of 15t.ha of rock dust. However, application of rock dust did not produced any significant ($P<0.05$) effect on the number of leaves. Also, rock dust showed a significant ($P<0.05$) effect on grain weight and 100 grain weight of maize. Application of 30t/ha rock dust produced the highest grain weight of 3895.20kg/ha of maize; which is at par with application of 15t/ha of rock dust, but higher than other rates of application and the control.

Keywords: *Rock dust, Soil, Amendment, Performance, Maize*

INTRODUCTION

Finely ground, chemically unprocessed rocks of different types have been used in agriculture since the latter half of the 19th century (van Straaten, 2002). One of the first advocate of the use of rock dust in agriculture was a German agricultural chemist Julius Hensel who described the use of stone meal in agriculture in his book '*Bread from Stones*'. Also, another scientist Hamaker (1982) developed Hensel's ideas and coined the expression '*soil remineralization';* theorizing that addition of ground rocks rejuvenates weathered soils by mimicking what happens after an ice age or volcanic eruption. Rock dust is a by-product of quarrying operations that extract and screen rocks for construction industry. Rock particles larger than 6 mm are generally used in asphalt production with a current high demand for 10 mm single-sized aggregate. Other descriptions of rock dust include: rock powder, rock fines, mineral fines and quarry tailings. Rock dust may be further processed to generate very fine grade material or used in the state that they are produced (a mix of very fine and coarser particles).

Soil fertility degradation is recognized as a constraint to increase food production and farm incomes in many parts of Sub-Saharan African (Henao and Baanate, 2004). Nigeria been one of the countries in Sub-Saharan African is also undergoing a serious problem of soil degradation. The current low soil fertility status of some Nigeria soil has been aggravated by improper and inappropriate soil conservation and management practices. The fastest and easier way of soil fertility rejuvenation is the use of chemical fertilizers (Asadu, 2014). The shortage and high cost of inorganic fertilizers have limited their uses for maize production among the peasant farmers in Nigeria. While, rock dust have been advocated to be use for soil amendment by van Straaten, (2006) as far back as 20th century; he demonstrated an increasing number of conceptual works on rock dust for soil amendment together with laboratory and field experiments. At infancy, research on rock dust applications in agriculture have failed to produce unambiguous results of its efficacy as a soil amendment material (Winiwarter and Blum, 2008). However, the increased yields earlier reported by Fyfe, *et.al*. (2006); was disputed because, the negative results of the experiment conducted by Bakken, *et. al.,* (2000) clearly showed that rock dust doesn't provide a *one fits all*-solution for soil fertility rejuvenation. The claims made about the benefits of using rock dust in agriculture originated from the work of Hamaker (1982) who promoted 'remineralization' of the soil using glacial rock dust which was reported to increase soil mineral content and increase plant quality. Van Straaten (2006) reviewed the advantages and disadvantages of using rock fertilizers in agriculture. He reported that the advantages of using rock dust for soil amendment include: the multi-elemental release; high pH; possible improvement to the acid neutralization capacity of some soils; or changes to the cation exchange capacity of some soils. While, the disadvantages were identified as the low solubility and slow nutrient release; large application rates required and that a large portion of the rock could be minerals with no nutrient value.

In view of the scanty available scientific evidence showing the usefulness of rock dust in amending the soil to increased plant growth and yield in Nigeria. Therefore, the present study was designed to consider the effect of application of rock dust on growth and yield of maize.

MATERIALS AND METHOD

3.1 Experimental Site

The experiment was conducted during 2023 rainy season at the research and teaching farm of the college of agriculture, Lafia, Nasarawa state, Nigeria. The study area falls within southern guinea savanna agroecological zone of Nigeria, and is located between latitude 08º 33' N and longitude 08º 32' E

3.2 Climatic Condition

Rainfall usually starts from March – October and the average yearly rainfall in Lafia, Nasarawa State, is around1100 - 1700 millimeters. This falls under the category of a tropical wet and dry climate, with the rainy season typically starting in April and ending in October. The months of July and August usually records heavy rainfall. The daily maximum temperature ranges from 20.0ºC – 38.5ºC and daily minimum ranges from 18.7ºC – 28.2ºC.

The months of February to early April are the months that have the highest maximum temperature while the lowest maximum temperature months are recorded in December and January because of the prevailing cold harmattan wind from the northern part of the country at this period. The relative humidity rises as from April to a maximum of about 75-90 percent in July (NIMET 2023).

3.3 Soil

The soil type of the study area composed of highly leached Alfisols with low base saturation. The soil is strongly acidic and has high content of iron and Aluminium oxides hence reddish brown in colour with very low organic matter content and low total nitrogen and available phosphate.

3.4 Treatments and Experiment Design

The treatments consisted of three levels of rockdust (0, 7.5, 15, and 30 t/ha). The experiment was laid in a Randomized Complete Block Design (RCBD) and replicated three times to form 12 plots. The plot size was 3 m by 4 m and 0.5m in between plots and 1 m between replicates.

3.5 Agronomic Practices

The land was cleared ploughed and harrowed; then rock dust was obtained from Chinese Road Construction Company and was incorporated base on the different treatment rates into the soil. Then, maize were planted on the plots at spacing of 75cm by 30cm and other agronomic practices like weeding, fertilizer application etc were carried out.

3.6 Data Collection

Soil samples were taken at a depth of 0-15cm before planting of maize and were analyzed as presented in (Table 1). Four maize plants were selected from the net plot and tagged and the following data were taken from them: Growth parameter (Plant height and number of leaves). The yield parameters: Cob length, cob width, number of lines/cob, 100 grain weight, cob weight/plant and seed weight (kg/ha).

3.8 Data Analysis

The data collected was subjected to analysis of variance using GENSTAT, and where there was a significant difference; the means was separated using F-LSD at 5% probability level.

RESULTS AND DISCUSSION

4.1 The results of the Physical and Chemical Properties of the soil before planting

The result of the soil analysis revealed that the textural classes in the experimental sites before cropping was loamy sand; low in nitrogen, phosphorus, potassium, organic matter and also cation exchange capacity. Also, the soil was slightly acidic in nature with pH of 5.63; high in percent sand fraction (88.00%) and also very high in percentage base saturation of 80.94%

Table 1: Results of Soil before incorporating into soil

Properties	Soil	Rock dust
Physical properties		
Sand%	88.0	ND
Silt%	3.4	ND
Clay %	8.6	ND
Textural class	Sandy loam	ND
Chemical properties		
pH in H_20	5.63	7.88
Ashes	ND	ND
Organic carbon%	1.8	ND
Organic matter(g kg^{-1})	2.37	ND
Total nitrogen(g kg^{-1})	2.1	0.8
P (ppm/mgkg^{-1})	3.01	1.3
Ca(cmolkg^{-1})	3.48	104.0
Mg(cmolkg^{-1})	2.63	27.6
K(cmolkg^{-1})	0.25	35.1
Na(cmolkg^{-1})	0.27	ND
CEC(cmolkg^{-1})	7.29	ND
BS%	80.94	ND

4.2 Effect of Rock dust on plant height

The result on table 2 showed that there was significant ($P<0.05$) difference in application of rock dust on plant height of maize. Application of 30t/ha of rock dust produced the tallest maize plant (85.20cm) which is statistical at par with the application of 15t.ha of rock dust. However, application of rock dust did not produced any significant ($P<0.05$) effect on the number of leaves.

Table 2: Effect of rock dust on growth parameters of maize at seven weeks after planting

Treatment	Plant height (cm)	Number of leaves
Rock dust (t)		
0	71.50	11.25
7.5	72.10	11.32
15	82.80	11.47
30	85.20	11.92
LSD(0.05)	1.15	0.98

4.3 Effect of rock dust on yield and yield component of maize

Rock dust showed a significant ($P<0.05$) effect on grain weight and 100 grain weight of maize (Table 3). Application of 30t/ha rock dust produced the highest grain weight of 3895.20kg/ha of maize; which is at par with application of 15t/ha of rock dust, but higher than other rates of application and the control. However, cobs length, width and the number of lines per cob were not significantly affected by application of rock dust.

Table 3: Effect of rice husk biochar and rock dust on yield and yield component of maize

Treatment	Cob length (cm)	Cob width (cm)	No of lines/cob	100 grain weight(g)	Cob weight/plt (g/plant)	Cob weight/ha (Kg/ha)
Rockdust (t)						
0	11.94	11.00	13.75	29.89	72.54	3143.38
7.5	12.83	12.67	13.25	31.04	79.34	3438.04
15	12.92	12.83	13.92	32.12	84.93	3680.32
30	12.92	13.17	14.33	32.24	89.89	3895.20
LSD(0.05)	1.82	0.92	1.77	1.05	2.08	192.56

Discussion

The study revealed that the soil is sandy loam, slightly acidic and generally low in soil nutrients and therefore very low in fertility and required nutrients supplementation before crops can be grown. This confirmed the findings of (Jayeoba, *et al.,* 2012) who reported that the soils around Nasarawa state were acidic and low in fertility. The incorporation of rock dust resulted in increase in the pH of the soil which brought about a reduction in soil acidity; also the rock dust used in this experiment is rich in Ca and Mg. This phenomenon enhanced the soil availability of the major plant nutrient (nitrogen, phosphorus and potassium). The vigorous growth in plant height of maize exhibited by rock dust application could be attributed to the fact that, rock dust has very high content of Ca, Mg and K. These are highly soluble mineral salt that could get into the soil very quickly. Also, the significant response of maize yield and yield parameter (cobs length and width, 100 grain weight and fresh fruit yield) may also be as a result of proper soil nutrient amendment which resulted to improvement in the soil fertility (Leonardos *et.al.* 2000).

Conclusion

From the result of the study, it can be concluded that 30t ha^{-1} of rock dust is the optimal rates of rock dust that can enhanced a good growth, yield and environmentally friendly production of maize

References

Asadu, C.L.A (2014) The Soil We Do Not Know. Inaugural Lecture (No 81) presented to the University Community at PAA Hall, University of Nigeria Nsukka.

Bakken, A. K., Gautneb, H., Sveistrup, T. and Myhr, K. (2000) Crushed rocks and mine tailings applied as NPK fertilizers on grassland. Nutrient Cycling In Agroecosystems, 56: 53-57.

Fyfe, W. S., Leonardos, O. H. & Theodoro, S. H. (2006) Sustainable farming with native rocks: the transition without revolution. Anais da Academia Brasileira de Ciencias, **78**, 715-720.

Leonardos, O.H., Theodoro, S.H. and Assad, M.L. (2000), "Remineralization for sustainable agriculture: A tropical perspective from a Brazilian viewpoint", *Nutrient Cycling in Agroecosystems*, No. 56, pp. 3–9.

Hamaker, J. D. (1982) The Survival of Civilization. Hamaker-Weaver Publishers

Henao, J. and Baanate, C.(2004). Agricultural production and soil nutrient, mining in Africa. Implication for Resource Conservation and Policy Development.

Ndor E, Agbede OO, Dauda SN.(2010) Growth and Yield Response of Cotton (Gossypium spp) to varying Levels of Nitrogen and Phosphorus Fertilization in Southern Guinea Savanna Zone, Nigeria. Journal of Production Agriculture 2010;6(2):119-125

NIMET (2023) Nigerian Meteorological Agency. Lafia station

van Straaten, P. (2006). Farming with rocks and minerals: challenges and opportunities. *Anais da Academia Brasileira de Ciencias , 78* (4), 731-747.

van Straaten, P. (2002). *Rock for Crops: Agrominerals of sub-Saharian Africa.* Nairobi, Kenya: ICRAF.

Winiwarter, V. and Blum, W.E.H. (2008), "From marl to rock powder. On the history of soil fertility management by rock materials", *Journal of Plant Nutrition and Soil Science*, Vol. 171 No. 3, pp. 316–324.

SOIL MOISTURE CHARACTERISTICS IN BAUCHI STATE, NIGERIA

[1]*Ekle, A.E., [2]Babaji, G.A., [2]Hassan, A.M., [2]Voncir, N. [1]Abdusalam, R.A
[1]Department of Soil Science Technology,
Federal College of Land Resources Technology, Kuru, Jos, Plateau State, Nigeria
[2]Department of Soil Science, Abubakar Tafawa Balewa University,
Bauchi, Bauchi State, Nigeria
Corresponding author email:ekleademu7@gmail.com

ABSTRACT
This study was undertaken to assess the soil water retention and release characteristics in parts of Bauchi State soils derived from basement complex parent material with the view to enhancing agricultural planning and management in the region. Triplicate core samples were collected randomly within 0 – 60 cm at an interval of 0-20 cm using 5.0 cm in diameter and 3 cm high rings of known weight (W) and volume (V). Soil moisture contents at pressure of 0.33 bar, 1.00 bar, 3.33 bar, 7.00 bar, 10.00 bar and 15.00 bar were determined using pressure plate extractor. These moisture contents on mass basis were graphed against their corresponding tension values to give a soil-specific curve known as the soil moisture characteristics (SMC) curve. Also three (3) disturbed samples were taken from each depth and composited to one in all locations and soil texture was determined following standard procedure. Toro and Gubi recorded the highest percentage particles above 2mm and therefore exhibited little or no jump in available moisture after 1bar, whereas Nabordo and Birshe Fulani exhibited jumps at higher tensions indicating presence of plant available water at higher tensions.
Keywords: Soil moisture retention, basement complex rock, Bauchi, plant available water.

Introduction

Water percolating through soil is filtered, stored for plant utilization, and redistributed across flow paths to groundwater and surface water bodies. As such, the sustainability of water resources (considering both quantity and quality) is directly influenced by soil. Thus, most aspects of terrestrial- and freshwater aquatic-life depend on hydrologic processes in soil (O'Geen *et al.,* 2010). Water dynamics in soil are governed by many factors that change vertically with depth, laterally across landforms and temporally in response to climate (Swarowsky *et al*., 2011).

Stored water in soil is a dynamic property that changes spatially in response to climate, topography and soil properties, and temporally as a result of differences between utilization and redistribution via subsurface flow (Western *et al.,* 1999). Changes in soil moisture storage can be generalized with a mass balance equation as a result of the difference between the amount of water added and that which is lost (Hillel, 1982).

Three soil moisture states, saturation, field capacity and permanent wilting point are used to describe water content across different water potentials in soil and are related to the energy required to move water (or extract water from soil). When the soil is at or near saturation the direction of the potential energy gradient is downward through the soil profile or laterally down slope. This mechanism of flow by the force of gravity occurs mainly in macropores. As the soil dries, field capacity is reached after free drainage of macropores has occurred. Field capacity represents the soil water content retained against the force of gravity by matric forces (in micropores and mesopores) at tension of -0.033 Mpa (Brady & Weil, 2002 and McCauley *et al.*, 2005). As water content decreases, soil matric potential decreases, becoming more negative, and as a result, water is held more strongly to mineral surfaces due to cohesive forces between water molecules and adhesive forces associated with water and mineral particles (capillary forces). Water held between saturation and field capacity is transitory, subject to free drainage over short time periods, hence is it is generally considered unavailable to plants. This free water is termed drainage porosity (O'Geen, 2013). In contrast, much of the water held at field capacity is available for plant uptake and use through evapo-transpiration (Brady & Weil, 2002 and McCauley *et al.*, 2005).

An assessment of water retention and release characteristics is an important agricultural practice that is not available in agriculturally potential Bauchi State, Nigeria. Keeping this in view, this study was undertaken to assess the soil water retention and release characteristics in parts of Bauchi State soil derived from basement complex parent material with the view to explore seasonal variations and long term trends in soil moisture dynamics for enhanced agricultural planning and management in the region.

Materials and Methods

Bauchi State occupies a total land area of 49,119km^2 representing about 5.3% of Nigeria's total land mass and is located between latitudes 9^0 30^1 and 12^0 30^1 North and longitudes 8^0 45^1 and $11^0$0' East (UNDP Report 2018). The state is bordered by seven states; Kano and Jigawa to the north, Taraba and Plateau to the south, Gombe and Yobe to the east and Kaduna to the West.

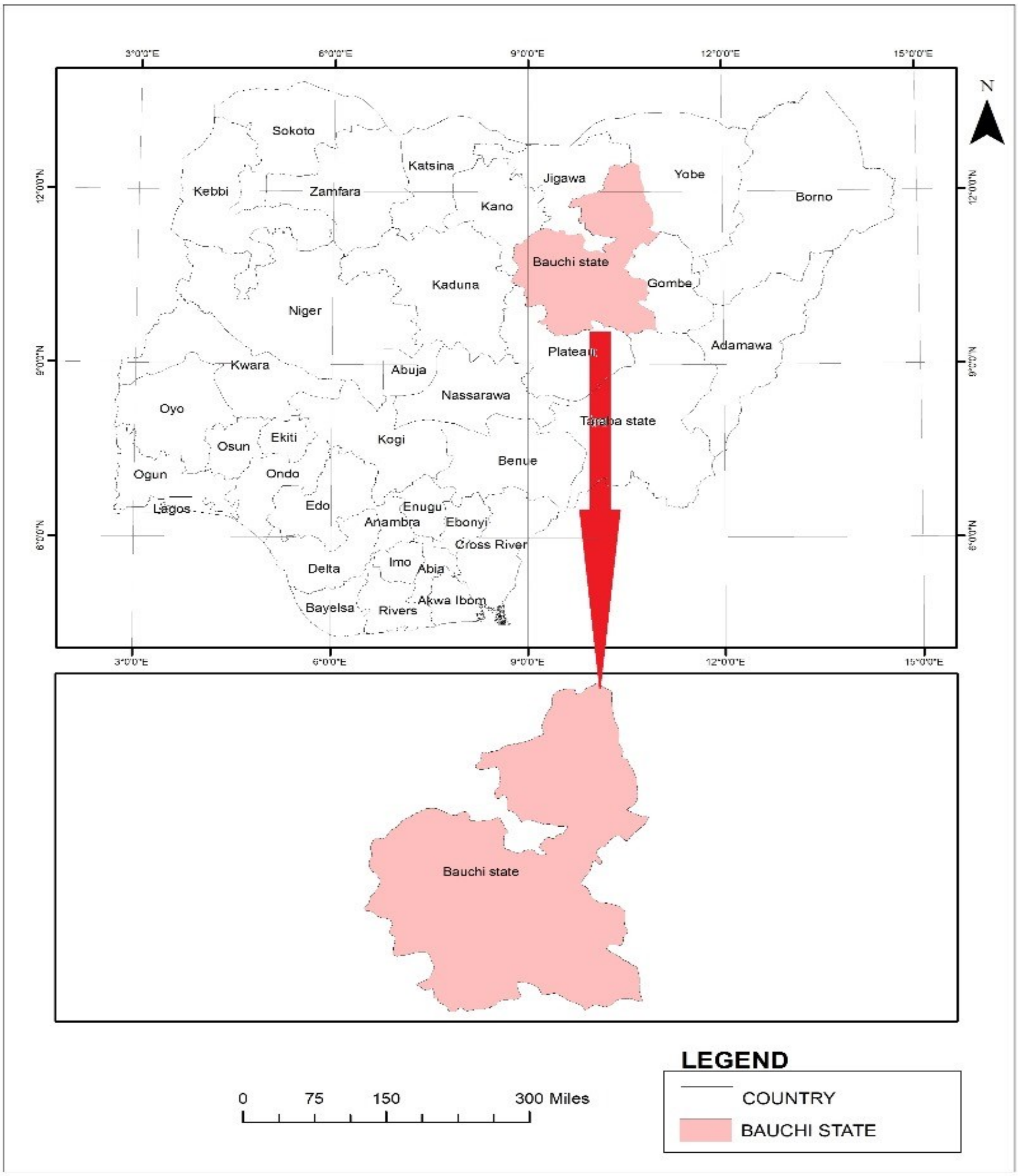

Fig 1: Study location

Climate of the Study Area

The state experiences two main seasons; rainy and dry season. The rainy season usually commences from May and ends in September with minimum rainfall of about 700mm per annum in the north to a maximum of about 1300mm per annum in the South. The vegetation is typically Sudan Savanna type comprising widely dispersed trees (Ibrahim, 2010)

Geology of Bauchi State.

Lithologically, soils in Bauchi State are formed from Basement Complex Rock (BCR) and the Sedimentary Rocks comprising the Kerri-Kerri Formation (KKF) and the Chad Formations (CF)

(Macleod *et al*., 1971). The BCR covers most part of the State. Bauchi is basically composed of crystalline rocks, basement complex mostly Precambrian to the early Paleolithic in age. The rocks include the mixture of granites, gneisses, pegmatite and some amount of charnokite at the margin around the area of Alkaleri. Granites are coarse grained and are composed of quartz, alkali, feldspar, biotite and muscouite with ancestry horn bled and haematite. Pegmatite veins within the gneisses are composed of potash feldspar and very large crystal may form. A charnokitic rock occurs around the margin where it forms small out crops. Bauchi metropolis lies within the undifferentiated basement complex with older granites outcrops and young granites out crops. The basement complex is best described as crystalline rocks of the area (Macleod *et al*., 1971).

Site Selection

Two local government areas were used. A total of 54 samples were used in each location given rise to 216 samples in all. The coordinates of the specific locations where samples were taken were marked using Geographic Positioning System (GPS) as follows; Toro 10º 08' 17.5"N and E009º 24' 10.4" on an elevation of 978m; Nabordo 10º12'57.6" and E009º 24' 10.4" on an elevation of 712m; Birshe Fulani N10º14' 46.3" and E009º 45' 39.7" on an elevation of 638m; Gubi N10º 27' 42.2" and E009º 49' 57.8" on an elevation of 603m above sea level.

Field Procedure

The collection of soil sample was done starting from the upper layer (0 – 20cm). The excavation of the soil to allow for taking of soil samples was carried out by the use of digger while shovel was used to move out the soil particles. After the excavation of the pit to 1m, a measuring tape was used to measure the depth at which the samples were taken (0 – 20cm, 20 – 40cm and 40 – 60cm) depth. The undisturbed samples were collected using the core samplers while the disturbed samples were taken using a hand trowel into sampling polythene bags. All the samples collected were labeled and the same procedure was used in collecting the samples from all locations and depths. Materials used in the field were Cutlass, Digger, Shovel, Meter rule, Sampling rings, Auger, Polythene bags, Hammer, Global Positioning System (GPS), Rubber ban, Piece of cloth.

Laboratory Procedure

Particle Size Determination

Soil samples were air-dried and served through a 2mm mesh. Particle size analysis was carried out by hydrometer method (Juo, 1979) using sodium hexametaphosphate as the dispersant.

Bulk density

Soil bulk density was determined by undisturbed core method (Klute, 1986). Three core samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm using 5.0cm diameter and 3cm high rings of known weight (W_1) and volume (V). The samples were put in an oven at 105^0C for 24hours and its weight (W_2) was recorded. Bulk density was calculated at each tension levels.

Determination of Soil Hydraulic Properties.

Soil moisture content on mass basis

Soil moisture content on mass basis (mass wetness) was determined by weight of water at a given tension level divided by weight of oven dried soil. The water content was then expressed on percent basis, thus: Mass of water/mass of soil solids x 100 as described by Anderson and Ingram, (1993) and presented in appendix i.

Moisture content at field capacity

Moisture content at field capacity was the mass wetness at 0.33bar as shown in appendix i (Anderson and Ingram, 1993).

Moisture content at permanent wilting point

Moisture content at permanent wilting point was the mass wetness at 15bar as shown in appendix i (Anderson and Ingram, 1993)

Available soil moisture in the soil

Available moisture in the soil is the difference between the soil moisture obtained on mass or volume basis at field capacity and permanent wilting point (Israelson and Hanson, 1962).

Soil moisture retention and release characteristics:

Soil moisture retention and released characteristics of the samples was determined using the pressure plate apparatus. A triplicate samples was used at each depth for each pressure head (0.33bar, 1.0bar, 3.3bar, 7bar, 10bar and 15bar) from 0 – 60cm depth at an interval 0 – 20cm for undisturbed samples as described by Smith & Mullins (1991). Each sample was carefully taken and covered at the bottom with a piece of cloth tied by rubber ring to the sampling ring. The rings were 50mm in diameter and 30mm in height. The soil samples while in the rings were soaked in water inside a tray overnight and pressure was applied to the system the next morning. For each depth, a moisture retention determination was made in triplicate at all the tension levels chosen. However, the triplicate samples were all place on the equipment at the same time. The amount of moisture was determined after equilibrium was reached in about 3 – 5days depending on the texture of the sample. The samples were oven-dried at 105^{0}C for 24hours and the results were expressed in percent moisture on a dry weight basis. All the water held between FC and PWP are available to plants, and all tension values from FC to PWP correspond to given moisture contents for any soil. These moisture contents on mass basis was graphed against their corresponding tension values to give a soil-specific curve known as the soil moisture characteristics (SMC) curve.

Results and Discussions

The soils in the four locations considered in this study were formed from the same parent material (basement complex) and therefore have similar textural characteristics (Table 1). The textural class obtained from the breakdown of basement rocks can vary depending on factors such as the specific mineral present, the intensity of weathering and the climate of the region. Mustapha *et al*., (2002) reported a strong influence of parent materials on the clay distribution in soil in Niger.

Table 1: Particle Size Distribution of Soils of the Study Area.

Location	Depth (cm)	% of soil in the sample(<2mm)	%Sand	%Silt	% Clay	Texture class
Toro	0-20	40.10	66.32	21.44	12.24	Sandy clay loam
	20-40	51.50	53.32	31.44	16.24	Sandy clay loam
	40-60	77.20	36.24	33.44	30.34	Sandy clay loam
Nabordo	0-20	88.00	64.32	16.24	19.44	Sandy clay loam
	20-40	89.60	64.32	25.44	10.24	Sandy clay loam
	40-60	91.80	62.32	25.44	12.24	Sandy clay loam

Birshe Fulani	0-20	81.50	55.60	13.44	30.96	Sandy clay loam
	20-40	77.40	57.60	9.44	32.96	Sandy clay loam
	40-60	79.60	53.60	17.44	28.96	Sandy clay loam
Gubi	0-20	88.80	56.60	25.44	18.96	Sandy clay loam
	20-40	77.10	54.24	22.80	22.96	Sandy clay loam
	40-60	43.20	58.24	16.80	24.95	Sandy clay loam

Table 2 showed the moisture content at field capacity, permanent wilting point of the study area. From the result, the value did not differ one and the other essentially. Table 2 also showed the values of available water content of the study area. The hydraulic parameters did not differ essentially from one another. This may have been as a result of the fact the soil is derived from the same parent material as also reported by Mustapha *et al*., (2002) who opined a strong influence of parent materials on the clay distribution in soil in Niger.

Table 2: Hydraulic Parameters of Soil of Basement Complex Origin (Toro and Bauchi LGA) on Cultivated Land in Bauchi State.

Sample No	Soil Depth	Bulk Density(g/cm^3)	FC (water%)	PWP (water%)	Available water(%)
TR (I)	0-20cm	1.37	17.90	31.70	13.80
TR (II)	20-40cm	1.36	19.50	23.60	4.10
TR (III)	40-60cm	1.38	21.30	27.40	6.10
NB(I)	0-20cm	1.36	18.40	26.20	7.80
NB(II)	20-40cm	1.33	20.60	27.80	7.20
NB(III)	40-60cm	1.36	18.20	24.20	6.00
BF(I)	0-20cm	1.37	15.50	22.70	7.20
BF(II)	20-40cm	1.23	24.40	37.80	13.40
BF(III)	40-60cm	1.24	25.60	32.50	6.90
GB(I)	0-20cm	1.42	15.20	19.50	4.30
GB(II)	20-40cm	1.52	26.80	31.40	4.60
GB(III)	40-60cm	1.51	23.00	29.50	6.50

FC = Field capacity, PWP = Permanent Wilting Point

Fig. 2 represents the moisture characteristics of soils of Toro sample location in Toro Local Government Area of Bauchi State. From the beginning, the curve experienced a very steep slope at low tension which is an indication of high available moisture lost at low tension of between 0 – 1bar. Afterwards, the curve ran more or less parallel to the soil moisture tension axis, indicating that little or no moisture was released between field capacity and permanent wilting point. This result was also reported by Obi and Akamigbo, (1981) "when the curve runs more or less parallel to the soil moisture tension axis, it implies that little or no available moisture is released between FC and PWP, as observed for some fine-textured soils in Nsukka; but when the curve slopes down quickly and then subsequently becomes gentle, it implies that much of the AWC of the soil sample is lost at very low tension".

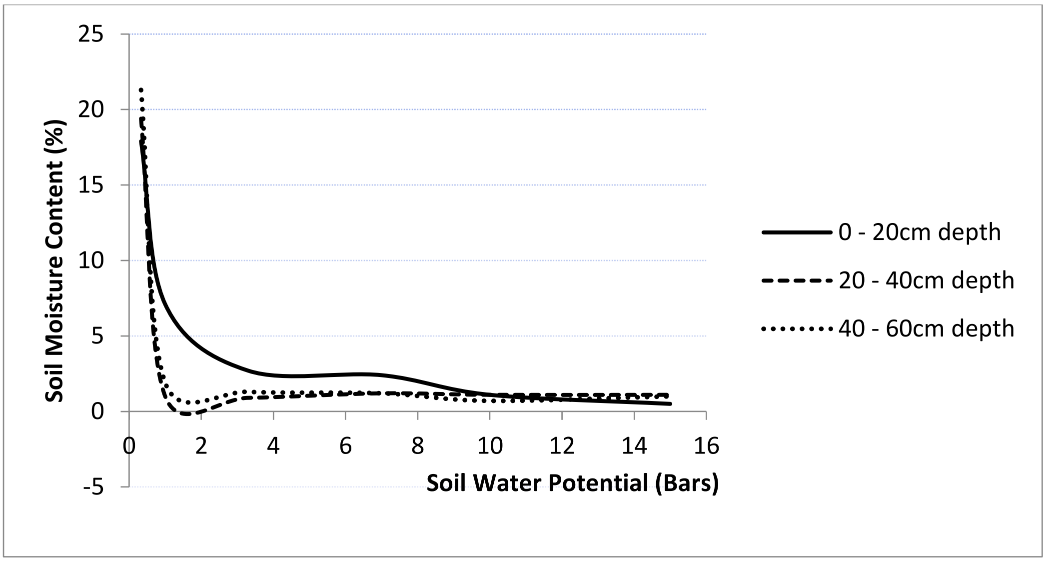

Fig. 2: Soil Moisture Characteristics Curve of Toro Town in Toro Local Government Area of Bauchi State.

The curves had a very steep slope up till 1bar and then jumped uptil 9bar. Afterwards, the curves of 20-40 and 40 – 60cm turned horizontal to the x-axis. The curves did not differ from each other essentially. The steep slope of SWRC increased the amount of water available to crops planted in the area at that tension as explained by peters, (1957) in his suggestion of mathematical relationship that the radius of soil from which plant roots must extract its water is directly proportional to the amount of water absorbed and inversely proportional to the slope of the moisture retention curve. Also, the horizontal phase of the curve at high tension could be due to materials with greater particle size heterogeneity, the effective pore size can be reduced by the effect of empty spaces between larger grains being occupied by smaller particles (packaging phenomenon); thus, it is possible for certain particle size distributions to cause soil compaction and minimize pore space as also reported by Donagemma *et al*., (2016). The third characteristic of the curves was that they exhibited the same behavior such that they are relatively close to each other.

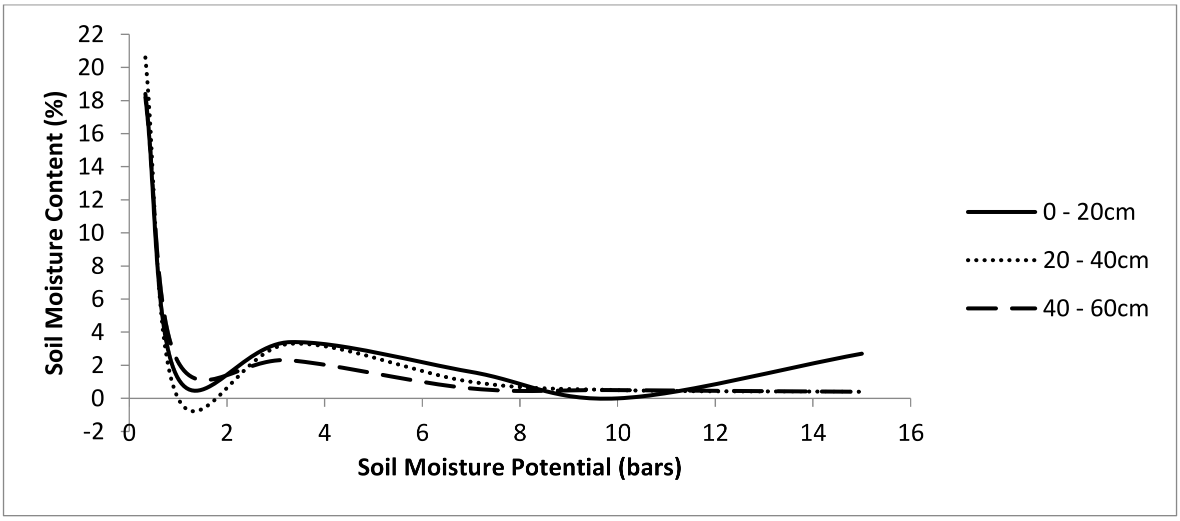

Fig. 3: Soil Moisture Characteristics Curve of Nabordo Town in Toro Local Government Area of Bauchi State.

The curves had a very steep slope up till 1bar and then jumped uptil 10bar. Afterwards, the curves of 20-40 and 40 – 60cm turned horizontal to the x-axis. The curves did not differ from each other essentially. This steep slope of SWRC increased the amount of water available to crops planted in the area at that tension as explained by peters (1957) in his suggestion of mathematical relationship that the radius of soil from which plant roots must extract its water is directly proportional to the amount of water absorbed and inversely proportional the slope of the moisture retention curve. The third characteristic of the curves was that they exhibited the same behavior such that they are relatively close to each other due to similar mechanical content as also supported by Vucic, (1987) who reported that soil water retention in different tension is in tight correlation with humus, clay, silt and mineralogical composition of the clay particles.

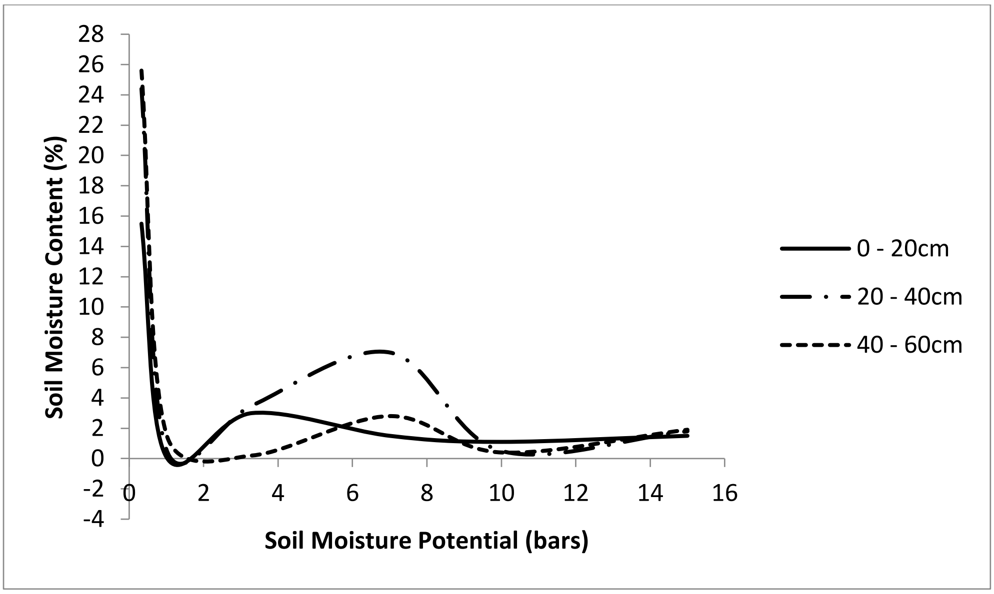

Fig. 4: Soil Moisture Characteristics Curve of Birshe Fulani Town in Bauchi Local Government Area of Bauchi State.

The curves had a very steep slope up till 1bar and a jumped between 2 to 8 bar and 10 to 14 bar.. This steep slope of SWRC increased the amount of water available to crops planted in the area at that tension as explained by peters (1957) in his suggestion of mathematical relationship that the radius of soil from which plant roots must extract its water is directly proportional to the amount of water absorbed and inversely proportional the slope of the moisture retention curve. Due to similar mechanical content of the samples at the different depth, the retention curves do not differ essentially from each other. The behavior of this curve is in agreement with the work of Vucic, (1987) who reported that soil water retention in different tension is in tight correlation with humus, clay, silt and mineralogical composition of the clay particles.

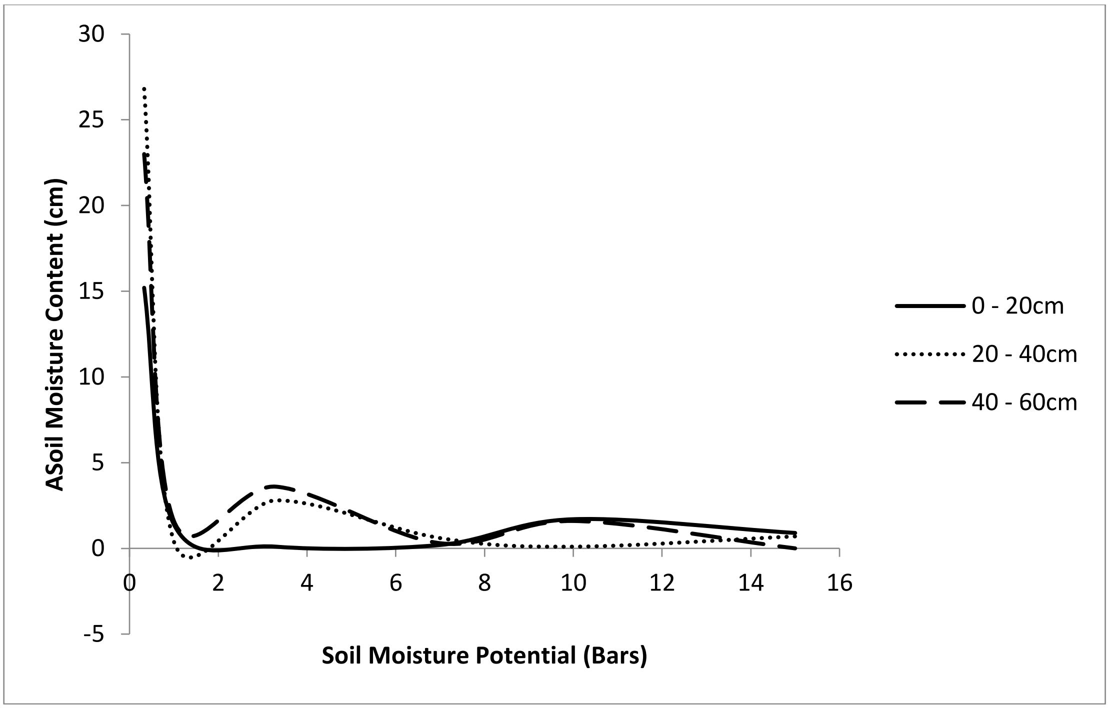

Fig. 5: Soil Moisture Characteristics Curve of Gubi Town in Bauchi Local Government Area of Bauchi State.

Conclusion

In all the locations studied, irrigation practice was required to prevent dry spell. Based on the curve, Toro location required irrigation scheduling first followed by Gubi sample location before Nabordo and finally Birshe Fulani sample location. Understanding these differences in irrigation schedule is essential for implementing tailored irrigation and soil management strategies to optimize agricultural productivity in the region.

References

Anderson, J.M. and Ingram, J.S. (1993). Tropical Soil Biology and Fertility. A Handbook of Methods. Information Press Eynsham.

Brady, N. C. & Weil, R. R. (2002). *The Nature and Properties of Soils*, 12th ed. Upper Saddle River, NJ: Prentice Hall.

Donagemma, G.K. et al., (2016): Caracterizacao, potential agicola e perspectivas de manejo de solos leves no Brazil. Pesq Agropec Bras 51: 1003-1020.

Juo, A.S.R. (1979). Selected Method for Soil and Plant Analysis. Ibadan; International Institute of Tropical Agriculture (IITA), Nigeria.

Hillel, D. (1980): Application of Soil Physics. Department of Plant and Soil Sciences, Massachusetts, Academic Press.

Ibrahim, O.I. (2010).. Application of VES for Groundwater Exploration in Inkil, Bauchi LGA, Bauchi State. Unpublished Project, Geology Programme, ATBU, Bauchi.

Israelson O.W., and Henson, V.O. (1962)..Irrigation Principles and Practices 3rd Edition, Wiley International Edition, New York, USA.

Klute, A. (ed) (1986). Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods. *American Society of Agronomy*. Madison.

McCauley, A., Jones, C. & Jacobsen, J. (2005) Soil and Water Management Module 1: Basic

Soil Properties. Bozeman, MT: Montana State University Extension Service.

Mustapha, S.; Singh, L.; Babaji, G.A.; Saddiq, A.M. (2002): Effects of Parent Rocks,

Topographic Position and Depth on Some Soil Extractable Micronutrients. Niger. *J. Tropic Agri*., **4**. 85-91.

Obi, M.E. and Akamigbo, F.O.R. (1981). Water relations of the soil of the Niger-Anambra flood plains of southeastern Nigeria. *Catena, **8**,* 282-288.

O'Geen, A. T. *et al*. (2010).Research connects soil hydrology and stream water chemistry in California oak woodlands. *California Agriculture***64**, 78-84.

O'Geen, A.T. (2013): Soil Water Dynamics. *Nature Education Knowledge*. 4(**5**): 9.

Peters, D.B. (1957). Water Uptake of Corn Roots as Influenced by Soil Moisture Content and

Soil Moisture Tension. Ibid. 21: 481-484.

Smith, K.A, and Mullins, C.E. (1991). Soil Analysis: *Physical Methods*, Marcel Dekker, New York, pp. 161 – 207.

Swarowsky, A., *et al*. (2011). Catchment-scale soil water dynamics in a Mediterranean-type oak woodland. *Vadose Zone Journal,* **10**,800-815.

Vucic, N (1987). Matter, Air and Thermal Regime of Soil, VANU Department of Natural Sciences. Novi Sad. Pp. 1-320.

United Nation Development Programme Report (2018). Human Development. Achieving *Human Development in North East,* Nigeria.

Western, A.W., Grayon, R.B., Bloschl, G., Willgoose, G.R. McMahon, T.A. (1999): Observed

Spatial Organization of Soil Moisture and its Relation to Terrain Indices. *WaterResources Research***35** (3): 797-810.

INTEGRATED SOIL FERTILITY MANAGEMENT: PANACEA FOR SUSTAINABLE CROP PRODUCTION AND IMPROVED LIVELIHOOD OF SMALLHOLDER FARMERS: A SURVEY

***Ande, O. T., B. O. Lawal, I. O. Fademi, S. A. Mesele1, K. S. Are, G. T. Oyerinde2, J. E. Huising, G. A. Oluwatosin and J. A. Adediran**

[1]*Institute of Agricultural Research and Training, O. A. U., Moor Plantation, Ibadan*

[1]*International Institute of Tropical Agriculture,*

[2]*Indorama Eleme Fertilizer and Chemicals Ltd, Abuja*

Corresponding author email: funmiande67@gmail.com

ABSTRACT

A survey was conducted to convey the significance of Integrated Soil Fertility Management (ISFM) to relevant stakeholders to boost agricultural productivity and enhance the livelihood of smallholder farmers in Southern Nigeria. The Nigeria Soil Health Consortium (South) coordinated by AGRA/IITA and hosted by Institute of Agricultural Research and Training was saddled with the responsibility to promote wider uptake of ISFM protocols among small holder farmers in southern ecologies of Nigeria. The survey was conducted in 8 States of Nigeria comprising: Ogun, Oyo, Osun, Ondo, Lagos, Akwa- Ibom, Edo and Delta States in collaboration with extension agents. Interview schedule was used to elicit information from farmers while questionnaires were produced for extension agents in all the selected States. Results showed that the age long problem of fertilizer availability, accessibility and affordability still persists. Moreover, lack of adequate knowledge in soil management in spate of climatic change has aggravated soil fertility decline among smallholder farmers. Hence, integrated soil fertility management approach where resources within the farms are pulled together with little external inputs based on farmers' knowledge of their soils will suffice the problem of low productivity. Strategic use of ISFM protocols is recommended for the region which include, improved high yielding seed varieties, combined use of organic and inorganic fertilizers, local adaptations strategies such as proper tillage, supplementary water supply, inclusion of cereal-legume cropping systems, live mulching, cover cropping as appropriate and continuous training of farmers on implementation of the strategies.

Keywords: Agricultural productivity, Extension workers, small holder farmers, Integrated soil fertility management strategies.

Introduction

Land degradation and decline in soil fertility have become serious threats to agricultural productivity in Sub-Saharan Africa, Nigeria inclusive. The declining fertility of soils as a result of soil nutrient mining is a major cause of decreased crop yields and per capital food production in Nigeria. Decreasing soil fertility accompanied with increasing population pressure is one of the major causes of the gap between demand for and supply of food.

Provision of adequate food supply to satisfy the needs of the whole population has always been one of the pressing needs of the Nigerian government. One of the reasons for the failure of agricultural plans in satisfying this need is underestimation of the importance of soil status and, therefore, mismanagement of the nation's soil. For soil to continue to meet the demand of crops for nutrient availability, there is need to protect and conserve the soil. In Nigeria, various attempts have been made to restore the fertility of degraded arable lands. Greater emphasis was given to the promotion and use of modern inputs such as improved seeds and mineral fertilizer. Facilitating the provision of fertilizer and promoting soil fertility replenishing technologies received continuous attention in all past extension programmes. Hence these efforts proved abortive as low soil fertility still persist. A major reason given for the decline in per capita food production in Nigeria over the last two to three decades is the gradual decline in land productivity.

Available information shows consistent decrease in yield per hectare of major food crops in Southern Nigeria. Evidence from the literature suggests that the main reason for this persistent decline in soil productivity is the perpetuation of unsustainable soil management practices by small food crop farmers that dominate the food production landscape in the country (Ande 2014, Agbonlahor, 2003). Long-term experiments have shown that combined organic and inorganic soil treatments such as Integrated organic and inorganic fertilizers, intercropping systems, improved fallows and integration of cereals-legumes lead to net soil bio-physical and economic gains than solitary applications (Mugwe *et al*., 2009; Ande et al, 2010; Ande and Senjobi, 2014a; Ande et al, 2018; Odunjo et al, 2022; Aruna et al, 2024). With much emphasis recently being placed on Integrated Soil Management Technologies in Nigeria, there is need to find out the gap and methods for eliminating and closing the gap. This is necessary to achieve optimum production through adoption of Integrated Soil Management Techniques.

Integrated soil fertility management (ISFM) is a knowledge intensive approach to soil management practice (Bationo *et al*., 2004). In order to create awareness on ISFM practices, dissemination of knowledge and information should be done through regular trainings. Training provides an understanding of what a technology entails and facilitates its efficient adoption and utilization.

Identifying training needs of stakeholders (farmers and extension agents) and addressing the needs will ensure optimum production. Extension agents are able to disseminate required information, tailor extension services on ISFM to effectively benefit farmers. Farmers on the other hand will be able to take up new technologies or innovations in ISFM to improve soil fertility, increase productivity, food security, protect environment and increase income.

This study therefore assessed the training needs of stakeholders (farmers and extension agents) in ISFM technologies and the preferred methods of achieving the training events. Understanding of this will assist in developing effective training package to close the gap identified. It will also lead to prioritization of areas of training, increase awareness on ISFM technologies and accelerate adoption and utilization.

Survey Objective

The major objective of the study was to assess stakeholders' awareness, knowledge level and training needs for sustainable uptake and utilization of ISFM technologies in Nigeria.

In order to achieve the major objectives, the following specific objectives were set:

1. To determine the soil fertility problems experienced by farmers and the level of severity of such problems;
2. To assess extension agents and farmers' competency (knowledge) in ISFM technologies;
3. To identify the training needs of stakeholders (farmers and extension agents) and most preferred training methods for ISFM by farmers.

Methodology

Location Survey Instrument & Data Collection

The survey was conducted in 8 states of Nigeria comprising: Ogun, Oyo, Osun, Ondo, Lagos, Akwa- Ibom, Edo and Delta states in collaboration with extension agents. The study population comprised farmers and extension agents from the selected states. Interview schedule was used to elicit information from farmers while questionnaires were produced for extension agents in all the selected states. Three farming communities were selected from each state with the help of the Agricultural Development Programmes. A list of all farmers was obtained from the village extension agent in each community. Random sampling technique was used to select farmers and a total of two hundred and forty-five farmers were selected and interviewed from the eight states, however, 214 interview schedules were used for the analysis. Also, a total of sixty-six extension agents were interviewed from all the selected states.

Data were collected using interview schedule all respondents were small- scale farmers who derive their income mainly from agricultural activities. A brief explanation of the study's objective was given to farmers after which they gave oral consent to participate in the survey. The interviews were however voluntary and farmers were assured of the confidentiality of their responses. The interview elicited information of socio-economic and farm related characteristics of farmers, which include: sex, age, years of schooling, marital status, household size, years of farming experience, membership of farmers/ cooperative association, farm size, ownership etc.

Farmers were also asked about awareness of ISFM technologies, sources of information and frequency of such information, severity of soil fertility problems on their farm, knowledge of farmers in the use of ISFM areas, importance of such areas, preferred extension delivery method(s) for each of the ISFM skill/ knowledge areas and best times to receive training/ extension services. Also, information was obtained from Extension agents on their background, awareness of ISFM technologies, involvement in training activities on ISFM, competency in training farmers on ISFM technologies, and their training needs in ISFM.

Training needs assessments were assessed by requesting farmers and extension agents to assess their current knowledge (competence) in different ISFM areas and also to rate the importance of the training need. The level of the current knowledge was measure on a five point Likert-type scale ranging from none (1) to very high (5). Farmers were also requested to assess the importance of the training on ISFM technologies on a three point Likert- type scale with response options ranging from not important (1) to very important (3).

The major ISFM areas of the training needs include conduct of soil fertility test, erosion control and soil conservation, use of improved varieties, minimal conservation tillage, use of inorganic fertilizers, management and use of animal & farmyard manure, composting and incorporating farm residues into the soil. Others include, use of cover crops/mulching, growing of Nitrogen fixing legumes, intercropping cereals and legumes, crop rotation, liming/reduction of acidity, agroforestry and combine usage of organic and inorganic fertilizers.

Data Analysis

Data for the survey were analyzed using IBM SPSS version 20. Descriptive statistics (frequencies, means, standard deviations) were used to analyse data. Training needs were assessed using Borich Model which is one of the most widely used models for assessing training needs in agricultural extension. Following this model, a weighted discrepancy score was calculated for evaluation and ranking of farmer's training needs. A Mean Weighted

Discrepancy Score was calculated to describe the overall rankings for each of the training areas. The competencies with the highest scores were those with the highest need and priority for training.

Results and Discussion

Personal and Socio-economic attributes of farmers

The data in Table 1 shows the socio-economic attributes of farmers. The majority of the farmers were male (69.9%) while 30.4% were female. The minimum number of years of farmers was 24 while the maximum was 79. Highest period of schooling was 25 while the least was 0. A sizable percentage of the farmers had no formal education which may hinder their ability to access different types of information and training. However, the mean year of schooling was 8.45. Majority (87.9%) of the farmers were married and had mean household size of 7.22. Years of farming experience was between 1 and 55 years. Majority (71.5%) of the farmers were members of farmers' association and cultivated between 0.2 and 50 hectares of land.

Table 1: Socio- economic of characteristics of farmers

S/N	Attributes	Definition	Distribution
1.	Sex	Sex of respondents as male and female	149 (69.9%) Male 65 (30.4%) Female
2.	Age	Actual age	Min 24 years: max 79 years
3.	Education/ years of Schooling	Highest education attained	Max=25 years; min=0
4.	Marital Status	Marital status of respondents	Married (87.9%)
5.	Household Size	Number of persons in the household	7.22
6.	Years of farming experience	Number of years spent in farming	Min 1: max 55 Mean 18.70
7.	Membership of farmers' association	Membership of farmers' association	Association member 153 (71.5%)
8.	Farm size	Areas of land cultivated or used for farming	Min=0.2ha; Max= 50ha mean=3.8

Sources of Information and ISFM areas training and advice have been received

The most common source of information for farmers was from the Agricultural Development Programme (ADPs) operating in each state of Nigeria (Table 2). ADPs are the extension arm of the States' Ministry of Agriculture saddled with the responsibility of disseminating information and new technologies to farmers. Fifty percent of farmers frequently obtain information from the ADPs. Other frequent sources of information include other farmers (38.8), Private Extension Agencies (11.6%), NGOs (9.3%) and National Agricultural Research Institutes (8.9%). The findings show that farmers also source information from other farmers which is an indication that farmers learn from other farmers' experimentation and experience.

The study clearly showed that more than half of the farmers had received trainings /advice on most of the ISFM technologies at one time or the other in time past (Table 3). These include use of improved varieties/germplasm (improved maize seeds and cassava cultivars etc) (62.1%), use of inorganic fertilizers (51.8%), composting (56.1%), use of cover crops/mulching (55.1%), intercropping cereals with legumes (52.3%), crop rotation

(52.3%) and use of organic and inorganic fertilizers (59.0%). Also, half of the farmers indicated they have received information/advice on erosion control and soil conservation (50%), growing of nitrogen fixing legumes (50%) and management and use of animal and farm yard manure (50.9%). A lesser percentage indicated they have received training/advice on conduct of soil fertility (48.1%), minimum and conservation tillage (49.1%), incorporation of farm residue into the soil (46.7%), liming (32.3%), agroforestry (44.9%). Other ISFM areas in which farmers have received training/advice include pest and diseases management (41.6%) and use of irrigation (36.4%).

The ease of use and the high yields associated with inorganic fertilizers could have made farmers to learn more about the inorganic fertilizers. It was observed during the survey that although farmers indicated the use of organic and inorganic fertilizers, majority of the farmers in the study area used the organic and inorganic fertilizers separately. They lack the knowledge of combining the two types of fertilizers in adequate proportions for improved productivity.

Table 2: Frequency of Information Source

S/N	Information source	Frequently	Occasionally	Never
1.	ADP	107 (50%)	31 (14.5%)	76 (35.5%)
2.	NARIs	19 (8.9%)	23 (15.4%)	162 (75.6%)
3.	Private Extension Agencies	25 (11.6%)	32 (14.9%)	157 (73.7%)
4.	NGOs	20 (9.3%)	37 (17.2%)	157 (73.7%)
5.	Other farmers	83 (38.8%)	107 (60.8%)	24 (17.2%)

Table 3. ISFM areas farmers have received training or advice

ISFM thematic areas	**Frequency**	**Percentage**
Conduct of soil fertility test	103	48.1
Erosion control and soil conservation	107	50.0
Use of Improved Varieties	133	62.1
Minimum/conservation Tillage	105	49.1
Use of Inorganic fertilizers	111	51.8
Management and use of animal and farmyard manure	109	50.9
Composting	120	56.1
Incorporating farm residues into the soil	100	46.7
Use of cover crops/mulching	118	55.1
Growing of nitrogen fixing legumes	107	50.0
Intercropping cereals and legumes	112	52.3
Crop rotation	112	52.3
Liming (soil acidity)	84	32.3
Agroforestry	96	44.9
Use of organic and inorganic fertilizers	127	59.3
Others-Pest/disease Management	89	41.6
Irrigation	78	36.4

*Multiple responses provided

Severity of Soil Fertility Problems

The severity of soil fertility problems on farm is presented in Table 4. The table show that declining crop yields, poor soil fertility, flood and erosion were the most severe soil fertility problems experience by farmers with mean of 2.66, 2.36, 2.35 and 2.35 respectively. Declining soil fertility, poor soil fertility, flood and erosion have been reported as major challenges facing smallholder farmers (Mugwe *et al* 2004). It is however necessary to give adequate consideration to the soil fertility problems technical skill gap of the farmers for effective delivery. The implication of these results is that there is need to improve on the farmers' knowledge through trainings in order to achieve the perceived maximum economic returns, feasibility and acceptability of the soil fertility management technologies in the study area.

Table 4: Severity of Soil Fertility Problems on Farm

S/N	Soil fertility problems	Highly severe	Severe	Moderately	Less severe	Not severe	Mean	SD
1.	Erosion	36 (16.6%)	19 (8.8)	25 (11.5%)	38 (17.5%)	96 (44.2%)	2.35	1.52
2.	Flood	27 (12.4%)	30 (13.8%)	24 (11.1%)	42 (19.4%)	91 (41.9%)	2.35	1.45
3.	Declining crop yields	55 (25.3%)	56 (25.8%)	38 (17.5%)	37 (17.1%)	28 (19.9%)	2.66	1.37
4.	Poor water retention by the soil	22 (10.1%)	17 (7.8%)	31 (14.4%)	43 (19.8%)	101 (46.5%)	2.14	1.36
5.	Gravel pan	25 (11.5%)	18 (8.3%)	14 (6.5%)	50 (23.0%)	107 (49.3%)	2.08	1.39
6.	Soil salinity	10 (4.6%)	32 (14.7%)	24 (11.1%)	59 (27.2%)	89 (41.1%)	2.13	1.24
7.	Poor soil fertility	84 (38.7%)	45 (20.7%)	31 (14.3%)	32 (14.7%)	22 (10.7%)	2.36	1.39

Farmers' Knowledge and Importance of ISFM Technologies

The knowledge/competency of farmers of ISFM technologies did not vary much across the two zones. Across the two zones, farmers were competent on the use of improved varieties (mean=3.14- SW; mean= 3.53-SS) and crop rotation (mean=3.18 -SW; mean=3.18 SS). Farmers in Southwest however were more competent in the use of organic and inorganic fertilizers (mean=3.15) and use of inorganic fertilizer (mean=2.97). Farmers in the area were however not competent in the use of composting (mean=2.03-SW; mean=1.89 SS), agroforestry (mean=2.26-SW; mean=2.44-SW), liming (mean=2.35 SW; mean= 2.02-SS) (Table 5). Also, farmers exhibit high importance to composting (mean=2.64-SW; mean=2.60-SS), use of organic and inorganic fertilizers (mean=2.55-SW; mean=2.56 SS), improved varieties (mean=2.46SW; mean=2.56 SS; and soil fertility test (mean=2.37-SW; mean=2.51-SS). However, they showed less importance to the liming and conservation tillage among others (Table 6). The findings call for the need to increase farmers' competency levels in the weak identified ISFM areas.

Table 5. Mean Scores of Farmers' Knowledge (Competency) of ISFM Technologies

ISFM technologies	(South West) Knowledge			(South South)		
	Mean	Standard Deviation (SD)	Rank	Mean	Standard Deviation (SD)	
Conduct of soil fertility test	2.48	1.42	11	1.89	1.16	12

Erosion Control and Soil Conservation	2.58	1.30	10	2.44	1.12	10
Use of Improved Varieties	3.24	1.41	1	3.53	1.19	1
Minimum/ Conservation Tillage	2.46	1.23	12	2.53	1.00	9
Use of Inorganic fertilizers	2.97	1.40	4	2.88	1.10	3
Management and use of animal farmyard manure	2.82	1.35	7	2.65	1.00	7
Composting	2.03	0.83	15	1.86	0.93	13
Incorporating farm residues into the soil	2.74	1.31	9	2.70	1.10	6
Intercropping cereals with legumes	2.92	1.31	5	2.88	1.16	3
Use of crop residue	2.79	1.22	8	2.35	0.97	11
Growing of Nitrogen fixing legumes	2.87	1.23	6	2.58	1.01	8
Crop rotation	3.18	1.29	2	3.18	1.15	2
Liming	2.35	1.17	13	2.02	1.28	12
Agroforestry	2.26	1.27	14	2.44	1.26	11
Use of organic and inorganic fertilizers	3.15	1.48	3	2.88	1.12	3

N=214 (1=None; low=2; medium=3; high=4; very high=5)

Table 6. Mean Scores of Farmers' Importance of ISFM Technologies

	South West Importance			**South South**		
ISFM technology	**Mean**	**Standard Deviation (SD)**	**Rank**	**Mean**	**Standard Deviation (SD)**	**Rank**
Conduct of soil fertility test	2.37	0.59	5	2.51	0.60	4
Erosion Control and Soil Conservation	2.31	0.60	7	2.39	0.62	7
Use of Improved Varieties	2.46	0.54	3	2.56	0.59	2
Minimum/ Conservation Tillage	2.19	0.69	15	2.25	0.71	13
Use of Inorganic fertilizers	2.40	0.63	4	2.39	0.62	6
Management and use of animal farmyard manure	2.24	0.67	8	2.25	0.80	14
Composting	2.64	0.48	1	2.60	0.49	1
Incorporating farm residues into the soil	2.22	0.68	9	2.33	0.60	12
Intercropping cereals with legumes	2.17	0.66	13	2.37	0.69	8

Use of crop residue	2.22	0.71	10	2.33	0.63	11
Growing of Nitrogen fixing legumes	2.21	0.62	11	2.35	0.64	10
Crop rotation	2.36	0.63	6	2.40	0.67	5
Liming	2.16	0.65	14	2.11	0.67	15
Agro forestry	2.20	0.73	12	2. 37	0.74	9
Use of organic and inorganic fertilizers	2.55	0.62	2	2.56	0.70	3

N=214 ; SW=157; SS=57 (1=Not Important; 2=Important; 3=Very Important)

Training needs of Farmers.

The training needs assessment revealed a number of ISFM technologies which farmers expressed need for training. Table 7 show the training needs of the respondents in the form of weighted scores, which were also ranked within each ISFM areas. The highest-ranking training needs are considered the most important training needs of the farmers. The highest-ranking training needs as expressed by farmers is in composting, followed by soil fertility test, agroforestry and liming. Crop rotation, use of improved germplasm, use of organic and inorganic fertilizers and incorporation of crop residue into the soil were the lowest ranked training needs as expressed by farmers. This shows ISFM areas where emphasis can be placed to increase farmers' productivity and income.

Table 7. Training needs of farmers in the ISFM Technologies

S/N	ISFM technologies	Mean Weighted Discrepancy Score (MWDS)	Rank
1	Conduct of Soil Fertility Test	0.19	2
2	Erosion Control and Soil Conservation	-0.50	5
3	Use of Improved Varieties	-1.92	14
4	Minimum/ Conservation Tillage	-0.62	6
5	Use of Inorganic fertilizers	-1.26	11
6	Management and use of animal farmyard manure	-1.19	9
7	Composting	1.69	1
8	Incorporating farm residues into the soil	-1.56	13
9	Intercropping cereals with legumes	-1.24	10
10	Use of crop residue	-0.91	7
11	Growing of Nitrogen fixing legumes	-0.92	8
12	Crop rotation	-1.94	15
13	Liming	-0.12	4
14	Agroforestry	0.23	3
15	Use of organic and inorganic fertilizers	-1.30	12

Personal Information of Extension Agents.

The personal information of the field staff (extension agents) is shown in Table 8. The survey revealed that 47.0% of the extension agents were within the age range of 41 and 50 years while 37.9% were within the age range of 51-60years. Only 15.1% were in the age range of 31-40 years while none of the extension staff were under thirty years of age. The extension staff are generally older and are not being replaced which gives great concern to the extension advisory system in the country. Male dominance (78.8%) was also evident among the extension staff with female constituting only 21.2%. Twenty-six percent of the staff were holders of either National Certificate in Education or Ordinary National Diploma certificate while 34.8% were holders of Higher National Diploma certificate. Thirty percent were holders of Bachelor of Science degree in agricultural related fields while 9.1% had Masters of Science degree. Almost 41% of the extension agents had crop production as their field of study, 39% were experts in Agricultural Extension and Economics. Only 7.7% and 6.1% of the Extension agents were experts in soil and Agricultural Technology respectively. Major responsibility of Extension agents was to train, disseminate and provide technical and advisory services for farmers. Number of years of work experience varies from 1 to more than 20years with 36.4% having more than 20years of experience and 25.7% having between 16 and 20 years of experience. Only 4.5% had <5years of work experience.

The data in the table also revealed that 66.6% of the Extension Agents indicated their awareness of ISFM. This implies the need to increase efforts at creating more awareness of the ISFM technologies.

Table 8 : Background Information of Extension Agents

Background Information	Frequency	Percentage
Age		
1-10	11	16.6
11-20	30	45.5
21-30	21	32.3
31-40	04	6.1
Sex		
Male	52	78.8
Female	14	21.2
Educational Qualification		fm
BSC	20	30.3
HND	23	34.8
NCE/OND	17	25.8
M.Sc	6	9.1
Field of Study		
Animal Production	3	4.5
Crop production	27	40.9
Agricultural Extension &Economics	26	39.4
Soil Science	5	7.6
Agricultural Technology	4	6.1
Agricultural education	1	1.5
Years of Experience		
<5	3	4.5
5-10	9	13.6
11-15	13	19.7
16-20	17	25.7
>20	24	36.4
Awareness		
Aware	44	66.6

Not Aware	22	33.3

Training needs of extension agents

The training needs assessment revealed a number of ISFM technologies which Extension agents (EAs) expressed need for training. Table 9 show the training needs of the EAs in the form of mean weighted discrepancy scores (MWDS), which were also ranked within each ISFM areas. Differences between EAs perceived relevance (importance) and ability for each competency produced identifiable needs. The highest-ranking training needs are considered the most important training needs of the Extension agents and include soil fertility testing, erosion control and soil conservation, incorporation of residues into the soil, agroforestry, composting, liming and conservation tillage. Use of inorganic fertilizers and the use of organic and inorganic fertilizers and incorporation of crop residue into the soil, intercropping cereals with legumes and management and use of animal and farmyard manure were the lowest ranked training needs as expressed by EAs

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Table 9. Training needs of Extension Agents on ISFM Technologies

S/N	ISFM technologies	Mean Weighted Discrepancy Score (MWDS)	Rank
1	Conduct of Soil Fertility Test	1.55	1
2	Erosion Control and Soil Conservation	0.75	2
3	Use of Improved Varieties	0.04	8
4	Minimum/ Conservation Tillage	0.08	7
5	Use of Inorganic fertilizers	-1.67	15
6	Management and use of animal farmyard manure	-1.63	14
7	Composting	0.15	5
8	Incorporating farm residues into the soil	0.51	3
9	Intercropping cereals with legumes	-1.44	12
10	Use of crop residue	-1.11	9
11	Growing of Nitrogen fixing legumes	-1.17	10
12	Crop rotation	-1.33	11
13	Liming	0.08	6
14	Agroforestry	0.27	4
15	Use of organic and inorganic fertilizers	-1.60	13

Preferred Training Methods by farmers

The results on preferred methods of training show that most farmers preferred on farm demonstration as most suitable training methods in teaching skills in almost all the ISFM technologies. This is as a result of the practical training it entails and the fact that it also enhances learning experience. However, research findings have shown that combination of two or more training methods should be promoted since these produce positive effects on farmers' acceptance of information than using only one method. On farm demonstrations, training and field days raises farmers' awareness where both literate and illiterate people learn best by seeing (Isiaka, 2001). Radio programme and Television were less preferred since most of these programmes are broadcast when farmers do not watch or listen to them.

Table 10. Preferred Training methods by farmers

S/N	ISFM	FD	FFS	OFD	TW	IFV	FFE	WM	RP	TV
1.	Conduct of soil fertility test	19 (8.8)	63 (29.4)	75 (35.0)	36 (16.8)	14(6.5)	3 (1.4)	2(0.93)	2 (0.93)	-
2.	Erosion control and soil conservation	2 (0.93)	28(13.5)	91(42.5)	45 (21.0)	16 (7.5)	4 (1.86)	1 (0.5)	17 (7.9)	10 (4.6)
3.	Use of improved varieties	10 (4.6)	26 (12.1)	72 (33.6)	40 (18.7)	39 (18.2)	17 (7.9)	5 (2.3)	4 (1.8)	1 (0.5)
4.	Minimum Tillage	22 (10.2)	24 (11.2)	79 (36.9)	44 (20.5)	16 (7.5)	12 (5.6)	6 (2.8)	-	-
5.	Use of inorganic fertilizers	16 (7.5)	19 (8.4)	86 (40.1)	39 (18.2)	25 (11.7)	21 (9.8)	-	-	8 (3.7)
6.	Management and use of animal and farmyard manure	27 (12.6)	19 (8.8)	99 (42.3)	37 (18.3)	7 (3.3)	23(10.7)	2(0.9)	-	-
7.	Composting	6 (2.8)	23 (10.7)	92 (42.9)	41 (19.1)	28 (13.1)	5 (2.3)	3 (5.0)	3 (1.4)	13 (6.1)
8.	Incorporating farm residues into the soil	11 (5.1)	23 (10.7)	101 (47.2)	44 (20.5)	18 (13.0)	9 (4.2)	5 (2.3)	3 (1.4)	2 (0.9)
9.	Use of crop residue	11 (5.1)	38 (17.7)	96 (44.8)	37 (17.2)	16 (7.4)	12 (5.6)	6 (2.8)	3 (1.4)	-
10.	Growing of nitrogen fixing legumes	10 (4.6)	35 (16.3)	91 (42.5)	42 (19.6)	11 (5.1)	3 (1.4)	3 1.4)	2 (0.9)	-
11	Crop rotation (cereal-legume)	8 (3.7)	27 (12.6)	133 (62.1)	29 (13.5)	7 (3.3)	10 (4.6)	4 (1.8)	2 (0.9)	5 (2.3)
12.	Liming (soil acidity)	13 (6.1)	27 (12.6)	102(47.6)	6 (2.8)	39 (18.2)	13 (6.0)	4 (1.8)	5 (2.3)	5 (2.3)
13.	Agroforestry	29 (13.5)	6 (2.8)	126 (58.9)	11 (5.1)	11 (5.1)	2 (0.9)	4 (1.8)	12 (5.6)	13 (6.07)

14.	Use of organic and inorganic fertilizers	24 (11.2)	19 (8.8)	124 (57.9)	11 (5.1)	10 (4.6)	11 (5.1)	4 (1.8)	5 (2.3)	6 (2.8)

FD=field days; FFS=Farmers' field schools; OFD=On-farm demonstration; TW=training workshops; IFV=individual farm visits; FFE=farmer to farmer extension; 7WM= Written materials; RD=Radio programme; TV=Television programme

Conclusions and Recommendations

The findings from the survey has shown the severity of soil fertility problems in the study area. It further revealed that both farmers and extension agents showed different competence and needs for training. However, there is need to prioritize training based on the identified gaps.

The highest-ranking training needs as expressed by farmers is in composting, followed by soil fertility test, agroforestry and liming. Crop rotation, use of improved germplasm, use of organic and inorganic fertilizers and incorporation of crop residue into the soil were the lowest ranked training needs as expressed by farmers. The highest-ranking training needs that are considered the most important training needs of extension agents include soil fertility test, erosion control and soil conservation, incorporation of residues into the soil, agroforestry, composting, liming and conservation tillage.

Based on the findings of the study, the following recommendations are made:

- There is need for awareness creation and training of both farmers and extension agents in the use of ISFM technologies.
- The highest ranked gaps should therefore receive more training and the training must be matched with best delivery methods. Priority should be given to composting, soil fertility test, agroforestry and liming for farmers while soil fertility test, erosion control and soil conservation, use of crop residue, agroforestry, composting liming and conservation tillage must be concentrated on for extension workers. Continuous in-service training on ISFM technologies should be facilitated for extension agents so as to be deeply educated in the identified areas.
- Training of farmers and extension agents should emphasize practical training and observation rather than theoretical training. This will help to ensure that new learning is absorbed by farmers and extension agents.
- Regular field surveys to assess and monitor changes in the training needs of farmers and Extension agents on ISFM technologies is also recommended.
- Soil information at large scale useful for advisory services for small-scale farmers should be made available and popularised for sustainable land use and food security.
- Development of policy brief from the comprehensive report.

References

Adesoji, S.A., Farinde, A. J., Ajayi, O.A. (2006). Assessment of the training needs of Fadama farmers for future agricultural extension work development in Osun State, Nigeria. *J. Appl. Sci*., 6(15): 3089-3095.

Agbonlahor, M.U., Aromolaran, A.B and Aiboni, V.I (2003). Sustainable soil management practices in small farms of southern Nigeria: A poultry -food crop Integrated Farming Approach. *Journal of Sustainable Agriculture* 22 (4): 1-8

Ande, O.T., Adeyolanu, O.D., Are, K.S. and Oke, A.O. (2014) Soil quality and variability assessment of Ultisols derived from sand stone in south western Nigeria. *Moor Journal of Agricultural Research* 15: 112-123. (Nigeria)

Ande O.T., Adeyolanu, O.D., Are, S.K., Adelana, A., Oke, A., Ojo, O.A., Oluwatosin G.A. Adelabu, L.A. and Taiwo, O. (2014). Digital soil mapping and morphogenetic characterization of soils of Ebonyi formation in South Eastern Nigeria. *Earth Science Research* 5 (1): 1-9. (Canada)

Ande, O.T., Senjobi B.A., Adediran, J.A. and Oluwatoyinbo, F.I. (2010). Effects of land use on nutrient distribution on a gently undulating landscape in the derived savanna of Southwestern Nigeria. *Moor Journal of Agriculture* 11: 1 – 7. (Nigeria)

Ande, O.T**.** and Senjobi, B.A. (2014). Land degradation assessment of agrarian soils in Ebonyi state for sustainable production. *Journal of Ecology and Natural Environment* 6 (6): 200-204. (Nigeria)

Ande, O.T**.**, Huising, J., Ojo, O.A., Azeez, J.O., Ojeniyi, S.O. Olakojo, S.A. and Fademi, I.O (2017). Status of integrated soil fertility management (ISFM) in Southwestern Nigeria. *International Journal of Sustainable Agricultural Research* 4 (2): 28-44. (UK)

Aruna O A., **O. T.** Ande**,** S. O.Dahunsi, J. O. Ogunwole and A. L. Ibaba (2024). Impact of bio-digestate and fertilization on the soil chemical properties, growth and yield of maize (Zea mays (L.) Research on crops, 28(1) 33-42 DOI:10.51830/2348-7542.2024.ROC-1039

Bationo, A., Kimetu , J., Ikeera, S., Kimani, S., Mugendi, D., Odendo, M., Silver, M., Swift,

M.J., Sanginga, N. (2004). The African network for soil biology and fertility: new challenges and opportunities. In: Bationo A (ed) Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science Publishers and Tropical soil Biology and Fertility Institute of CIAT, Nairobi, pp 1–23

Isiaka, B.T. (2001). "Information Technology".11th National Congress of the Nigerian

Rural Sociological Association (NRSA). University of Uyo, Nigeria, September 17th - 20th, 2001.

Mugwe, J., Mugendi, D., Mucheru-Muna, M., Merchx, R., Chianu, J., Vanlauwe. B. (2009)

Determinants of the Decision to Adopt Integrated Soil Fertility Management Practices by Small Holder Farmers in the Central Highlands of Kenya. *Expl Agricu*. Volume 45, pp 61-75 Cambridge University Press

Odunjo, T.E., Oguweide, T.A., Fademi, I.O., Anoke, E.O., Uthman, A.C.O. and Ande, O.T**.** (2023). Soil quality improvement with verti-compost for sustainable maize cultivation on degraded soils. *Moor Journal of Agricultural Research* 22: 1-12. (Nigeria)

ASSESSMENT OF NUTRIENT RELEASE IN ULTISOL AMENDED WITH SAWDUST BIOCHAR AND THE EFFECTS ON MAIZE GROWTH

[1]Ebido, N. E., [1]Uzoh, I. M., [1]Igwe, C. A, [1]Obalum, S. E., [2]Chizaram-Ndubuaku, C. A., and [2]Ndubuaku, U. M.

[1]Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka

[2]Department of Crop Science, Faculty of Agriculture, University of Nigeria, Nsukka

ABSTRACT

A Organic amendments such as biochar provide important nutrients for crop productivity and soil health. This study assessed the nutrient release dynamics in Ultisols amended with sawdust biochar and evaluated its effects on maize (Zea mays) growth. The treatments used had different biochar rates (Control (0 t/ha) 5, 10, 15 and 20 t/ha), all laid out in a completely randomized block design with three replications per treatment. The physicochemical properties of the amended soils were analysed three times at monthly intervals; number of leaves, plant height, and stem girth were used to evaluate the effects of different biochar rates. The results showed significant differences among the sawdust application rates, on the soil chemical properties across the incubation intervals. The application rate of 15 – 20 t/ha across incubation intervals had the highest effects on the soil properties. After 4, 8 and 12 weeks of incubation (WOI), when compared with control, pH increased with 13.2% in 15 t/ha, 15.7% in 20 t/ha and 15.6% in 20 t/ha respectively, total nitrogen increased with 115.4% in 20 t/ha, 200% in 15 t/ha, 100% in 15 t/ha respectively, organic matter increased with 24.7% in 20 t/ha, 23.6 in 15 t/ha, 28.3% in15 t/ha respectively, CEC increased with 88.2 % in 20 t/ha, 58.1% in 20 t/ha, 12.2% in 20 t/ha respectively and available phosphorus increased with128.5% in 15 t/ha, 74.8%in 15 t/ha, 70.0% in 15 t/ha respectively. There were significant differences ($P \leq 0.05$) in plant height at 8 and 12 weeks after planting (WAP) and the number of leaves of maize following the application of sawdust biochar. Also, the different rates of biochar influenced the growth of maize relative to the control. In conclusion, sawdust biochar had remarkable effects on soil chemical properties and maize growth.

Keywords: *Biochar,* Sawdust, Ultisol, and Zea mays

Introduction

Ultisols, characterized by their low fertility and high acidity, pose significant challenges to agricultural productivity (Adubasim et al., 2017), particularly in regions where they are predominant. To address these challenges, various soil amendments have been explored, among which biochar, a carbon-rich material derived from the pyrolysis of organic matter (Lehmann et al., 2006; Chan and Xu, 2009), has gained considerable attention due to its potential to improve soil properties and enhance crop productivity. Biochar, as an organic soil amendment, can have a variety of effects on soil properties, plant growth, and overall ecosystem health (Major, 2011). Biochar has a porous structure that can enhance soil aggregation and porosity. This improves soil aeration, water infiltration, and drainage, leading to better root growth and nutrient uptake by plants (Edeh et al., 2020). Its high surface area and cation exchange capacity (CEC), allows it to adsorb and retain nutrients such as nitrogen (Ebido et al., 2021; Van Zwieten et al., 2010), phosphorus, potassium, and micronutrients (Laird, 2010; Deluca et al., 2009). This can reduce nutrient leaching, making nutrients more available to plants over time. The slow release of nutrients from biochar as it decomposes in soil can provide a steady supply of nutrients to plants, promoting healthy growth and higher yields. Additionally, biochar can stimulate microbial activity in the soil, which further contributes to nutrient cycling and soil fertility (Kloss et al., 2012; Spokas et al., 2012).

Depending on its feedstock and production conditions, biochar can affect soil pH differently (Chan and Xu, 2009). Generally, biochar tends to have a neutral to slightly alkaline pH, which can help buffer acidic soils and improve conditions for plant growth. However, the impact on soil pH will depend on factors such as biochar dosage and soil type (Bagreev et al., 2001). Biochar is a stable form of organic carbon that can persist in soil for hundreds to thousands of years (Burrell et al., 2016). By sequestering carbon in soil, biochar can help mitigate climate change by reducing atmospheric carbon dioxide levels and improving soil carbon storage (Kataki et al., 2012; Shafie et al., 2012). Biochar-amended soils have been shown to have increased water holding capacity, reducing water stress on plants during periods of drought (Downie et al., 2009). This can improve water use efficiency in agricultural systems (Cheng et al., 2008) and contribute to greater resilience to climate variability. It has also been found to adsorb pollutants such as heavy metals and organic contaminants, reducing their bioavailability and potential for environmental harm (Rumi Narzari et al., 2015). This makes biochar a potentially valuable tool for soil remediation and environmental restoration. Overall, the effects of biochar as an organic amendment can vary depending on factors such as feedstock, production method, application rate, soil type, and climate conditions (Downie et al., 2009). Properly managed, biochar has the potential to enhance soil quality, promote sustainable agriculture, and contribute to broader environmental goals.

Sawdust biochar, produced from the pyrolysis of sawdust, has shown promise as a soil amendment in Ultisols due to its high surface area, porous structure, and ability to retain water and nutrients (Han et al., 2013). The PTE (Potentially toxic elements) removal ability of wood biochar in water might be attributed to its surface properties originating from feedstock materials as well as pyrolysis conditions (Rosales et al., 2017). Additionally, its gradual decomposition in soil can contribute to long-term soil fertility improvement. Understanding the interactions between sawdust biochar and soil nutrients is crucial for optimizing its application and harnessing its potential benefits for sustainable agriculture in Ultisols. However, investigating the nutrient release kinetics of sawdust biochar in Ultisols involves assessing the release patterns of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients over time, considering factors such as biochar particle size, soil moisture, and temperature.
This study aims to assess the nutrient release dynamics in Ultisols amended with sawdust biochar and evaluate its effects on maize (*Zea mays*) growth.

The specific objectives of the study are to:

1. Evaluate the impact of sawdust biochar amendment on soil chemical properties following biochar application.
2. Assess maize growth response to sawdust biochar amendment.

Materials and Methods

Location / Sample collection

The experiment was carried out in the Glass house of the Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka. Nsukka is located on Latitude $06^{0}25`$N and Longitude $07^{0}24`$E and altitude of approximately 400 m above sea level. Soil Samples were collected from the premises of the Teaching and Research Farm. The sawdust was collected from Saw Mill, Nsukka. Hybrid maize (*Zea mays* L.) variety (Oba super II) obtained from the Department of Crop Science, University of

Nsukka, was used as a test crop because of its short maturation, sensitivity to a wide range of contaminants, and soil nutrient status (Wong et al., 1991). It is also commonly grown in the study area.

Biochar Production

A metal drum with a cover was used as an improvised kiln. The drum was constructed having a of size 60 cm in length and a diameter of 45 cm, one end is sealed while the other end has a cover that can be screwed tightly to reduce the amount of oxygen introduced during burning. The drum was mounted horizontally on a closed-chamber furnace of burning wood supplying heat at 500-550°C. It would have a handle at both ends of the drum for turning in an oscillatory motion. Inside the drum are bars on opposite sides; this helps to turn the materials for uniform burning while the drum is rotating. The materials in the drum were externally ignited (Ebido et al., 2021). After production, portions (200 grams) of the charred biochar were analyzed for pH, Total Nitrogen, Total Phosphorus, and Exchangeable base contents.

Incubation Study

This experiment studied the rate of nutrient release of the sawdust biochars into the soil. It was laid out in a Completely Randomised Design with three replications. Fifteen plastic buckets of 2kg soil capacity were used for the experiment. The treatment was applied to the soil at different levels (weight/weight, i.e., g/kg). The levels were 0g/2kg soil (Control), 5g/2kg soil, 10g/2kg soil, 15g/2kg soil, and 20g/2kg soil. The topsoil and the biochar were thoroughly mixed in the buckets. The media in each plastic bucket were thoroughly moistened with one liter of distilled water after mixing, and constantly kept moist but not waterlogged throughout the experimental period, which lasted for three months. Soil samples were collected thrice at monthly intervals for chemical laboratory analysis at the Department of Soil Science Laboratory

Laboratory Analysis of Soil Samples

Particle size distribution of the < 2 mm fractions was measured by the hydrometer method as described by Gee and Bauder (1986). Soil pH was measured in distilled water at the ratio of 1: 2.5 (Soil: Liquid), as described by Mclean (1982). Soil organic matter (SOM) was derived from organic carbon (OC) determined using the modified Walkey – Black wet digestion and combustion method as described by Nelson and Sommers (1996) (% SOM = % OC x 1.724). Total nitrogen was determined by the Kjedahl Digestion and Distillation Method as described by Bremmer and Mulvaney (1982). The exchangeable bases (Na^+, K^+, Ca^{2+}, Mg^{2+}) were determined by the complex-metric titration method described by Chapman (1982). Available phosphorus was obtained using the Bray 2 method as described by Olsen and Sommers (1990). Cation exchange capacity (CEC)was determined using the ammonium acetate displacement method as described by Rhoades (1982). The base saturation was obtained by dividing the total exchangeable bases by cation exchange capacity and multiplying by 100.i.e. BS = TEB/CEC x 100

Data Collection

Growth Characteristics

The plant height was measured to the nearest centimetre (cm) from the base of the plant to the base of the unopened apical leaf at 4, 8, and 12 WAP. Stem diameter was measured at the first nodal point at the base of the plants and used to compute the mean stem diameter score for each plot at 4, 8, and 12 WAP. The number of fully opened, mature, and non-senescence leaves were counted per plant and used to compute the score for each plot at 4, 8, and 12 WAP.

Statistical Analysis

The data collected was subjected to analysis of variance (ANOVA) using GENSTAT Discovery Version (2009). Differences between means of treatments were compared using Fisher's Least Significant Difference (F-LSD) at 5 % probability.

Results and Discussion

The Physical and Chemical Properties of Initial Soil for Incubation and Field Study

Table 1 shows the physical and chemical properties of the initial soil used for incubation and field study. The soil was a sandy loam with a higher percentage of sand than silt and clay. The soil sample was acidic (4.7). The soil organic carbon was low (7.39 g/kg). Exchangeable calcium and sodium were low, potassium and magnesium were very low, while cation exchange capacity was high. Available phosphorus (7.65 mg/kg) was low. The soil's total nitrogen was low. The fertility indices were based on Landon (2014) ratings.

Chemical Properties of Sawdust Biochar

The chemical properties of sawdust biochar amendments, as shown in Table 1, indicate that the amendment was alkaline (8.4) in nature. The exchangeable bases were low. Available phosphorus was moderate. The amendments had high organic carbon with high nitrogen content. The resulting nutrient content of biochar has been reported to depend largely on the nutrient content in the feedstock and process of pyrolysis, as reported by Lehmann et al. (2009) and Antal et al. (2003).

Table 1: Physical and chemical properties of untreated soil and Chemical properties of the biochar amendments (Sawdust)

Properties	Soil values	Properties	Biochar values
pH (H_2O)	4.7	pH (H_20)	8.4
pH (KCl)	4.2	pH (KCl)	7.5
SOC (g/kg)	7.39	OC (%)	33.63
OM (g/kg)	12.74	OM (%)	57.97
TN (g/kg)	0.78	TN (%)	6.304
Ex. Na^+ (cmol/kg)	0.208	T. Na^+ (%)	0.46
Ex. K^+ (cmol/kg)	0.116	T. K^+ (%)	0.99
Ex. Ca^+ (cmol/kg)	2.376	T. Ca^+ (%)	0.56
Ex. Mg^{2+} (cmol/kg)	0.8	T. Mg^{2+} (%)	0.34
Ex. Al^{3+} (cmol/kg)	0.2	T. Al^{3+} (%)	-
Ex. H^+ (cmol/kg)	4.0	T. H^+ (%)	-
Av. P (mg/kg)	7.65	T. P (%)	0.365
CEC (cmol/kg)	32.0	CEC (cmol/kg)	-
CL (%)	17		
SI (%)	3		
FS (%)	60		
CS (%)	20		
TC	SL		

CEC: Cation exchange capacity; CL: Clay; SI: Silt; FS: Fine sand; CS: Coarse sand; TC: Textural class; SL: Sandy loam; Ex: Exchangeable; T: Total; P: Phosphorus

Properties of the soil after 4, 8, and 12 weeks of incubation with sawdust biochar

Results of soil properties after 4 weeks of incubation

The results in Table 2 represent the effect of the five different rates of sawdust biochar on the chemical properties of the soil after four weeks of incubation. The results show significant differences (p ≤

0.05) amongst the different rates of amendments on the soil pH. The soil pH in H_2O and KCl increased from 5.25 in 0t/ha to 5.95 in 15t/ha and 4.10 in 0t/ha to 5.00 in 20t/ha, respectively. The pH of the treated soil at different rates increased with increasing time intervals. The increase in soil pH is characterized by the integration of the highly alkaline nature of biochar, and high base cation concentration which in turn releases protons into the soil solution and the acidity reduced, through proton consumption reaction and higher $CaCO_3$ availability (Liu et al., 2025). The results show the treatments had a significant difference ($P \leq 0.05$) in the nitrogen level of the soil. Nitrogen increased from 0.091 g/kg in the control to 0.196 g/kg in 20 t/ha. This is in accordance with the study carried out by Ebeheakey et al. (2018) that sawdust biochar performed well in increasing the total nitrogen.

There were significant differences ($p \leq 0.05$) amongst treatments on the soil organic matter content. The organic matter content increased from 2.154 % in 0 t/ha to 2.676 % in 20 t/ha. The soil organic matter increased with the increasing rate of sawdust biochar application. Anand et al. (2018) reported that sawdust biochar from pine wood positively influences SOM, and this mediates total nitrogen in the soil. The available phosphorus increased partially but was highest at 15 t/ha (14.92 mg/kg). These findings agree with other research studies (Ros et al., 2003). The addition of biochar could enhance microbial activity, thereby releasing microbial metabolites, which could be a reason for the increase in phosphorus with increasing application rates.

The results (Table 2) further show that the treatments had significant differences on calcium, with no significant difference on magnesium. The calcium content of the soil increased, with values ranging from 0.90 Cmol/kg in the control to 1.60 Cmol/kg in 15 and 20t/ha. There was also an increase in magnesium, ranging from 0.50 Cmol/kg in the control to 1.00 Cmol/kg in 15t/ha. The exchangeable cation (calcium and magnesium) gradually increased at an increasing rate. Yan et al. (2014) reported that the application of sawdust biochar increased the Ca, Mg, and K levels of the soil. The results showed significant differences among the treatments on hydrogen and aluminium content of the soil. The hydrogen content of the soil decreased with increasing rates of application, from 2.90 Cmol/kg in the control to 1.80 Cmol/kg in 20t/ha. The exchangeable acidity of the treated soils decreased with increasing intervals. Ndor et al. (2015) reported that the application of sawdust biochar amendment on soil properties and the yield of sesame varieties increased soil pH, which in turn decreased the H^+ and Al^{3+} levels of the treated soil.

The results show significant differences ($p \leq 0.05$) among the treatments on CEC. The CEC increased from 5.20 Cmol/kg in 0 t/ha to 9.60 Cmol/kg in 20 t/ha. The treatments had significant differences in the phosphorus level of the soil. Phosphorus increased with increasing rates from 6.53 mg/kg in 0t/ha to 14.92 mg/kg in 15t/ha. The cation exchange capacity of the treated soils increased. Research on the effect of sawdust biochar on soil properties and cocoyam yield, in a tropical sandy loam soil, was shown to have increased its CEC within its two years of planting (Aruna et al., 2020).

Table 2: Soil chemical properties after four weeks of incubation with sawdust biochar

TRT SB	pH H_20	pH KCl	OM (%)	TN (g/kg)	Ca^{2+} cmol/kg	Mg^{2+} cmol/kg	K^+ cmol/kg	Na^+ cmol/kg	CEC cmol/kg	Al^{3+} cmol/ kg	H^+ cmol/kg	Av.P mg/kg
0t/ha	5.3	4.1	2.154	0.091	0.90	0.50	0.05	0.03	5.80	-	2.90	6.53
5t/ha	5.6	4.4	2.293	0.119	1. 10	0.60	0.06	0.03	7.40	-	3.60	13.99
10/ha	5.8	4.8	2.223	0.119	1.30	0.80	0.08	0.04	5.20	-	1.90	11.66
15t/ha	6.0	4.9	2.606	0.175	1.60	1.00	0.06	0.03	7.20	-	1.90	14.92
20t/ha	5.9	5.0	2.680	0.196	1.60	0.90	006	0.04	9.60	-	1.80	13.52
$LSD_{(0.05)}$	0.07	0.1	0.385	0.063	0.355	0.620	NS	NS	3.73	-	0.71	3.35

TRT- Treatment; SB- Sawdust biochar; C - Carbon; T.N - Total nitrogen; N^+ - Sodium; K^+- Potassium; Mg^{2+}- Magnesium; Al^{3+}- Aluminium; H^+= Hydrogen; Av. P- Available phosphorus; CEC - Cation exchange capacity; LSD- Least significant difference of means; WOI- weeks of incubation

Results of soil properties after 8 weeks of incubation

The results in Table 3 represent the effect of the five different rates of sawdust biochar on the chemical properties of the soil at eight weeks of incubation. The soil pH in H_2O increased from 5.05 (moderately acidic) at 0t/ha to 5.90 (slightly acidic) at 20t/ha. The pH of the treated soil at different rates increased with increasing time intervals. Major et al. (2010) reported that the application of biochar amendments increases soil pH, especially in acidic soils. This, in turn, could influence the sorption capacity for nutrients in acidic soils; this is in agreement with Sohi et al. (2010) and reduces the exchangeable acidity (Van Zwieten et al., 2009).

The results show the treatments have a significant difference ($p \leq 0.05$) in the nitrogen level of the soil, nitrogen increased from 0.091 g/kg in control to 0.196 g/kg and 0.273 g/kg in 20 and 15 t/ha, respectively. Reports from this study showed that biochar played an essential role in nutrient cycling, thus affecting N retention when applied to soils. This also corroborates with Steiner et al. (2008), who reported that biochar lowers N leaching and its intake by plants.

There were significant differences ($p \leq 0.05$) among treatments on the soil organic matter content; the organic matter content increased from 1.911 % in 0t/ha to 2.363 % in 15t/ha, indicating increases with the increasing rate of sawdust biochar application. This report is in agreement with the findings of Yan et al. (2014), stating that sawdust biochar increased the total C by 72 % over the control. The available phosphorus increased from 7.47 mg/kg in the control to 13.06 mg/kg in 15 t/ha, which was higher than the 20 t/ha amended soil. Biochar appears to be a helpful tool for recycling P in agricultural systems. However, this is contrary to the findings of Adjei-Nsiah (2012) that wood-derived biochar did not affect P bioavailability.

The results in Table 3 show that the treatments had significant differences ($p \leq 0.05$) in calcium and magnesium. The calcium content of the soil increased, ranging from 1.00 Cmol/kg in the control to 1.90 Cmol/kg in 20t/ha, and the magnesium ranged from 0.50 Cmol/kg in 0t/ha to 1.00 Cmol/kg in 15 t/ha. Also, the exchangeable cation (calcium) was increasing, while magnesium increased with increasing rates. Latini et al. (2019) reported that biochar from wheat straw had a stronger impact on durum varieties, with higher levels of available K and Na. The hydrogen content of the soil decreased from 3.40 Cmol/kg in the control to 1.50 Cmol/kg in 20 t/ha. The exchangeable acid cation (H^+) of the treated soils decreased with increasing application rates. Biochar application might have resulted in the neutralization of soil acidity by a series of proton consumption reactions, as reported by several studies (Yuan and Xu, 2011; Yuan et al., 2011; Chintala et al., 2014).

The results show significant differences ($p \leq 0.05$) among the treatments on the CEC of the soil. There were significant increases ranging from 6.20 Cmol/kg in 0 t/ha to 9.80 Cmol/kg in 20 t/ha. The cation exchange capacity of the treated soils increased. According to Jien and Wang (2013), the incubation for 105 days of Leucaena wood waste-derived biochar significantly increased the CEC of weathered soils from 7.41 to 10.8 Cmol kg^{-1}. The treatments had significant differences ($p \leq 0.05$) in the phosphorus level of the soil, phosphorus increased with increasing rates from 7.47 mg/kg in 0t/ha to 13.06 mg/kg in 15t/ha.

Table 3: Soil chemical properties after eight weeks of incubation with sawdust biochar

TRT SB	pH H_20	pH KCl	OM (g/kg)	TN (g/kg)	Ca^{2+} cmol/kg	Mg^{2+} cmol/kg	K^+ cmol/kg	Na^+ cmol/kg	CEC cmol/kg	Al^{3+} cmol/kg	H^+ cmol/kg	Av.P mg/kg
0t/ha	5.1	4.1	1.911	0.091	1.00	0.50	0.07	0.03	6.20	-	3.40	7.47
5t/ha	5.5	4.5	2.219	0.175	1.10	0.50	0.07	0.03	6.60	-	1.90	7.93
10/ha	5.5	4.8	2.085	0.182	1.70	0.50	0.08	0.04	7.00	-	1.80	7.93
15t/ha	5.6	5.0	2.363	0.273	1.70	1.00	0.08	0.03	9.20	-	1.90	13.06
20t/ha	5.9	5.1	2.258	0.210	1.90	0.50	0.07	0.03	9.80	-	1.50	9.83
$LSD_{(0.05)}$	0.27	0.1	0.403	0.049	0. 163	0.230	0.004	0.004	1.84	-	0.53	4.55

TRT- Treatment; SB- Sawdust biochar; C - Carbon; T.N - Total nitrogen; N^+ - Sodium; K^+- Potassium; Mg^{2+}- Magnesium; Al^{3+}- Aluminium; H^+= Hydrogen; Av. P- Available phosphorus; CEC - Cation exchange capacity; LSD- Least significant difference of means; WOI- weeks of incubation

Results of soil properties after 12 weeks of incubation

The results in Table 4 represent the effects of the five different rates of sawdust biochar on the chemical properties of the soil after twelve weeks of incubation. The results show significant differences among the different rates of amendments on the soil pH. At twelve WOI, the level of soil pH in H_2O increased from 4.45 (acidic) in 0t/ha to 5.20 (moderately acidic) in 15t/ha. The pH of the treated soil at different rates increased with increasing time intervals. Major et al. (2010) reported that the application of biochar amendments increased soil pH, especially in acidic soils. This, in turn, is capable of increasing the sorption capacity for nutrients in acidic soils (Sohi et al., 2010) and reducing the exchangeable acidity (Van Zwieten et al., 2009). The results show the treatments had a significant difference ($p \leq 0.05$) in the nitrogen level of the soil. At twelve, the WOI nitrogen content of the soil increased from 0.119 in the control to 0.238 in 10 and 15 t/ha. The total nitrogen increased with increasing planting intervals (4, 8, and 12 weeks). These results corroborate with Steiner et al. (2008), who reported that biochar lowers N leaching and its intake by plants. Lehmann et al. (2008) also reported that biochar decreases nitrogen leaching when added to agricultural soil, thereby improving fertilizer use efficiency and reducing leaching.

There were significant differences among treatments on the soil organic matter content. At 12 WOI, the organic matter content increased from 1.841% in 0t/ha to 2.362% in 15t/ha. The organic matter of the soil increased with the increasing rate of sawdust biochar application. This report is in agreement with the findings of Yan et al. (2014), stating that sawdust biochar increased the total C by 72 % over the control. The available phosphorus increased partially but was highest at 15 t/ha (15.86mg/kg). Thus, biochar appears to be a helpful tool for recycling P in agricultural systems. However, this is contrary to the findings of Adjei-Nsiah (2012) that wood-derived biochar did not affect P bioavailability

The results (Table 4) show that the treatments had significant differences ($p \leq 0.05$) in calcium and magnesium. The calcium content of the soil increased, ranging from 1.20 Cmol/kg in the control to 1.70 Cmol/kg in 20t/ha, and the magnesium ranged from 0.40 Cmol/kg in the control to 0.60 Cmol/kg in 20t/ha. The exchangeable cation (calcium) was increasing, while magnesium increased with increasing rates. The results show that there are significant differences among the treatments on hydrogen and aluminum content of the soil. The hydrogen content of the soil also decreased from 4.00 Cmol/kg in the control to 1.60 Cmol/kg in 10t/ha. The exchangeable acidity of the treated soils decreased with increasing intervals. Biochar application might have resulted in the neutralization of soil acidity by a series of proton consumption reactions, as reported by many studies (Yuan and Xu 2011; Yuan et al., 2011; Chintala et al., 2014). The results show a significant difference ($p \leq 0.05$) among the treatments on CEC, which increased from 8.20 Cmol/kg in 0 t/ha to 9.20 Cmol/kg in 20 t/ha.

Table 4: Soil chemical properties after twelve weeks of incubation with sawdust biochar

TRT SB	pH H_2O	pH KCl	OM (%)	TN (g/kg)	Ca^{2+} cmol/kg	Mg^{2+} cmol/kg	K^+ cmol/kg	Na^+ cmol/kg	CEC cmol/kg	Al^{3+} cmol/kg	H^+ cmol/kg	Av.P mg/kg
0t/ha	4.5	3.9	1.84	0.12	1.20	0.40	0.08	0.04	8.20	-	4.00	9.33
5t/ha	4.7	4.0	2.08	0.18	1.20	0.60	0.08	0.03	8.40	2.00	3.00	15.40
10/ha	5.1	4.4	2.02	0.24	1.40	0.60	0.09	0.04	8.00	-	1.60	14.00
15t/ha	5.2	4.6	2.36	0.24	1.60	0.60	0.13	0.06	8.60	-	1.90	15.86
20t/ha	5.2	4.6	2.08	0.22	1.70	0.60	0.12	0.05	9.20	-	1.70	10.26
LSD (0.05)	0.26	0.2	0.50	0.07	0.244	0.282	0.023	0.013	1.58	1.63	0.26	4.03

TRT - Treatment; SB - Sawdust biochar; C - Carbon; T.N - Total nitrogen; N^+ - Sodium; K^+ - Potassium; Mg^{2+} - Magnesium; Al^{3+} - Aluminum; H+ - Hydrogen; Av. P - Available phosphorus; CEC - Cation exchange capacity; LSD - Least significant difference of means; WOI - Weeks of incubation.

Effects of Sawdust Biochar on Maize Growth

There were significant differences ($p \leq 0.05$) in plant height and the number of leaves of maize following the application of sawdust biochar. Plant height was significantly different ($p \leq 0.05$) at 8 and 12 WAP. At 4 WAP, the values increased from 25.30 cm (5 t/ha) to 30.00 cm (15 t/ha). At 8 WAP, it increased from 35.93 cm (5 t/ha) to 48.53 cm (10 t/ha), and at 12 WAP, it also increased from 46.70 cm (5 t/ha) to 67.20 cm (0 t/ha).

The number of leaves was significantly different ($p \leq 0.05$) only at 4 WAP. At 4 WAP, the values ranged from 4.33 (5 t/ha) to 5.67 (10 t/ha). At 8 WAP, it ranged from 7.00 (5 t/ha) to 8.33 (15 t/ha), and at 12 WAP, it ranged from 9.30 (0 t/ha) to 11.67 (15 t/ha). The stem girth of maize was not significantly different ($p \leq 0.05$) at 4, 8, and 12 WAP. At 4 WAP, the values ranged from 1.60 cm (0 t/ha) to 1.70 cm (20 t/ha). At 8 WAP, it ranged from 2.13 cm (0 t/ha) to 2.43 cm (20 t/ha), and at 12 WAP, it ranged from 2.30 cm (15 t/ha) to 2.57 cm (20 t/ha).

The report indicates that sawdust biochar influenced the growth of maize relative to the control. This suggests that biochar contains essential nutrients necessary for plant growth, although the nutrient content of biochar depends on the feedstock used, as reported by several researchers (Barrow, 2012; Ippolito et al., 2012). This study has proven that plant-based biochar (sawdust) has positive effects on plant growth, as evidenced by the different responses of maize to this biochar source.

Table 5: Main effects of different rates of sawdust biochar on maize growth

Rates t/ha	Plant Height (cm)			No of Leaves			Stem Girth (cm)		
	4WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
0	26.30	43.90	67.20	5.67	7.33	9.30	1.60	2.13	2.33
5	25.30	35.93	46.70	4.33	7.00	11.33	1.67	2.20	2.27
10	27.10	48.53	60.40	5.67	8.33	11.67	1.60	2.27	2.33
15	30.00	37.77	47.93	4.67	8.33	11.67	1.50	2.23	2.20
20	29.60	39.13	49.43	4.67	7.67	10.00	1.70	2.43	2.57
LSD (0.05)	NS	8.056	13.266	1.3286	NS	NS	NS	NS	NS

Lsd=least significant difference, t/ha=tonnes per hectare, WAP= weeks after planting, NS= not significant

Conclusion and Recommendation

Biochar amendment on soil influenced soil properties and maize growth. Biochar incorporation improved the chemical properties of the soil for crop production. Its use as a soil amendment can boost soil fertility and improve soil quality by reducing soil acidity, improving cation exchange capacity (CEC), and retaining nutrients. After the 4, 8, and 12 weeks of incubating the soil with sawdust biochar, the pH, total nitrogen, organic matter, CEC, and available phosphorus increased. These effects of sawdust biochar amendment on soil properties were more pronounced at higher application rates of 15-20 t/ha. The findings could inform agricultural practices aimed at enhancing soil fertility, improving crop productivity, and promoting long-term sustainability in Ultisols-based agro-ecosystems. Therefore, the use of biochar as an amendment to agricultural soils must be based on biochar properties with special attention to their effects on soil nutrient availability.

References

Adubasim, C. V., Law-Ogbomo, K. E., and Obalum, S. E. (2017). Sweet potato (Ipomoea batatas) growth and tuber yield as influenced by plant spacing on sandy loam in humid tropical environment. Agro-Science, 16(3): 46-50. https://doi.org/10.4314/as.v16i3.7.

Adjei-Nsiah S, (2012). Response of Maize (Zea mays L.) to Different Rates of Palm Bunch Ash Application in the Semi-deciduous Forest Agro-ecological Zone of Ghana. Applied and environmental soil science (Soil Management for Sustainable Agriculture) Volume 2012, 5 pages doi.org/10.1155/2012/870948

Anand, M. and Yoshiyuki, S. (2018). Effects of biochar on soil physic-chemical properties. Sciences (IEICES) 4, 102-105.

Antal M. J. and Gronli M. (2003). The art, science and technology of charcoal production. Industrial and Engineering Chemistry Research. 42(8): 1619-1640.

Bagreev, A., Bandosz, T. J. and Locke, D. C. (2001). Pore structure and surface chemistry of adsorbents obtained by pyrolysis of sewage sludge-derived fertilizer, Carbon 39: 1971–79.

Barrow, C. J. (2012). Biochar: Potential for countering land degradation and for improving agriculture. Applied Geography 34: 21–28.

Bremner, J. M. and Mulvaney, C. S., (1982). Nitrogen - Total. In: Methods of Soil Analysis (A. L. Page et al., ed.). Agronomy Monograph 9, Part 2, 2nd ed. American Society of Agronomy, Madison, WI. pp. 595-624.

Burrell, L. D., Zehetner, F., Rampazzo, N., Wimmer, B., and Soja, G. (2016). Long-term effects of biochar on soil physical properties. *Geoderma*, **282**, 96–102. doi.org/10.1016/j.geoderma.2016.07.019

Chan, K. Y. and Xu, Z. (2009). 'Biochar: nutrient properties and their enhancement', In: Lehmann, J. & Joseph, S. Biochar for Environmental Management: Science and Technology, Earthscan, United Kingdom: 67–84 pp. ISBN: 978-1-84407-658-1

Chapman, H. D. (1982). Total exchangeable bases. In C.A. Black (ed). Methods of Soil Analysis Part 11: ASA Madison, Wisconsin. 902 – 904.

Cheng C. H., Lehmann J., Thies J. E. and Burton S. D. (2008). Stability of black carbon in soils across a climatic gradient. J Geophys Res 113:G02027

Chintala, R., Mollinedo, J., Schumacher, T. E., Malo, D. D. and Julson, J. L. (2014). Effect of biochar on chemical properties of acidic soil. Arch. Agron. Soil Sci. 60: 393–404.

DeLuca, T.H., MacKenzie, M.D. and Gundale, M.J. (2009). 'Biochar effects on soil nutrient transformations', in Lehmann, J. and Joseph, S. Biochar for environmental management: science and technology, Earthscan, United Kingdom: 251 – 270.

Downie A., Crosky A. and Munroe P. (2009). Biochar production technology. Physical properties of biochar. In: Biochar for environmental management. Science and technology (Eds. Lehmann, J. & Joseph S.). 13-29. Earth Scan.

Ebeheakey, A., Adzraku, H. and Tandoh, P. K. (2018). Use of Different Sawdust Biochar as Soil Amendments to Improve Allelochemical-laden Soils Caused by Bamboo in the Landscape. Asian Journal of Environment and Ecology. 6: 1-11. 10.9734/AJEE/2018/40546.

Ebido, N.E., Edeh, I.G., Unagwu, B.O., Nnadi, A.L., Ozongwu, O.V., Obalum, S.E. and Igwe, C.A. (2021). Rice-husk biochar effects on organic carbon, aggregate stability and nitrogen-fertility of coarse-textured Ultisols evaluated using Celosia argentea growth. Sains Tanah Journal of Soil Science and Agroclimatology, 18(2): 177-187. https://dx.doi.org/10.20961/stjssa.v18i2.56330

Edeh, I. G., Mašek, O., and Buss, W. (2020). A meta-analysis on biochar's effects on soil water properties – New insights and future research challenges. Science of the Total Environment, 714: 136857. doi.org/10.1016/j.scitotenv.2020.136857.

Gee, G. W. and Bauder, J. W. (1986). Particle size analysis. In: Methods of soil analysis, part 1, 2nd edition. Klute, A. (Ed.). American Society of Agronomy, Madison, WI. pp. 383-414.

Geng, Y., Cao, G., Wang, L., Wang, S. (2019). Effects of equal chemical fertilizer substitutions with organic manure on yield, dry matter, and nitrogen uptake of spring maize and soil nitrogen distribution. PLoS One. 14(7):e0219512. doi: 10.1371/journal.pone.0219512.

Han, Y., Boateng, A.A., Qi, P.X., Lima, I.M. and Chang, J. (2013) Heavy Metal and Phenol Adsorptive Properties of Biochars from Pyrolyzed Switch Grass and Woody Biomass in Correlation with Surface Properties. Journal of Environmental Management, 118, 196-204.doi.org/10.1016/j.jenvman.2013.01.001

Igwe, C. A. (2004). Soil properties influencing the stability of structure of B-horizons of ultisols in semi-arid Nsukka, Eastern Nigeria. Arid Land

Research and Management. 18: 185-195.

Ippolito J. A., Laird D. A. and Busscher W. J. (2012). Environmental benefits of biochar. Journal of Environmental Quality 41(4): 967s

Kataki, R., Das, M., Chutia, R. S. and Borah, M. (2012). Biochar for C-sequestration and soil amelioration. In: Renewable Energy Technology: Issues and Prospects, (eds G. Shankar, B. Das, R. Blange). Excel India Publishers, New Delhi. pp. 131-137

Kloss, S., Zehetner, F., Dellantonio, A., Hamid, R., Ottner, F., Liedtke, V., Schwanninger, M., Gerzabek, M. H. and Soja, G. (2012). Characterization of slow pyrolysis biochars: Effects of feedstocks and pyrolysis temperature on biochar properties. Journal of Environmental Quality 41(4): 990

Laird, D. A., Fleming, P., Davis, D. D., Horton, R., Wang, B. and Karlen, D. (2010). Impact of biochar amendments on the quality of typical Midwestern agricultural soil. Geoderma, 158: 444– 449.

Landon, J. R. (2014). Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Routledge.

Latini, A., Bacci, G., Teodoro, M., Mirabile, G. D., Bevivino, A. and Trakal, L. (2019). The Impact of Soil-Applied Biochars from Different Vegetal Feedstocks on Du=rum Wheat Plant Performance and Rhizospheric Bacterial Microbiota in Low Metal-Contaminated Soil. Frontier Microbiology 10:2694. doi: 10.3389/fmicb.2019.02694.

Lehmann, J. and Rondon. M. (2006). Biochar soil management on highly weathered soils in the humid tropics. In: N. Uphoff et al. (eds.), Biological approaches to sustainable soil systems. Florida: CRC Press, Taylor and Francis Group. pp. 517-530.

Liu, S., Cen, B., Yu, Z., Qiu, R., Gao, T. and Long, X. (2025). The key role of biochar in amending acidic soil: reducing soil acidity and improving soil acid buffering capacity. *Biochar* **7**, 52 (2025). doi.org/10.1007/s42773-025-00432-8

Major, J. (2011). Biochar: a new soil management tool for farmers and gardeners. Appalachian sustainable agricultural development. IBI report.

Mclean, E. O. (1982). Soil pH and lime requirement in: Page, A.L, Miller, R. H. and Kenney, D. R (eds). Methods of soil analysis, part 2: Chemical and microbial properties. Madison Wisconsin: American Society of Agronomy Monograph no. 9, 199-224.

Narzari, R., Bordoloi, N., Chutia, R., Borkotoki, B., Gogoi, N., Bora, A. and Kataki, R. (2015). Chapter 2-Biochar: An Overview on its Production, Properties and Potential Benefits. 10.13140/RG.2.1.3966.2560.

Nelson, O. W. and Sommers, L. E. (1996). Total carbon, total organic carbon, and organic matter in: Sparks, D. L. (ed.). Methods of soil analysis, part 3: Chemical and microbial properties. Madison Wisconsin: American Society of Agronomy Monograph no. 9, 961-1010.

Ndor E., Jayeoba O. J. and Asadu, C. L. A. (2015). Effect of biochar soil amendment on soil properties and yield of sesame varieties in Lafia, Nigeria. American Journal of Experimental Agriculture, 9(4): 1-8.

Okoroafor, I. B., Okelola, E. O., Edeh, O. N., Emehute, V. C., Onu, C. N.,Nwaneri, T. C. and Chinaka, G. I. (2013). Effect of Organic Manure on the Growth and Yield Performance of Maize in Ishiagu, Ebonyi State, Nigeria. IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS), 5(4): 28-31.

Olsen, S. R. and Sommers, L. E. (1990). Phosphorus In Page, A. L. (Ed), Methods of soil Analysis Part 2, Agron.,Monogr. No. 9 ASA. Madison, WI. pp. 403 – 431.

Rhoades, J. D. (1982). Cation exchange capacity. In: Page, A.L, Miller, R. H. and Kenney, D. R (eds). Methods of soil analysis, part 2: Chemical and microbial properties. Madison Wisconsin: American Society of Agronomy Monograph no. 9, 961-1010.

Rosales, E., Meijide, J., Pazos, M. and Sanromán, M. A. (2017). Challenges and recent advances in biochar as low-cost biosorbent: from batch assays to continuous-flow systems – a review. Bioresource Technol., 246: 176 – 192.

Shafie, S. M., Mahlia, T. M. I., Masjuka, H. H. and Ahmad Yazid, A. (2012). A review on electricity generation based on biomass residue in Malaysia. Renewable and sustainable energy reviews, 16 (8): 5879-5889.

Spokas, K. A, Cantrell, K. B., Novak, J. M., Archer, D. W., Ippolito J. A., Collins H. P. and Boateng, A. A. (2012). Biochar: A synthesis of its agronomic impact beyond carbon sequestration. Journal of Environmental Quality 41(4): 973

Van Zwieten, L., Sigh, B., Joseph, S., Kimber, S., Cowie, A., and Chan, K.Y. (2009). Biochar and emissions of non-CO2 greenhouse gases from soil. In: Lehmann, J. & Joseph, S. (Eds.), Biochar for Environmental Management – Science and Technology, Earthscan, London: pp 227 – 247.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K. Y., Downie, A., Rust, J., Joseph, S. and Cowie, A. (2010). Effects of bio-char from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant Soil. 327: 235-246.

Wong, W., Gorsuch J. W. and Lower W. R. (1991). Plants for toxicity assessment. ASTM STP1091, ASTM Philadelphia.

EVALUATION OF FERTILITY STATUS OF *FADAMA* SOILS ALONG *KOFAR KWARE*, SOKOTO WESTERN BYPASS, SOKOTO STATE, NIGERIA

Yusuf, B.[1*] and Lukman, S. A.[1]
[1]*Department of Soil Science and Land Resources Management, Usmanu Danfodiyo University, P.M.B. 2346, Sokoto, Sokoto State, Nigeria*
[*]*Corresponding author's e-mail address: ybashir985@gmail.com*

ABSTRACT
This study examined soil fertility status of Fadama farms along Kofar Kware, Sokoto Western Bypass in Sokoto State. The objective was to identify factors contributing to declining crop yields reported by farmers during reconnaissance surveys and the gradual conversion of Fadama farms to non-irrigation uses such as filling stations, heavy metal dumping grounds, football fields, and schools in the area. Nine Fadama farms denoted as F1 to F9 were randomly selected for the study. Composite soil samples were obtained at a depth of 0-20cm using auger. Simple random sampling method was used in collecting composite samples and was further analyzed for selected physical and chemical properties. Data obtained were analyzed using descriptive statistics. The results obtained indicated that, soil electrical conductivity (EC) fall within classes ranging from slightly saline to strongly saline, while soil pH fall within the optimal range (6.00 to 7.00) for growing most tropical crops. Particle size distribution analysis showed that Fadama soils range from silt-loam to silt, indicating higher silt content with relatively low sand fraction. The organic carbon and available phosphorous were low with total nitrogen within the medium range. Meanwhile, the EC, were at different instances found to exceed >4dSm^{-1} conceivably contributing to declining yields of the cultivated crops. It is recommended that farmers conduct periodic soil tests before and after crop production activities to assess the fertility status of their farms. However, there is a pressing need for government departments and relevant agencies, particularly those responsible for environmental protection, to intervene and address the deteriorating trend of Fadama farms.
Keywords: Soil, Fertility, *Fadama*, Evaluation, Sokoto.

Introduction

Soil fertility evaluation is a central feature of modern soil fertility management. The fundamental purpose of soil fertility evaluation is to quantify the ability of soils to supply nutrients for plant growth (Nitesh *et al.,* 2024). Low fertility of Nigerian soils is the major constraint in achieving high productivity goals (Nafiu *et al*., 2012). The soil must be loose and sufficiently soft and friable to permit germination and root development without mechanical obstruction, this refers to physical fertility (Dobo, 2019). In both rain-fed and irrigated systems, nutrient replenishment through fertilizers and manures remains far below the crop removal, thus causing mining of native reserves over the years (Julio and Carlos, 1999; Nafiu *et al*., 2012).

Soil nutrients depletion has grave implication in terms of more acute and widespread nutrients deficiencies. This weakened the foundation for high yielding sustainable farming and escalating remedial cost for re-building depleted soils (SFE, 2014). Continuous cropping without adequate nutrient restorative practices may endanger the sustainability of agriculture (FAO, 2014). Indeed many government and private farming activities failed due to failure to understand the values and significance of soil evaluation and monitoring through proper sampling and testing techniques which could be the bedrock of sound soil management decision while making the most efficient use of environmental resources (FAO, 2003). Consequently, numerous sections of *Fadama* farms have been repurposed for premium motor spirit (PMS), kerosene, and gasoline filling stations, as well as industrial and residential zones, and refuse dumping sites, among other uses. This transformation has resulted in the wetland areas of *Fadama* farms being diverted from their traditional use for irrigation farming to serve alternative purposes (Reconnaissance survey, 2022).

As human societies become increasingly urbanized, fewer people have intimate contact with the soil and individuals tend to lose sight of the many ways in which they depend upon soils for their prosperity and survival (Brady and Weil, 2010). Irrigation has contributed significantly to poverty alleviation, food security, and improving the quality of life (Rufai *et al.,* 2020). Proper soil testing would help reach the goal of sound soil management decision, that best meet crop needs and maintain the nutrient supplying power of the soil, while making the most efficient use of fertilizer and avoiding environmental problems (FAO, 2014).

Approximately, two-thirds of the *Fadama,* comprising the wetland areas along *Kofar Kware*, have been repurposed for industrial and residential use. Only the remaining one-third of the *Fadama* is currently designated for irrigation farming practices. Plants grown in this area exhibited signs of poor or stunted growth, yellowish leaves, and the presence of whitish particles on the soil surface. These factors are pointers leading to a consistent reduction in crop yields, posing a threat to sustainable food security (Reconnaissance survey, 2022). When questioned, one of the guardians of the wetland areas along *Kofar Kware* explained the occupation of *Fadama* farms by activities other than traditional irrigation practices. He stated, "The soil in that area has become unproductive and is no longer suitable for irrigation farming." Furthermore, he noted that some portions of the *Fadama* farms were inherited by individuals not inclined towards farming, leading to a lack of interest in the irrigation farming system (Reconnaissance survey, 2022). Prior to this present research, there had been no reported similar study conducted on the *Fadama* farms along *Kofar Kware,* Sokoto Western Bypass in Sokoto State.

This study was, therefore, embarked to evaluate the soil fertility status of the *Fadama* farms situated along *Kofar Kware*, identify factors contributing to declining crop yields, conversion of *Fadama* to non-irrigation uses and examine specific physical and chemical properties of the soils in the study area.

Materials And Methods

The study was conducted at the *Fadama* farms along *Kofar Kware*, Sokoto Western Bypass, Sokoto State, Nigeria. The area is located between Latitude 13° 4’ 40” to 13° 4’ 37” N and Longitude 5° 14’ 33” to 5° 14’ 22” E at an altitude of 271m above sea level (GPS).

Sokoto State is in the North-West Sudano-Sahelian Savannah ecological belt of Nigeria between Latitudes 11° 03' and 13° 50' N of the Equator and Longitudes 4° 14' and 6° 40' E of the Greenwich Meridian (Abubakar, 2006; Patrick *et al.* 2024). It is characterized by a long dry season and an average rainfall of 750mm (Abdullahi *et al.,* 2011). The rainy seasons are usually short, which is often within the ranges of four to five months (May/June to September/October) (Patrick *et al.,* 2024). Ambient temperature ranges from 14ºC during the Harmattan periods to 38ºC during the hot season (SERC, 2004; Abdullahi *et al.,* 2011). With 15 - 20% relative humidity during the dry season and up to 70 - 75% during the rainy season (Arnborg, 1988; Abdullahi *et al.,* 2011).

Image displaying the coordinates of the nine (9) randomly selected Fadama Farms.
Source: Google Earth

Image showing the coordinates of Fadama Farms from F1 to F3. Source: Google Earth

Image showing the coordinates of Fadama Farms from F4 to F9. Source: Google Earth

Kofar Dundaye

One of the Study Location Areas (F1)

Kofar Kware

Composite soil samples were collected from nine (9) randomly selected wetland farms; denoted as F1 to F9. The samples were collected using soil sampling auger at a depth of 0-20cm, labeled properly in a clean black polythene bag and air dried for 72hrs at 25˚C room temperature. To ensure homogeneity, the air dried soil samples were gently grounded using pestle and mortar. The samples were then sieved through a 2mm mesh sieve, labeled, stored and sealed prior to laboratory analysis.

Particle size distribution analysis was conducted using the Bouyoucous hydrometer method as described by Gee and Bauder, (1986) and soil textural classes were established using USDA textural triangle. Core soil samples were used to analyse bulk density as described by Blake and Hartge, (1986). Electrical conductivity was determined using a conductivity cell by measuring the electrical resistance of a 1:5 soil:water suspension (USDA, 2011). Soil pH was analysed in distilled water (1:1 soil solution ratio) as described by Bates, (1954). Organic carbon was determined using Walkey-Black method (1934). Total nitrogen was examined using micro-kjeldahl digestion distillation method (Jackson, 1962). Available phosphorus was determined using Bray-P1 method (Juo, 1979). Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted by saturating soil with neutral 1*M* NH_4OAc (Thomas, 1982). Ca^{2+} and Mg^{2+} were analyzed using atomic absorption spectrophotometer, while K^+ and Na^+ were determined using flame emission spectrophotometer (Black, 1965). The cation exchange capacity was analysed by saturating the soil with 1*N* NH_4OAc at pH 7.0 (Chapman, 1965). Percentages base saturation of the samples was computed using the following expression;

$$Base\ saturation = \frac{\text{Base cations}}{\text{CEC}} \times 100$$

Data collected were subjected to descriptive statistics.

Results And Discussion

Particle Size Distribution

The particle size distribution results are outlined in Table 1. In the 0-20cm depth layer, the soils sampled from the nine (9) randomly selected *Fadama* farms exhibited silt to silt-loam texture. The values ranged from 4.96% to 5.09% for sand, 70.96% to 90.24% for silt, and 14.11% to 24% for clay. The mean values were 5.04% for sand, 80.70% for silt, and 14.23% for clay content in the soils.

The results indicated that, the soils in the area belonged to the silt-loam to silt textural classes. Moreover, the classification also suggested, soils in the area predominantly compose of silt, with lesser amounts of clay and a relatively low proportion of sand. This characterization aligns with the findings of a previous study conducted by Uke and Haliru (2021) at the Sokoto *Fadama* wetland farms. In their study, they also observed that silt content outweighed clay content, with sand being the least abundant fraction in the soil. While specific values may vary, the general trend of soil texture in both studies indicates a dominance of silt over clay and sand.

Bulk Density

The results of bulk density (BD) are presented in Table 1. The values ranged from 0.83-1.48g cm^{-3} with a mean value of 1.19 g cm^{-3} at a uniform soil depth of 0-20cm for the (9) selected *Fadama* farms. These results indicated that, except for F7 and F9, all the soils had a bulk density (BD) range of less than or equal to 1.3g cm^{-3} which is rated as good while for F7and F9 fell between the range of 1.3 and 1.55g cm^{-3} which is rated as fair. According to Hunt and Gilkes, (1992) the soils of the study area are within the desirable bulk density range, which is (<1.5g cm^{-3}). It is generally desirable to have soil with a low bulk density (<1.5g cm^{-3}) (Hunt and Gilkes, 1992) for optimum movement of root, air and water through the soil.

This discovery further supports the conclusions drawn in a prior investigation conducted by Danmowa *et al.,* (2020) at *Dingyadi* District of Sokoto State, Nigeria. In their research, they noted an average bulk density of 1.53g cm-^{3}. While there may be slight variations in precise figures, both soil types shared overall characteristics that provide an optimal bulk density (BD) range for facilitating root, air, and water movement in the soil subsurface, thus promoting the growth of a variety of agricultural crops.

Both bulk density and porosity give a good indication of the suitability for root growth and soil permeability and are vitally important for the soil-plant atmosphere system (Cresswell and Hamilton, 2002; McKenzie *et al.,* 2004). The bulk density (BD) of clay, clay loam and silt loam soils may range between 1.00-1.60g cm^{-3} depending on their condition (Landon, 1991). The optimal and critical limits of soil BD are dependent on soil texture, particle size, management practices, and organic matter content (Reichert *et al.,* 2009)

Table 1: Selected physical properties of *Fadama* soils along *Kofar Kware*, Sokoto State, Nigeria.

Location	Coordinates	Sampling Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	BD (g cm^{-3})
F1	N 13° 4' 40 E 5° 14' 33	0-20	4.96	76.22	18.82	Silt-loam	0.83
F2	N 13° 4' 40 E 5° 14' 30	0-20	4.97	76.21	18.82	Silt-loam	0.90
F3	N 13° 4' 41 E 5° 14' 29	0-20	5.05	76.13	18.82	Silt-loam	1.15
F4	N 13° 4' 34 E 5° 14' 27	0-20	5.06	76.12	18.82	Silt-loam	1.25
F5	N 13° 4' 35 E 5° 14' 26	0-20	5.02	80.87	14.11	Silt-loam	1.10
F6	N 13° 4' 35 E 5° 14' 27	0-20	5.06	90.24	4.7	Silt	1.31
F7	N 13° 4' 35 E 5° 14' 25	0-20	5.09	89.91	5	Silt	1.48
F8	N 13° 4' 35 E 5° 14' 23	0-20	5.08	89.92	5	Silt	1.29
F9	N 13° 4' 37 E 5° 14' 22	0-20	5.04	70.76	24	Silt-loam	1.39
Mean			5.04	80.70	14.23		1.19

BD= Bulk density, Coordinates= Geographical positioning system of the farms, Locations= Fadama farms.

Electrical Conductivity

Electrical conductivity (EC) results are presented in Table 2. The EC values ranged from 2.33 to 9.76dS m-^{1}, with a mean value of 5.50dSm^{-1} observed across sampling locations and depths.

The electrical conductivity (EC) of the soils ranged from slightly saline to strongly saline. Under slightly saline conditions, yields of sensitive crops may be restricted, while in moderately saline soils, many crops face limitations in yield. Only tolerant crops can yield satisfactorily in strongly saline soils. Excessive soil salinity results in poor and patchy crop stands, uneven and stunted growth, and reduced yields, with the severity varying according to the degree of salinity.

In general, the EC values indicated a significant accumulation of soluble salts to the sampled depth, capable of potentially limiting crop production. However, this finding contradict those of Rufai *et al.*. (2020), who conducted a study at *Tutudawa*; main canal of the *Wurno* Irrigation Scheme in Sokoto, Nigeria and observed no accumulation of soluble salts, thus posing no salinity hazards compared to the results of this present study. FAO, (2014) reported that EC of (<0.8 dS m^{-1}) as low in range, to cause any salinity hazards. According to Richards (1954) saline soils are those which have an electrical conductivity of the saturation soil extract of more than 4dS m^{-1} at 25°C.

There is no critical point of salinity where plants fail to grow. As the salinity increases, growth decreases until plants become *chlorotic* and die. Plants differ widely in their ability to tolerate salts in the soil. Salt tolerance ratings of plants are based on yield reduction on salt affected soils when compared with yields on similar non-saline soils (Richards, 1954).

Soil pH

The soil reaction findings for the selected locations are showcased in Table 2. The average pH of the *Fadama* soils is 6.54, ranging from 6.46 to 6.65, indicating slightly acidic to neutral soil conditions, which suggested, generally the soils are within the optimal range suitable for most crops. This characterization corresponds with the results of a prior study conducted by Abdullahi *et al.,* (2010) in *Gantsare* Village, *Wamakko* Local Government, Sokoto State. Their research revealed slightly acidic soil pH in Girabshi village and neutral pH in all areas affected by dust in *Gantsare* village. Despite potential slight variations in exact measurements and locations, both soil types support ranges conducive to most crop production. Landon (1991) reported that soils with pH range value of between 5.5 and 7.0 are suitable for most tropical crops and are within the range that favour nutrient availability in the soils. According to Chude *et al.* (2011), pH range is categorized as follows; those with values from 5.0-5.5 as strongly acid, soils with values from 6.1-6.5 as slightly acid, and soils values ranging from 6.6-7.2 as neutral while those with values from 7.3-7.8 are categorized as slightly alkaline.

Soil Organic Carbon

Table 2 display the result of soil organic carbon content. Within the 0-20cm depth, the average organic carbon content is 7.8g kg-^{1}, with values ranging from 7.4g kg^{-1} to 8.2g kg^{-1} for the selected *Fadama* farms. The results suggest low organic carbon content in the soils, corroborating the conclusions of a previous study by Uke and Haliru (2021) at the Sokoto *Fadama* wetland farms in Nigeria. In their study, they also highlighted low levels of organic carbon across the study area. Contrarily, this study contrasts with a previous findings by Abdullahi *et al.* (2010) in *Gantsare* Village, *Wamakko* Local Government, Sokoto State. Their research revealed generally medium to high organic carbon content in the soils. Esu, (1991) reported that values range from <10, 10-15 and >15 gkg^{-1} are low, medium and high respectively.

Total Nitrogen

The results of the total nitrogen content are presented in Table 2. Within the 0-20cm depth, the average total nitrogen content of the soils is 0.09 g kg^{-1} with values ranging from 0.04 g kg^{-1} to 0.10g kg^{-1} across *Fadama* farms. The results showed that total nitrogen content of the *Fadama* soils, except for F3, falls within the range of 0.1-0.2 gkg^{-1}, categorizing them as medium. However, the F3 *Fadama* soil, with a value of < 0.1g kg^{-1}, is rated as low in total nitrogen content. In all *Fadama* farms except for F3, this study contradicts the prior investigation by Uke and Haliru (2021) at the Sokoto *Fadama* wetland farms in Nigeria. Their study indicated generally very low nitrogen levels in the study area. However, their finding also align with the present study regarding the F3 *Fadama* farm, which showed similarly low total nitrogen content.

According to Esu, (1991) total nitrogen content with values ranges from < 0.1, 0.1-02 and > 0.2g kg^{-1} was rated as low, medium and high respectively.

Table 2: Selected chemical properties of *Fadama* soils along *Kofar Kware*, Sokoto State, Nigeria.

Locations	Coordinates	Sampling Depth (cm)	pH (H_2O) (1:1)	OC (g kg^{-1})	TN (g kg^{-1})	Available P (mg kg^{-1})	EC (dSm^{-1})
F1	13° 4’ 40N 5° 14’ 33E	0-20	6.47	7.6	0.11	0.61	9.76

F2	13° 4’ 40N 5° 14’ 30E	0-20	6.47	8.1	0.08	0.60	5.73
F3	13° 4’ 41N 5° 14’ 29E	0-20	6.46	8.1	0.04	0.63	8.98
F4	13° 4’ 34N 5° 14’ 27E	0-20	6.65	7.9	0.13	0.59	3.54
F5	13° 4’ 35N 5° 14’ 26E	0-20	6.59	7.5	0.10	0.55	5.79
F6	13° 4’ 35N 5° 14’ 27E	0-20	6.55	8.0	0.12	0.56	3.89
F7	13° 4’ 35N 5° 14’ 25E	0-20	6.64	7.4	0.10	0.62	2.33
F8	13° 4’ 35N 5° 14’ 23E	0-20	6.57	7.4	0.08	0.56	3.34
F9	13° 4’ 37N 5° 14’ 22E	0-20	6.48	8.2	0.07	0.56	6.17
Mean			6.54	7.8	0.09	0.58	5.50

Coordinates= Geographical positioning system of the farms, Locations= Fadama farms, pH (H_2O) = Soil reaction in water, OC= Organic carbon, TN= Total nitrogen, AP= Available phosphorus, EC= Electrical conductivity of the soils

Available Phosphorus

Table 2, display the available phosphorus results. The mean soil available P value is 0.58, ranging from 0.55 to 0.63mg kg^{-1}. These findings indicate that *Fadama* soils fall within the value of <10.0 range, rated as having low level of available phosphorus, as reported by Esu (1991) rating standards.

The available phosphorus distributions across the chosen *Fadama* farms were predominantly low, aligning with Esu's (1991) classification where values below < 10.0mg kg^{-1} are considered low, 10.0-20.0mg kg^{-1} as medium, and > 20.0mg kg^{-1} as high. This is consistent with findings by Patrick *et al.* (2024) in *Dundaye* District, Sokoto, Nigeria.

Exchangeable Bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+})

Calcium (Ca^{2+})

Table 3 displays the findings of exchangeable calcium (Ca^{2+}) content. Soil calcium content ranged from 1.15 to 1.75 cmol kg^{-1}, with a mean value of 1.43 cmol k kg^{-1} across the selected farms. This result indicate that the calcium content of *Fadama* soils is generally low. This discovery supports the conclusion drawn in a previous study by Abdullahi *et al.* (2011) which similarly reported low levels of calcium content in the study areas. Esu (1991) rating standard, reported that calcium content ranged < 2, 2-5, and > 5 cmol kg^{-1}, is categorized as low, medium and high respectively.

Magnesium (Mg^{2+})

The result of the exchangeable magnesium (Mg2+) content are presented in Table 3. At a depth of 0-20cm, the magnesium content of the soils ranged from 0.18-0.71cmol kg^{-1} with a mean value of 0.34cmol kg^{-1} across the selected farms.

The results suggest that magnesium content of the *Fadama* soils is generally medium, except for F3, F6, and F7 *Fadama*, which fall within the low range and are thus rated as having low magnesium content. Contrarily, Abdullahi *et al.,* (2011) observed and reported high levels of magnesium content in a previous study. As reported by Esu, (1991) rating standard, soils with value ranges of < 0.3, 0.3-1, and > 1 cmol kg^{-1} are classified as low, medium, and high in magnesium content, respectively.

Table 3: Selected chemical properties of *Fadama* soils along *Kofar Kware*, Sokoto North Local Government, Sokoto State, Nigeria.

Locations	Coordinates	Sampling Depth (cm)	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	CEC	BS
						(cmol kg^{-1})		(%)
F1	N 13° 4’ 40 E 5° 14’ 33	0-20	1.75	0.32	0.10	0.08	6.8	33.08
F2	N 13° 4’ 40 E 5° 14’ 30	0-20	1.55	0.36	0.14	0.04	6.5	32.15
F3	N 13° 4’ 41 E 5° 14’ 29	0-20	1.25	0.18	0.12	0.07	6.2	26.12
F4	N 13° 4’ 34 E 5° 14’ 27	0-20	1.3	0.71	0.09	0.05	5.7	37.72
F5	N 13° 4’ 35 E 5° 14’ 26	0-20	1.35	0.35	0.13	0.09	6.1	31.48
F6	N 13° 4’ 35 E 5° 14’ 27	0-20	1.4	0.25	0.09	0.05	6.6	27.12
F7	N 13° 4’ 35 E 5° 14’ 25	0-20	1.15	0.23	0.12	0.06	5.7	27.37
F8	N 13° 4’ 35 E 5° 14’ 23	0-20	1.55	0.30	0.10	0.08	6.6	30.76
F9	N 13° 4’ 37 E 5° 14’ 22	0-20	1.6	0.33	0.14	0.06	6.5	32.77
Mean			1.43	0.34	0.11	0.06	6.3	30.95

Coordinates= Geographical positioning system of the farms, Locations= Fadama farms, Ca^{2+}= Calcium content, Mg^{2+}= Magnesium content, K^{+}= Potassium content, Na^{+}= Sodium content, CEC= Cation exchange capacity, BS(%)= Base saturation percentage

Potassium (K^{+})

The result of the exchangeable potassium (K+) content are presented in Table 3. The potassium content of the soils ranged from 0.09-0.14cmol kg^{-1} with a mean value of 0.11cmol kg^{-1} across the selected farms.

The results indicate that the potassium content in the soils is generally low. This contradicts the findings of a prior study by Abdullahi *et al.,* (2011) where they observed high levels of potassium content. According to Esu, (1991) rating standard soils with value range of < 2, 2-5 and > 5cmol kg^{-1} are low, medium and high in potassium content respectively.

Sodium (Na^{+})

Table 3 display the result of sodium (Na^{+}) concentration of the *Fadama* farms. The sodium (Na^{+}) concentration in the soils ranges from 0.04-0.09cmol kg^{-1} with a mean value of 0.06cmol kg^{-1} across the selected farms. The results indicate that sodium (Na^{+}) concentration in the *Fadama* soils is generally low. This finding is in contrast with a previous study by Abdullahi *et al*. (2011) According to Esu, (1991) ratings standard, soils with value ranges of < 0.1, 0.1-0.3 and > 0.3cmol kg^{-1} are low, medium and high in sodium (Na^{+}) concentration respectively.

Cat-ion Exchange Capacity

Table 3 display the cat-ion exchange capacity result. The mean value of the cat-ion exchange capacity is 6.3, ranging from 5.7 to 6.8 cmol kg^{-1} across the selected *Fadama* soils. The results indicate that, the cation exchange capacity (CEC) of the *Fadama* soils generally falls within the medium range except for F4 and F7 Fadama soils, which are within the low range values and are consequently rated as having a low level of cation exchange capacity. Similarly, Abdullahi *et al.,* (2011) reported low levels of CEC in the control soils and observed high CEC levels in *Kwalkwalawa, Bakin Gulbi*, and *Rumbun Fadama* soils. According to Esu, (1991) ratings standard, soils with value ranges of < 6.0, 6.0-12.0 and > 12cmol kg^{-1} are low, medium and high in cat-ion exchange capacity respectively.

Base Saturation Percentage

The result of base saturation percentage are presented in Table 3. The base saturation percentage in the soils ranged from 26.12-37.72% with a mean value of 30.95 across the selected soils. The result indicated that, the selected *Fadama* farms have low base saturation and therefore fertility rating. This contradicted a previous study by Uke and Haliru (2021) at the Sokoto *Fadama* wetland farms in Nigeria, where they reported generally fertile soils across the study areas. Anni *et al.* (2018) reported that soils with base saturation of >50% are regarded as fertile soils while soils with less than 50% were regarded as not fertile soils. Based on this, the soils are generally not fertile.

Conclusion

This study showed that soils across selected *Fadama* farms are generally not fertile as per Anni *et al.* (2018), leading to declining crop yields due to low levels of soil nutrients and imbalances of essential elements, with high EC values recorded above 4dS m^{-1} in the study areas, attributed to continuous crop production without proper soil nutrient restoration through effective soil management practices. Also farmers cultivated these farms without knowing the fertility status of their soils. The conversion of *Fadama* farms for purposes other than irrigation farming stemmed from the decrease in crop yields.

The following soil management practice can be adopted for these *Fadama* farms to restore soil fertility and improve overall soil health; incorporation of organic matter into the soil through practices such as composting, mulching, and cover cropping as organic matter improves soil structure, enhances nutrient retention, and promotes beneficial microbial activity. Implementation of a balanced nutrient management practices by applying fertilizers judiciously based on soil test recommendations and crop nutrient requirements and the use of organic fertilizers and amendments to supplement soil nutrients and promote long-term soil health (FAO. 2016).

It is recommended as imperative for farmers to conduct periodic soil tests both before and after engaging in crop production on their farms. This practice enables them to monitor the fertility status of their land, thus optimizing agricultural productivity. Nevertheless, the application of both organic and inorganic fertilizers in suitable proportions is necessary and advised to replenish deficient nutrient elements in the soils.

References

Abdullahi, A. A., Lawal, J. B., Dikko, A. U., Noma, S.S. and Audu, M. (2011). *Fertility Status of Fadama and Upland Soils Around the Main Campus, Usmanu Danfodiyo University, Sokoto, Nigeria.* Proceedings of the 45th Annual Conference of the Agricultural Society of Nigeria (ASN), 24th-28th Oct., "UDUS 2011" Supplement

Abdullahi, A.A., Usman, Y.D., Noma, S.S., Audu, M., Danmoma, N.M. and Shuaibu, H. (2010). Fertility Status of Fadama Soils in Gantsare Village, Wamakko Local Government, Sokoto State As Affected by Cement Dust. *Nigerian Journal of Basic and Applied Science*, 18(1):58-64. Available online at http://ajol.info/index.php/njbas/index

Abubakar, M. G. (2006). An Investigation of Ground Water Potential of Gada Town, Sokoto State Using Vertical Electrical Sounding. An unpublished Msc. thesis, Department of Geography, Ahmadu Bello University, Zaria, Nigeria.

Agboola, A, Ayodele, O. (1987). *Soil test calibration for upland rice in south western Nigeria.* 14:227-234.

Anni, Y., Mahfud, A., Emma, T, S., Betty, N., Rija, S. and Dewi, D. (2018). The effect of Sinabung volcanic ash and rock phosphate nanoparticle on CEC (cation exchange capacity) base saturation exchange (K, Na, Ca, Mg) and base saturation at Andisol soils Ciater, West Java", AIP Conference Proceedings : 030003.

Arnborg, T. (1988). *Where Savannah turns into Desert. Rural Development Studies.* 24 Swedish Uniersity of Agricultural Science, Uppsala, Sweden.

Bates, R. C. (1954). Electrometric pH determination. Jones Wiley and Sons Inc. New York. Pp. 21-23

Bhatt Rajan and Manoj Sharma (2014) *Importance of soil testing and techniques of soil sampling Paperback* – May 20 2014

Black, C. A. (1965). (ED). *Methods of Soil and Plant Analysis. Agronomy. No. 9 part 2 Amer. Soc.*

Blake, G.R. and Hartge, K.H. (1986) Bulk density. In: Klute, A., Ed., Methods of Soil Analysis, Part 1—Physical and Mineralogical Methods, 2nd Edition, Agronomy Monograph 9, American Society of Agronomy—Soil Science Society of America, Madison, 363-382.

Brady, N. (1990) *The nature and properties of soils*. 10th Edition, Macmillan Publishing Company, Cranbury.

Brady, N.C. and R. Weil, (2010) *Elements of the Nature and Properties of Soils.*13th editon. Pearson Education, Inc, Upper Saddle River, New Jersey.960p

Brady, N.C. and R.R. Weil. 1999. *Nature and properties of soil 12^th^ ed*. Prentice hall, New

Chapman, H.D. (1965) *Cation Exchange Capacity*. In: Black, C.A., Ed., Methods of Soil Analysis, American Society of Agronomy, Madison, 891-901.

Christopher, S., Marcel, G., Schaap, I., Jon, D. and Pelletier, C.R. (2017). *A probabilistic approach to quantifying soil physical properties via 2 time-integrated energy and mass input*. Department of Soil, Water and Environmental Science, The University of Arizona, Tucson, AZ, 7 USA, 85721-0038 Department of Geosciences, The University of Arizona, Tucson, AZ, USA 85721-0077

Chude, V.O., Jayeoba O.J. and Berling F. (2011). *A soil fertility map of Nigeria showing Different P, N, Zn, B, and K Classes of the top soil.* National Programme for Food Security.

Cresswell, H. P., Hamilton, G. J. (2002). *Bulk Density and Pore Space Relations.* In N. J.

Dobo, B. (2019). *Fertility Evaluation Of Soil For Cereal Production,* Hawassa University; College of Natural and Computational Sciences; Department of Biology; P.O.Box: 05; Email: beyeneashl@yahoo.co.uk

Esu, I.E. (1991). *Detailed Survey of NIHORT Farm at Bunkure, Kano State, Nigeria.*

Flynn, R., Shane, T.B. and Baker, R.D (2004). Sampling for Plant Tissue Analysis. Guide A-123, College of Agriculture and Home Economics New Mexico State University.

Food Agricultural Organization FAO (2016). Soil Management for Sustainable Agriculture. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/3/a-i5774e.pdf

Food Agriculture Organization-FAO (2003). *Guidelines for Soil Description*. 4th edition. Food and Agriculture Organization of the United Nations, Rome, Italy. 97pp.

Food and Agriculture Organization-FAO (2014). *Assessment of soil nutrient balance approaches and methodologies.*

Gee, G. W and Bauder, J. W (1986). Particle size in Aklate (Ed) in *Methods of Soil Analysis 2nd edition ASA. Pp. 383-409*

Hunt, N. and Gilkes, B. (1992) *Farm Monitoring Handbook*. Published by University of Western Australia, Land Management Society, and National Dryland Salinity Program

Institute for Agricultural Research, Ahmadu Bello University, Zaria.

Jackson, M. J and Wild (1962). Soil chemical analysis. Pentice hall, New York. USA. Jones D and J. Farrar (1999). Phosphorus Mobilization by root exudates in Rhizophere fact and friction. Agro forest forum 9(4): Pp20-24

Julio, H. and Carlos, B. (1999). *Nutrient Depletion in Agricultural Soils of Africa*" International Food Policy Research Institute. Vision 2020 Brief.p.62

Juo, A.S.R (1979). Selected methods for soil and plant analysis. International institute of tropical agriculture manual series. Pp55.

Kidder, G. (1993). Methodology for calibrating soil tests. Soil Crop Sci Soc. Fla. Proc. 52:70-73

Landon, J.R. (1991) *Booker Tropical Soil Manual*. A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and sub Tropics. Longman Scientific & Technical Publ., Harlon.

McKenzie NJ, Jacquier DJ, Isbell RF, Brown KL (2004) *Australian Soils and Landscapes An Illustrated Compendium*. CSIRO Publishing: Collingwood, Victoria.

McKenzie, et al. (Eds.), *Soil Physical Measurement and Interpretation for Land Evaluation*. Australian Soil and Land Survey Handbook (pp. 35-58). CSIRO.

Nafiu, A.K., Abiodun, M.O., Okpara I. M. and Chude, V. O. (2012). Soil Fertility Evaluation: a potential tool for predicting fertilizer requirement for crops in Nigeria. *African Journal of Agricultural Research*, 7(47): 6204-6214

Nasiru M. Danmowa, Peter Nkedi-Kizza, Kelly T. Morgan and Kamal Mahmoud (2020). *Soil Fertility Assessment of Semiarid Soils from Nigeria Cropped to Sorghum.* International Journal of Plant & Soil Science 32(9): 36-46, 2020; Article no.IJPSS.58370 ISSN: 2320- 7035

Nitesh Kumar Dandasena, Pritom Pal, Nasrullah Mollah, Subhayu Das and Parijat Bhattacharya (2024). *Soil Fertility Evaluation and Mapping*. Int J Adv Biochem Res 2024; 8(4): 363- 367 DOI: 10.33545/26174693.2024.v8.i4e.967

Patrick, U.I., Noma, S.S. and Ikpe E. (2024) *Characterization and Classification of Soil Along a Toposequence and its Implications on Crop Production in Dundaye District Sokoto, Nigeria.* International Journal of Weather, Climate Change and Conservation Research, 10(1):21-41

Potash and Phosphate Institute (2004). Agric Briefs: Pay Attention to Soil Sampling Details. Georgia. p. 5.

Reichert, J. M., Suzuki, L., Reinert, D., Håkansson, I. (2009). Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. *Soil & Tillage Research - SOIL TILL RES.* 102:242-254. 10.1016/j.still.2008.07.002.

Reisenauer, H.M., Quick, J., Voss, R.E., Brown, A.L. (1983). Chemical soil tests for soil fertility evaluation. In: H.M Reisenauer, (ed.), *Soil and plant tissue testing in California*, pp 39-41. University of California Division of Agriculture and Natural Resources, Oakland, CA. Bulletin 1879. Report on Soil and Water Baseline Survey for National Fadama III Project in Nigeria (2010).

Richards, L.A. (1954) *Diagnosis and Improvement of Saline and Alkali Soils.* United States Salinity Laboratory Staff. Agriculture Handbook No. 60, USDA and IBH Pub. Coy Ltd., New Delhi, 98-99. http://dx.doi.org/10.1097/00010694-195408000-00012

Rufai, A.Y., Umar Adamu G., S. S. Noma, and A. C. Odunze (2020). *Fertility/Salinity Assessment of Soil along Tutudawa Main Canal of the Wurno Irrigation Scheme, Sokoto, Prior to September, 2020 Flood*: Proceedings Of The Nmets 2020 International Conference & 34th Annual General Meeting (Virtual): Weather, Covid-19 And Consequences Held In University Of Ilorin, Ilorin, Nigeria, Nov 23 – 24, 2020.

SERC (2004). Sokoto Energy Research Centre. Meteorological Data of Sokoto, Usmanu Danfodiyo University, Sokoto

Soil Fertility Evaluation-SFE, (2014): *A potential tool for balance use of fertilizer*.http://www./pni.net/pp/web/india. accessed online..

Steinhilber P, Salak J. (2010). Plant Tissue Analysis : PL-1 in the Soil Fertility Guide. University of Maryland College of Agriculture and Natural Resources. pp. 2-10.

Udo, E. J., Ogunwale, J. O., and Esu, I., (2009). Manual of Soil, Plant and Water Analysis. Sibon Books Ltd, Lagos. Pp. 183

Uke, O. D. and Haliru, M. (2020). *Salinity study of the soils of Fadama farms, Sokoto, Nigeria*. Article in Farming and Management, June 2021 DOI: 10.31830/2456-8724.2021.001 available at: https://www.researchgate.net/publication/353488233

USDA-Natural Resources Conservation Service. Soil Survey Laboratory Information Manual; Burt, R., Ed.; Soil Survey Investigations Report No. 45; version 2.0.; Aqueous Extraction, Method 4.3.3.; USDA-NRCS: Lincoln, NE, USA, 2011; p. 167.

Verchot, L.V., Van Noordwijk, M., Kandji, S. *et al. Climate change: linking adaptation and mitigation through agroforestry. Mitig Adapt Strat Glob Change* **12**, 901–918 (2007). https://doi.org/10.1007/s11027-007-9105-6

Wade, B. (2010). *Symptoms of Deficiency in Essential Minerals*. In Plant Physiology, 5th Edition by Taiz Lincoln and Zeiger Eduardo.

Walkey, A. and Black, I.A. (1934). 'An examination of the digestive method for determining soil Organic matter and a proposed modification of the chromic acid titration method'. *Soil Science*, 37: 29-38.

EFFECTS OF DIFFERENT TYPES AND RATES OF BIOCHAR AMENDMENTS ON REDOX POTENTIAL OF A SEASONALLY FLOODED SOIL IN YOLA, ADAMAWA STATE, NIGERIA

Solomon, R. I.*; Ibrahim, A. M., Musa Y., Musa, A. M. and Musa, S. A.
Department of Soil Science, Faculty of Agriculture,
Modibbo Adama University Yola, Adamawa State, Nigeria
Corresponding author email: solomonri@mau.edu.ng

ABSTRACT
Seasonally flooded soils represent a significant portion of the global landscape, playing crucial roles in biogeochemical cycling, water regulation, and agricultural production. However, these ecosystems face unique challenges due to fluctuating redox potentials (Eh) caused by variations in oxygen availability. This study was therefore carried out to examine the impact of biochar amendments on the redox potential of seasonally flooded soils. Soil samples were collected from 0-20 cm depth from Modibbo Adama University Teaching and Research Farm (MAUTRF) and amended with maize cob biochar (MCB) and rice husk biochar (RHB). The soil-biochar mixtures were arranged in a two (2)-factorial completely randomized design (CRD) and submerged for 35 days in the laboratory. Soil redox potential was measured for the duration the study. Results revealed that 10-ton ha-1 MCB at 1 day of submergence recorded the lowest Eh value of -86.67 mV and was not significantly different from the rest of the treatments at the time of submergence. However, as the interval of submergence increases from one day to seven (7) days interval, redox potential values also increased with 10-ton ha-1 RHB at 35 days of submergence recording the highest Eh value of 55.0 mV. This Eh value was not significantly different from all other treatments at 35, 28 and 21 days of submergence. However, it differed substantially from 7.5-ton ha-1 MCB at 28 days, 5-ton ha-1 MCB at 21 days and 10-ton ha-1 MCB at 21 days. The application MCB induced more reduced conditions in soil of the study area. Therefore, high doses of MCB should be used with caution or avoided in areas where soil metal toxicities may constitute a problem. However, RHB can be an effective management strategy for mitigating reduced conditions in seasonally flooded soils. Further research under field condition should be conducted across a wider range of soil types and environmental conditions
Keywords: *Amendments; biochar; seasonally flooded soil; redox potential*

Introduction
Seasonally flooded soils are an important portion of the global landscape facing unique challenges due to fluctuating redox potentials (Eh) caused by changes in oxygen availability (Jackson et al., 2005). They create dynamic redox conditions in soils, alternating between periods of saturation and aeration. These fluctuations play a crucial role in regulating the availability and mobility of soil nutrients, contaminants, and the development of greenhouse gases in soils (Glaser et al., 2002). Under flooded conditions, anaerobic microbial processes prevail, leading to reduced conditions where certain elements such as iron and manganese undergo reduction, affecting nutrients availability (Cotrufo et al., 2019). Redox potential (Eh) is a critical indicator of these oxygen levels and the associated biogeochemical processes that govern nutrient cycling, microbial activity, and contaminant transformations (Ketterer et al., 2019; Glaser et al., 2002). It directly affects

the transformation and availability of essential plant nutrients, particularly iron and phosphorus (Marschner, 2012) and greenhouse gas emissions (Cotrufo et al., 2019; Glaser et al., 2002). Fluctuations in redox potential can significantly impact greenhouse gas emissions, particularly methane, a potent greenhouse gas produced under reducing conditions (Wu et al., 2020, 2023; Neue et al., 1997). Managing redox potentials in seasonally flooded soils is vital for sustainable agriculture and ecosystem health.

Although traditional soil management practices such as drainage and water management systems, aim to mitigate flooding impacts on soil productivity, these methods may not address the underlying biogeochemical processes that govern nutrient cycling and soil health under dynamic redox conditions (Cotrufo et al., 2019) sustainably. Biochar; a carbon-rich material produced through the pyrolysis of plant biomass, has emerged as a promising alternative for mitigating the adverse effects of extreme weather conditions on soil-plant systems (Kumar et al., 2022), enhanced soil properties and mitigate environmental stressors (Lehmann & Joseph, 2024). This amendment alters soil redox dynamics by enhancing water-holding capacity, modifying soil micro-environments, and influencing microbial communities (Lehmann, 2007; Major et al., 2010). The key mechanism by which biochar can enhance soil resilience is through its influence on submerged soil redox processes. Biochar's unique properties make it a promising amendment for managing redox potentials in seasonally flooded soils. Its porous structure and high surface area can adsorb and retain water and nutrients, reducing leaching losses during flooding events (Solomon, 2022; Novak et al., 2009; Lehmann, 2007). Furthermore, biochar can provide a stable carbon source to soil microorganisms, influencing redox reactions and enhancing soil fertility (Lehmann and Joseph, 2024; Major et al., 2010). These amendments offer a potential solution by stabilizing redox potentials and enhancing soil resilience to flooding stress.

Despite growing interest and research into biochar's effects on soil redox potentials, and considering the seasonal flooding of MAUTRF soils, and the series of electro-chemical processes that take place during the period of flooding undoubtedly affect the transformations and availability of the essential nutrient elements under flooded conditions. It has therefore become necessary to study the impact of some biochar amendments on the redox potential of these soils.

Materials And Methods

Soil Sampling, Collection and Preparation

Soil samples were collected from 20 points at the depth of 0-20 cm using stratified random sampling techniques from the MAUTRF, Yola, located between latitude 9.355905° to 9.356225° N and longitude 12.50531° to 12.49425° E at an altitude of 200 m above sea level within the northern guinea savannah zone of Nigeria. The collected soil samples were made into a composite sample air-dried, gently crushed and sieved through 2 mm mesh sieve for routine laboratory analysis. Similarly, undisturbed soil samples were collected using core sampler for determination of bulk density and Water holding capacity (WHC). Subsamples were taken from the composite sample for the incubation studies. The collected samples were analyzed for particle size distribution, bulk density, porosity, water holding capacity, soil reaction, electrical conductivity, organic carbon, total N, available P, total exchangeable bases, total exchangeable acidity, and effective cation exchange capacity as described by Black et al. (1965).

Biochar Preparation and Analysis

Biochar was produced using slow pyrolysis from two feedstocks; Maize cob and rice husk which were sourced from MAUTRF and other farms around. The feedstocks were stashed in to an air-tied stainless-steel container placed into a muffle furnace. The furnace was heated to 450 °C and turned off on attainment of the desired Temperature. The biochar samples were left inside the furnace to cool then ground and sieved through a 0.5 mm mesh sieve to obtain a powdery consistency that would mix uniformly with the soil samples

Biochar Characterization

The biochar samples were characterized for pH, EC, total ash content, fixed carbon, specific surface area and porosity and volatile matter as described by Abdu et al. (2021). Similarly, the surface morphology and some elemental composition of ground biochar samples were examined using scanning electron microscopy (SEM) with energy-dispersive X-ray analysis (EDX).

Incubation Studies

Two hundred (200) g was weighed into plastic containers used as experimental pots and amended with 0, 2.5-, 5-, 7.5- and 10-ton ha^{-1} of the two different biochar materials. The soil-biochar mixture was submerged for 35 days. Water was added into the experimental pots and maintained at 2 cm above the soil surface after each sampling time to mimic flooding as described by Ponnamperuma (1972). Initially, the soil redox potential and pH were measured daily for a period of seven (7) days, then at 3 days interval for a period of 21 days than at 28 and 35 days after submergence using an Eh and pH meter.

Data Analysis and Experimental Design

Data obtained was analyzed using analysis of variance (ANOVA) using a 2 two factorial completely randomized design (CRD). The factors were nine (9) biochar rates and twelve (12) intervals of flooding replicated three times. Where significant differences were observed among the treatments, means were separated using Tukey's honest significant difference test (HSD). Similarly, multiple regression analyses were carried out to determine the nature and extent of relation of redox potential with some soil physical and chemical properties.

Results And Discussion

Results of the soil physical and chemical properties before the experiment are presented in Table 1. The soil was found to contain predominantly sand fraction than other soil separates with a mean value of 74%. The silt and clay contents were 16% and 10 % respectively. The textural class of the soil was sandy loam according to the USDA textural triangle. The high sand content of the soil may be due to the parent material from which the soil was formed. The low silt content could be attributed to a low degree and intense weathering as stated by Madueke *et al*. (2021). Table 1 also showed bulk density value of 1.41 Mgm^{-3} which is ideal for plant growth and development. Data obtained on water holding capacity is low with a value of 26.90 % and may be attributed to the coarse textured nature of the soil.

The result on soil reaction showed that the soil is slightly acidic with a mean pH value of 6.36. The slight acidity nature of the soil might be attributed to the sandy nature of the soil which encourages leaching of basic cations. The soil recorded an EC value of 0.10 dSm^{-1}. This indicates that the soil is non-saline. Result values for soil organic carbon (OC), total nitrogen (TN), available (AVP), Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, total exchangeable bases (TEB), total exchangeable acidic (TEA) and effective cation exchange capacity (ECEC), were 12.7 g kg^{-1}, 1.10 g kg^{-1}, 13.01 mg kg^{-1}, 2.34, 1.52, 0.39, 0.38, 4.63, 0.86 and 5.49 cmol (+)/kg respectively. These values are generally low based on the rating of Usman (2005). The low nutrient reserve of this soil may be due to the coarse nature of the soil which encourages leaching of basic cations. It might also be due to low content of soil clay fraction and the high temperature observed throughout the season in the study area, which has led to rapid organic matter decomposition apparent in the low organic carbon of the soil.

Table 1: Soil Physical and Chemical Properties before the Experiment

Parameter		Mean Value
Sand	(%)	74.00
Silt	(%)	16.00
Clay	(%)	10.00
Textural class	Sandy loam	
Water Holding Capacity	(%)	26.90
Bulk Density	Mg m^{-3}	1.41
pH (1:2.5)		6.36
Electrical Conductivity	(dSm^{-1})	0.10
Organic Carbon	(g kg^{-1})	12.70
Total Nitrogen	(g kg^{-1})	1.10
Available Phosphorus	(mg kg^{-1})	13.01
K^+	cmol (+) kg^{-1}	0.39
Ca^{2+}	cmol (+) kg^{-1}	2.34
Mg^{2+}	cmol (+) kg^{-1}	1.52
Na^+	cmol (+) kg^{-1}	0.38
Total Exchangeable Bases	cmol (+) kg^{-1}	4.63
Total Exchangeable Acidity	cmol (+) kg^{-1}	0.86
Effective Cation Exchange Capacity	cmol (+) kg^{-1}	5.49
Percentage Base Saturation	(%)	75.36

Biochar Characterization

The results on biochar biochar properties used in this study are presented in Table 2. Data obtained revealed that MCB has the highest pH value of 9. 39 while RHB recorded a pH value of 7.10. The slightly alkaline to strongly alkaline pH of the biochar samples may be due to the pH of the original feedstock. It may also be as a result of the high pyrolysis temperature as it makes it more stable and resistant to decomposition with a greater surface area and more porous structure which enhances its ability to adsorb nutrients, contaminants, and water, making it more effective for use in soil improvement and environmental remediation (Lauren and Susan, 2017). This agrees with the assertion of Verheijen et al., (2010) that anaerobic charring of feedstock leads to the production of biochar with a pH between neutral and strongly alkaline. A higher EC value of 3.5 dS m^{-1} was recorded in MCB compared to the

EC of 2.7 dS m^{-1} recorded by RHB. The high pH and EC recorded in MCB may be associated with the higher ash contents of the biochar (Table 2). Yue *et al*. (2017) also obtained a similar result and opined that ash content in biochar has a direct effect on its pH and EC values and attributed it to the high pyrolysis temperature as well as the nature of the feed-stock.

A bulk density value of 0.41 Mg m^{-3} was recorded in both MCB and RHB (Table 2). This may be due to the nature of the original feed-stock materials. This agrees with the findings of Mary *et al*. (2016) who reported that the bulk density of biochar differs with feed-stocks and pyrolysis temperature. The BET surface area, pore volume and average pore diameter of 285.0 m^2 $g^{-1,}$

Table 2: Physical and Chemical Properties of the Biochar Materials

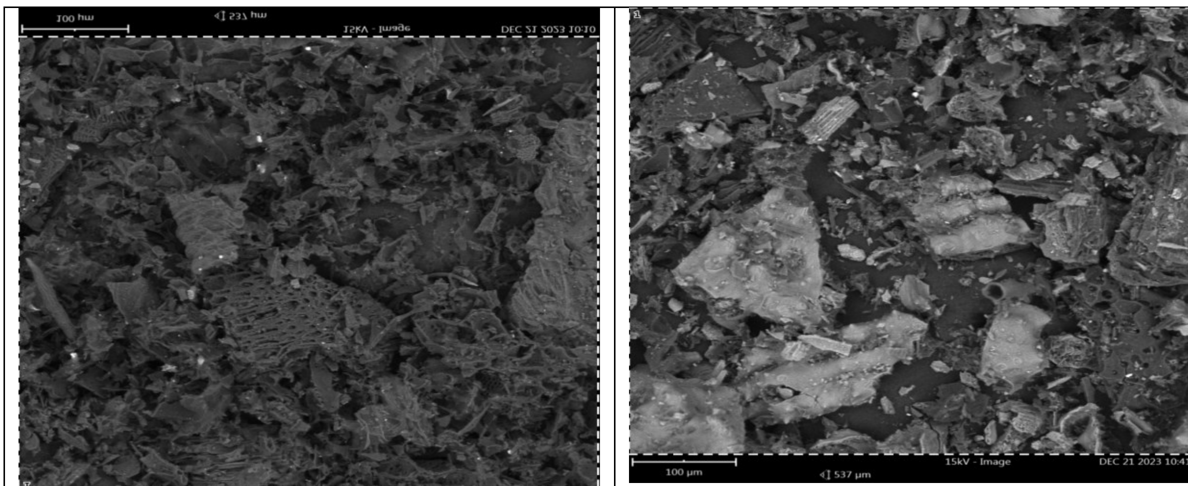
Parameters	Maize cob biochar (MCB)	Rice husk biochar (RHB)
pH (1:10 Biochar: H_2O)	9.39	7.10
Electrical Conductivity (dS m^{-1})	3.50	2.70
Bulk density (Mg m^{-3})	0.41	0.41
Moisture content (%)	1.90	1.32
Biochar yield (%)	23.60	30.10
Fixed Carbon (%)	65.61	39.02
Specific surface area (m^2 g^{-1}) (BET)	285.0	325.5
Pore volume (cm^2/g)	11.63	14.75
Pore diameter (nm)	2.840	2.800
Potassium (%)	12.35	5.13
Nitrogen (%)	5.42	6.40
Silicon (%)	2.54	35.21
Phosphorus (%)	2.04	1.80
Magnesium (%)	1.96	1.90
Sodium (%)	1.74	1.53
Aluminum (%)	1.68	2.04
Iron (%)	1.16	0.00
Sulfur (%)	0.90	0.78
Calcium (%)	0.55	1.74

11.63 cm^2 g^{-1} and 2.840 nm were recorded for MCB biochar and 352.5 m^2 $g^{-1,}$, 14.75 cm^2 g^{-1} and 2.800 nm for RHB respectively. The lower BET surface area observed in MCB may be due to the higher ash content recorded in the biochar. This is in line with the findings of Jindo *et al*. (2014) who observed reduced surface area of some biochar with increasing ash content in the biochar and opined that the high ash content occupied and obstructed the access to micropores, causing the surface area to reduce. Higher fixed carbon content of 65.61 % was recorded by MCB while a lower value of 39.02 % was recorded in RHB biochar. Similar carbon content for RHB biochar was reported by Jindo *et al*. (2014). Table 2 also revealed that MCB recorded higher elemental composition except Nitrogen, silicon, Aluminium and calcium contents. The higher contents of elements recorded by MCB may be due to the higher ash content recorded by the biochar compared to R HB.

Figure 1 shows the scanning electron microscopic image (SEM) of MCB and RHB. The image revealed that MCB has many meso pores and a rough surface with irregularly distributed gaps. On the other hand, large pores were observed in RHB which may be due to its higher surface area, an indication of high pore volume and surface area. Abdu et al. (2021) and Jindo *et al.* (2014) reported similar results and opined that RHB is highly porous and has a large surface area which increases with pyrolysis temperature.

Effects of Biochar and Interval of Submergence on Soil Eh and pH

The effects of biochar and interval of submergence on Eh and pH are presented in Table 3. Result obtained on redox potential indicates that there was a significant ($P<0.05$) difference among the biochar treatments. Highest Eh value of -51.39 mV was recorded with the application of 10 ton/ha RHB and was not significantly different from the rest of the treatments.



(A) Maize cob biochar (MCB) (B) Rice husk biochar (RHB)

Figure 1: Scanning Electron Microscope Image of (A) Maize cob biochar (MCB), (B) Rice husk biochar (RHB)

Table 3: Effects of Biochar and Interval of Submergence on Soil Eh and pH

Treatments	Eh (mV)	pH
Control	-53.19a	6.70c
MCB 2.5 ton/ha	-70.83ab	6.74bc
MCB 5 ton/ha	-76.39b	6.78ab
MCB 7.5 ton/ha	-76.39b	6.76ab
MCB 10 ton/ha	-66.67ab	6.80a
RHB 2.5 ton/ha	-65.97ab	6.79a
RHB 5 ton/ha	-58.33ab	6.78a
RHB 7.5 ton/ha	-54.71a	6.79a
RHB 10 ton/ha	-51.39a	6.78a
MSD	21.990	0.046
Interval of submergence (days)		
1	-79.44k	6.39f
2	-69.81j	5.98i
3	-62.04i	6.18h
4	-52.04h	6.20h
5	-40.37g	6.32g
7	-13.81f	6.61e
11	17.96d	7.13c
14	4.63e	6.99d
17	21.11d	7.28b
21	28.70c	7.30b
28	40.56b	7.42a
35	51.67a	7.44a
MSD	5.3554	0.056

Means with the same letters in the same column are not significantly different from each other at P<0.05

However, it was significantly ($P< 0.05$) different from the -76.39-mV recorded by 5-ton ha^{-1} MCB and 7.5-ton ha^{-1}MCB. Higher Eh recorded by RHB at 10-ton ha^{-1} may be due to improved water retention and higher surface area of the biochar. It is also possible that as biochar fragments, new redox-active surfaces are exposed, thus resulting in a more complex series of redox reactions. Similarly, lower concentrations of redox species in RHB (Table 2) may have influenced the higher Eh value observed by the treatment, since less species are available to be reduced on submergence. Yuan et al. (2022) reported that biochar application increases soil redox potentials by enhancing soil pH, electrical conductivity, and nutrient content. Xu et al. (2019) opined that Biochar application can have varying effects on soil redox potentials depending on the specific submergence conditions and interactions involved. However, Fan et al. (2022); and Yuan et al. (2020)

indicated that biochar can act as an electron shuttle, influencing redox reactions in soil by providing electrons and promoting the reduction of contaminants thereby reducing their efficacy. They asserted that biochar application has been shown to interact with electric potential, accelerating soil nitrate reduction while simultaneously suppressing nitrous oxide emissions. Also, Joseph *et al*. (2015) reported that biochar impacts on soil Eh can change over time especially if biochar reacts/interacts with micro-organisms, soil mineral, organic matter, chemical fertilizers and plant roots.

Table 3 revealed that the highest pH value of 6.798 was recorded by the application of 10 t ha^{-1} MCB and was significantly (P< 0.05) higher than 6.70 recorded by the control. The significantly (P<0.05) higher soil pH value (>6.797) recorded in biochar amended pots may be due to the alkaline nature of the biochar materials. Quin et al. (2015) reported that pH and Eh in the soil/biochar mixture increased with an increase in both soil water and biochar content and linked it to the alkaline nature of the biochar materials.

The effect of the interval of submergence on Eh and pH is also presented in Table 3. Results obtained from the analyzed data showed that there were highly significant (P<0.01) differences for the interval of submergence on both Eh and pH. There was also a significant (p<0.05) difference in the Interval of submergence on soil EC (Table 3). The highest Eh value of 51.66 mV was recorded on Day 35 and was significantly (p<0.05) different from all the other days of submergence. However, the lowest Eh value of -79.44 mV was recorded on day 1 of submergence which might have been due to the depletion of oxygen in the soil-biochar mixture as flooding was maintained at 2 cm above the soil surface. It may also be due to the use of alternative electron receptors like NO_3^-, Fe^{3+}, and SO_4^{2-} in place of oxygen leading to the production of reduced organic compounds and organic acids and/or as a result of methanogenesis which further contributed to the reduction of soil redox potential. Rubin et al. (2020); LaCroix et al. (2019) opined that submergence resulted in a stabilization of redox potential at lower values, impacting the availability of elements like Fe, Mn, and P. Similarly, Yang et al. (2022); and Larson (1991) explained that the duration of submergence affects nitrification rates, with longer submergence periods causing a further reduction in nitrification in subsurface soils. However, Barczok et al. (2023); Marschner (2021); and Weeraratna (1981) reported that the redox potential in seasonally flooded soils fluctuates between oxidizing and reducing conditions based on the duration of submergence and subsequent drying and rewetting cycles, influencing the release of Fe and P.

The interaction of biochar and interval of submergence on redox potential is presented in Figure 2. The result shows that MCB 10-ton ha^{-1} at 1 day of submergence recorded the lowest Eh value of -86.67 mV and was not significantly different from other treatments at the time of submergence. However, as the interval of submergence was increased from one day to seven (7)

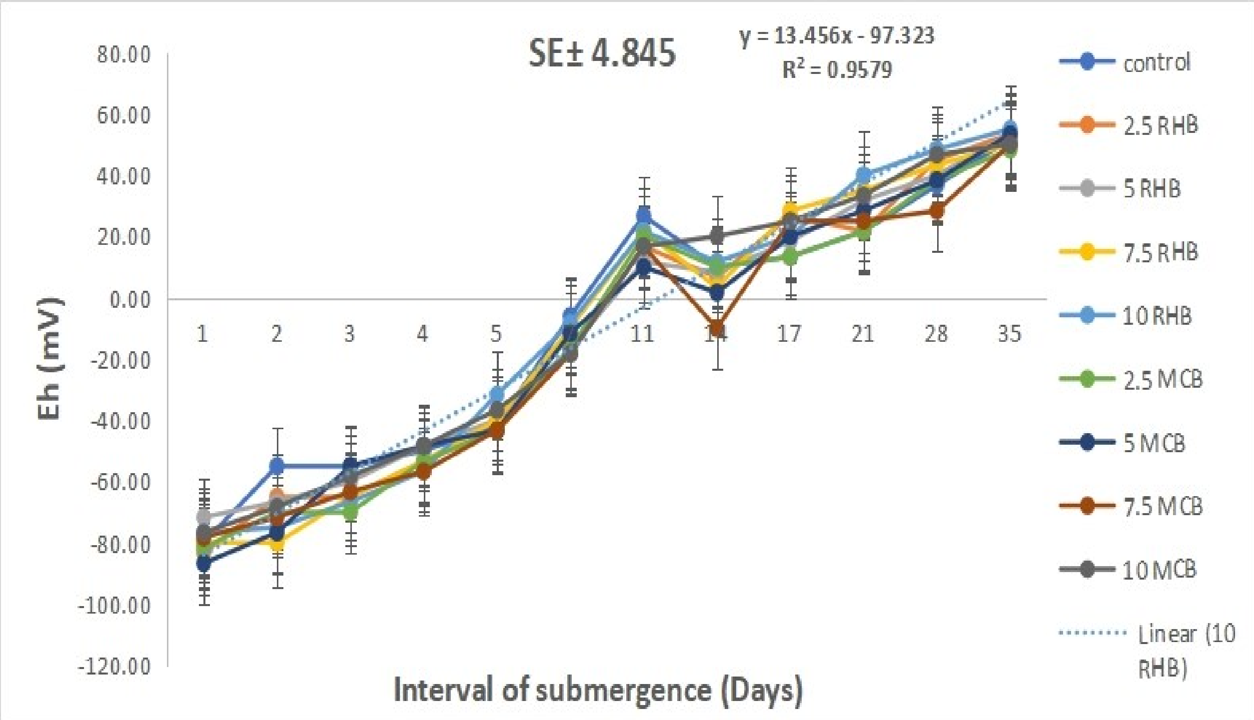


Figure 2: Interaction of biochar and interval of submergence on soil Eh

days interval, redox potential values also increased with RHB 10-ton ha^{-1} at 35 days of submergence recording the highest Eh value of 55.0 mV. This Eh value was not significantly different from all other treatments at 35, 28 and 21 days of submergence. However, it was significantly ($P<0.05$) higher than Eh values recorded by MCB 7.5-ton ha^{-1} at 28 days, MCB 5-ton ha^{-1}, and MCB 10-ton ha^{-1} at 21 days. The highest Eh value recorded by RHB 10-ton ha^{-1} at 35 days may be due to the combined influence of the high surface area of RHB and oxygen being readily available to support aerobic microbial processes, maintaining higher redox potential (Eh) values as the frequency of flooding event was reduced to 7-day interval. It may also be due to lower concentration of C and Fe in RHB which are important redox species. Lehmann & Joseph (2009) and Major et al. (2010) reported that the addition of biochar can create microsites with different redox conditions within the soil matrix, influencing the distribution of microbial communities and their metabolic activities. Similarly, Yuan et al. (2017) and Major et al. (2010) opined that by promoting conditions favourable for aerobic microbial processes and serving as a habitat for beneficial microorganisms and stimulating microbial activity which plays a crucial role in redox reactions within soil environments, affecting the availability of electron acceptors and donors that determine soil redox potentials (Glaser et al., 2002) even under flooded conditions, biochar may mitigate the negative effects of prolonged waterlogging on soil fertility and crop productivity.

The interaction of biochar and time of submergence on pH is presented in Figure 3. The result showed that the pH was lowest at day 2 of submergence irrespective of biochar treatment. The pH value increased between day 7 and day 11 and then slightly decreased at day 14 irrespective of biochar treatment. However, the soil pH continued to increase steadily and reached a maximum value of 7.48 at day with the application of 10 t ha[-1] MCB. The highest pH value recorded at day 35 with an application of 10 t ha[-1] MCB may be attributed to the high pH value of MCB and the transition from anaerobic to aerobic conditions as the frequency of flooding events was reduced. Kefas et al. (2022) observed increased soil pH in biochar-treated pots and linked it to the alkaline nature of the biochar materials. Major et al. (2010) opined that biochar's high cation exchange capacity (CEC) allows it to retain nutrients such as nitrogen and phosphorus, reducing nutrient leaching and improving soil pH. Similarly, Lehmann and Joseph (2009) assert that biochar amendments can increase soil pH and buffer soil acidity, creating more favourable conditions for plant growth in addition to its effects on soil physical and chemical properties.

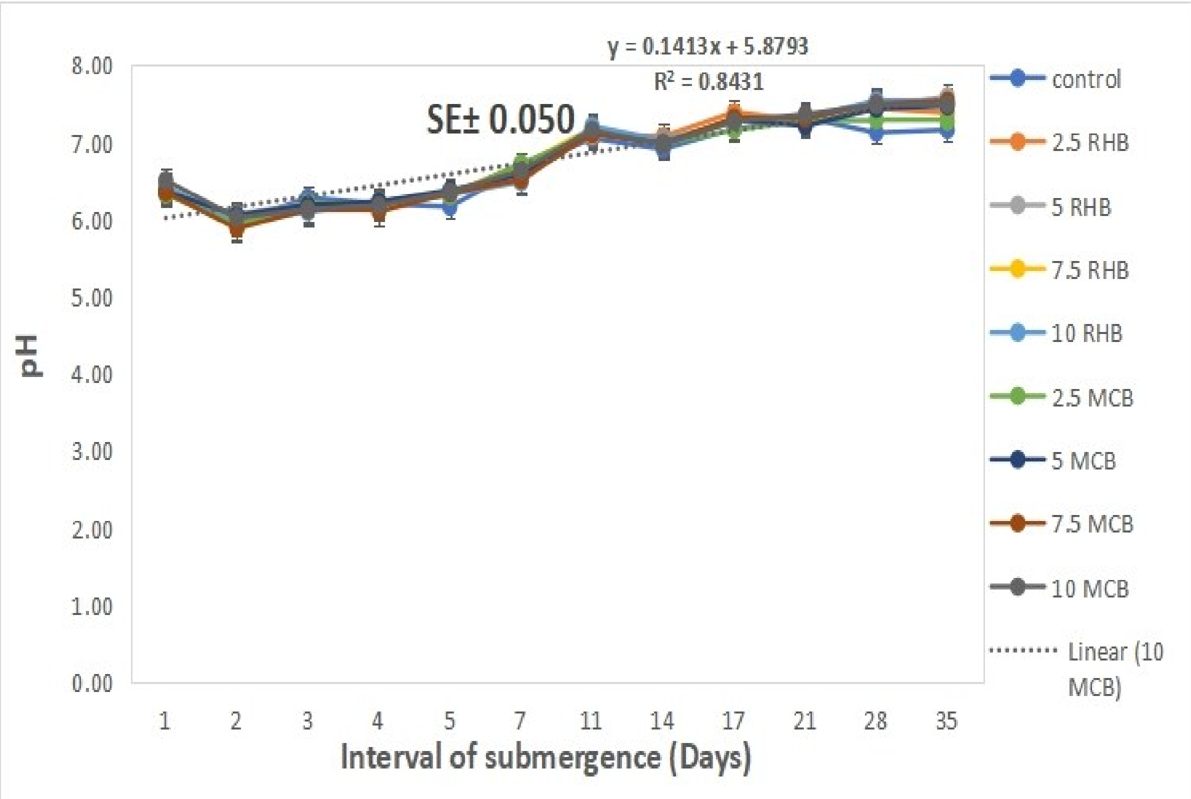


Figure 3: Interaction of biochar and Interval of submergence on soil pH

Stepwise regression analysis of Eh with some soil properties revealed that only soil pH significantly ($p<0.05$) influenced Eh in the experimental soil ($R^2 = 0.89$) as shown in Table 5. This revealed that about 89 % of the significant ($p<0.05$) change in Eh in the study area is accounted for by soil pH alone. This strong relationship between Eh and soil pH has also been reported by Lu *et al*. (2022); Kicińska et al. (2022); Joseph *et al*. (2010); and Chesworth (2004). They opined that changes in pH significantly affect metal mobility, causing metal ions to become more or less active hence, involved in redox reactions. Similarly, they opined that the reduction of Fe (III) oxides plays a leading role in increasing soil pH with time of submergence.

Table 4: Summary of Multiple Regression output of Eh and pH

Analysis of Variance				
Source	**DF**	**Sum of Squares**	**F Value**	**Pr > F**
Model	1	14417961	2481.94	<.0001
Error	322	1870544		
Corrected Total	323	16288506		

Variable	**Parameter Estimate**	**Standard Error**	**F Value**	**Pr > F**
Intercept	-2766.80035	54.42321	2584.56	<.0001
pH	399.33762	8.01575	2481.94	<.0001

Summary of Stepwise Selection

Step	**Variable Entered**	**Variable Removed**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	pH		0.8852	0.8852	1.0087	2481.94	<.0001

Eh = -2766.80 + 399.34 pH

Conclusion

It can therefore, be concluded that biochar amendments significantly alter the redox potential (Eh) of seasonally flooded soils with MCB-induced more reducing conditions due to its higher redox species content compared to RHB at the same application rates. Also, Eh values decreased as submergence time increased from 1 to 7 days. RHB at 10 tons per hectare recorded the highest Eh of 55 mV at 35 days of submergence which was significantly different from some MCB treatments at earlier time points. Therefore, high doses of MCB should be used with caution or avoided in areas where soil reduction may constitute a problem. However, RHB can be an effective management strategy for mitigating Fe and Mn toxicities induced by reduced conditions in seasonally flooded soils. However, further studies especially under field condition should be conducted to validate the results across a wider range of soil types and environmental conditions

References

Abdu, N., Yusuf, A.A., Mukhtar B., Solomon, R. I. 2021. Kinetics and thermodynamics of nitrate adsorption by biochar. *EQA - International Journal of Environmental Quality ISSN 2281-4485 - Vol. 41 (2021): 17-32 Jou.*

Barczok, M., Smith, C., Di Domenico, N., Kinsman-Costello, L., and Herndon, E. 2023. Variability in soil redox response to seasonal flooding in a vernal pond. *Frontiers in Environmental Science*, *11*, 1114814.

Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., and Clark, F. E.

1965. Methods of soil analysis. Parts 1 and 2. *American Society of Agronomy, Madison*.
Chesworth, W. 2004. Redox, soils, and carbon sequestration. *Edafologia*, *11*(1), 37-43.
Cotrufo, M. F., Ranalli, M. G., Haddix, M. L., Six, J., Grandy, A. S., Morris, H., and Paul, E. A. 2019). Soil carbon storage informed by particulate and mineral-associated organic matter. *Nature Geoscience, 12*(12), 989-994. https://doi.org/10.1038/s41561-019-0486-3
Fan, C., Leng, Y., Zhang, Q., Zhao, X., Gao, W., Duan, P., ... and Li, Q. 2022. Synergistically mitigating nitric oxide emission by co-applications of biochar and nitrification inhibitor in a tropical agricultural soil. *Environmental research*, *214*, 113989
Glaser, B., Lehmann, J., and Zech, W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – A review. *Biology and Fertility of Soils, 35*(4), 219-230. https://doi.org/10.1007/s00374-002-0466-4
Jackson, T. B., Saikia, S., and Möller, A. 2005. Flood plain dynamics and vegetation patterns in the Amazon Basin. Journal of South American Earth Sciences, 20(1-4), 200-211.
Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M. A. and Sonoki, T. 2014. Physical and chemical characterization of biochars derived from different agricultural residues. *Biogeosciences*, *11*(23), 6613–6621. https://doi.org/10.5194/bg-11-6613-2014
Joseph, S., Husson, O., Graber, E. R., Van Zwieten, L., Taherymoosavi, S., Thomas, T., and Donne, S. 2015) The electrochemical properties of biochars and how they affect soil redox properties and processes. *Agronomy*, *5*(3), 322-340.
Joseph, S., Husson, O., Graber, E.R., Van Zwieten, L., Taherymoosavi, S., Thomas, T., Nielsen, S., Ye, J., Pan, G., Chia, C. and Munroe, P. 2015. The electrochemical properties of biochars and how they affect soil redox properties and processes. *Agronomy*, *5*(3), 322-340.
Joseph, S. D., Camps-Arbestain, M., Lin, Y., Munroe, P., Chia, C. H., Hook, J., and Amonette, J. E. 2010. An investigation into the reactions of biochar in soil. *Soil Research*, *48*(7), 501-515.
Kicińska, A., Pomykała, R., and Izquierdo-Diaz, M. 2022. Changes in soil pH and mobility of heavy metals in contaminated soils. *European Journal of Soil Science*, *73*(1), e13203.
Kefas, H. D., Solomon, R.I., Suhailu, A. and Abdullahi, Z. 2022. Impact of Biochar Amendment on Some Physical and Chemical Properties of a Loamy Sand with Low Organic Matter Content. *Nigerian Journal of Tropical Agriculture,* 26: 127-142
Ketterer, M. E., Chantigupta, S., Sander, M., and Conrad, R. 2019. Diverse electron acceptor utilization by methanotrophic communities in rice field soil. *Environmental Microbiology,* 21(3): 1228-1242.
Kumar, A., Bhattacharya, T., Mukherjee, S., and Sarkar, B. 2022. A perspective on biochar for repairing damages in the soil–plant system caused by climate change-driven extreme weather events. *Biochar*, *4*(1), 22.
LaCroix, R. E., Tfaily, M. M., McCreight, M., Jones, M. E., Spokas, L., and Keiluweit, M. 2019. Shifting mineral and redox controls on carbon cycling in seasonally

flooded mineral soils. *Biogeosciences*, *16*(13), 2573-2589.

Larson, K. D., Graetz, D. A., and Schaffer, B. 1991. Flood-induced chemical transformations in calcareous agricultural soils of south Florida. *Soil Science*, *152*(1), 33-40.

Lauren M. D and Susan E. C. 2017. Biochar and Greenhouse Gas Emissions: Reference Module in Earth Systems and Environmental Sciences http://dx.doi.org/10.1016/B978-0-12-409548-9.10524-X. *Biochar,* Pp 1- 5.

Lehmann, J. 2007. A handful of carbon. *Nature, 447*(7141), 143-144. https://doi.org/10.1038/447143a

Lehmann, J., and Joseph, S. (Eds.). 2024) *Biochar for environmental management: science, technology and implementation*. Taylor and Francis.

Lehmann, J., and Joseph, S. 2015. Biochar for environmental management: *Science and Technology* (Vol. 5). Routledge.

Liu, X., Jin, J., Yang, G., Wei, D., and He, Y. 2013. Effects of biochar on the growth of maize and ryegrass seedlings in a cadmium-contaminated soil. Journal of Soils and Sediments, 13(8), 1420-1427.

Liu, X., Shi, Y., Zhang, Q., and Li, G. 2021. Effects of biochar on nitrification and denitrification-mediated N 2 O emissions and the associated microbial community in an agricultural soil. *Environmental Science and Pollution Research*, *28*, 6649-6663.

Lu, H. L., Li, K. W., Nkoh, J. N., He, X., Xu, R. K., Qian, W., ... and Hong, Z. N. 2022. Effects of pH variations caused by redox reactions and pH buffering capacity on Cd (II) speciation in paddy soils during submerging/draining alternation. *Ecotoxicology and Environmental Safety*, *234*, 113409.

Madueke, C. O., Okore, I. K., Maduekeh, E. C., Onunwa, A. O., Okafor, M. J., Nnabuihe, E. C., and Nwosu, T. V. 2021. Characterization and land evaluation of three tropical rainforest soils derived from the coastal plain sands of southeastern Nigeria. *Agro-Science*, *20*(2), 25-36.

Major, J., Lehmann, J., Rondon, M., and Goodale, C. 2010. Fate of soil-applied black carbon: Downward migration, leaching and soil respiration. *Global Change Biology, 16*(4), 1366-1379. https://doi.org/10.1111/j.1365-2486.2009.02044.x

Marschner, P. 2021. Processes in submerged soils–linking redox potential, soil organic matter turnover and plants to nutrient cycling. *Plant and Soil*, *464*(1), 1-12.

Marschner, P. 2012. Rhizosphere biology. In *Marschner's mineral nutrition of higher plants* (pp. 369-388). Academic Press.

Mary, G. S., Niveditha, P. S. S. and Mary, G. S. 2016. Production, characterization and evaluation of biochar from pod (Pisum sativum) , leaf (Brassica oleracea) and peel (Citrus sinensis) wastes. *International Journal of Recycling of Organic Waste in Agriculture*, *5*(1), 43–53. https://doi.org/10.1007/s40093-016-0116-8

Neue, H. U., Liss, P. S., and Andreae, M. O. 1997. The organic carbon content of aerosols over the Indian Ocean during the Indian Ocean Experiment (IndOEx). *Journal of Geophysical Research: Atmospheres*, 102(D25): 28307-28317.

Novak, J. M., Busscher, W. J., Laird, D. L., Ahmedna, M., Watts, D. W., and

Niandou, M. A. S. 2009. Impact of biochar amendment on fertility of a southeastern coastal plain soil. *Soil Science, 174*(2), 105-112. https://doi.org/10.1097/SS.0b013e3181981d9a
Ponnamperuma, F. N. 1972. The chemistry of submerged soils. *Advances in agronomy*, *24*, 29-96.
Quin, P., Joseph, S., Husson, O., Donne, S., Mitchell, D., Munroe, P., Phelan, D., Cowie, A. and Van Zwieten, L. 2015. Lowering N_2O emissions from soils using eucalypt biochar: the importance of redox reactions. *Scientific reports*, *5*(1), 16773.
Rubin, R. L., Anderson, T. R., and Ballantine, K. A. 2020. Biochar simultaneously reduces nutrient leaching and greenhouse gas emissions in restored wetland soils. *Wetlands*, *40*(6), 1981-1991.
Satawathananont, S. 1986. Redox, pH, and ion chemistry of acid sulfate rice soils in Thailand. Louisiana State University and Agricultural and Mechanical College.
Solomon, R. I. 2022. Biochar Amendments for Reducing Nitrate Leaching from Soils of Different Textural Classes in the Nigerian Savanna. *Turkish Journal of Agriculture - Food Science and Technology, 10(8): 1363-1368, 2022*
Usman, B. H. 2005. The Soils of Adamawa State, North Eastern Nigeria. In *Agriculture in Adamawa State. Pracletes Publishers, Yola- Nigeria* (pp. 62-83.).
Verheijen, F., Jeffery, S., Bastos, A. C., Van der Velde, M., and Diafas, I. 2010. Biochar application to soils. A critical scientific review of effects on soil properties, processes, and functions. *EUR*, *24099*(162): 2183-2207.
Wang, J., Zhong, W., Kang, Y., Deng, H., and Han, C. 2019. N_2O emission mitigation and microbial activity after Biochar and Cao application in a flooded nitrate-rich vegetable soil. *Acta Agriculturae Scandinavica, Section B—Soil and Plant Science*, *69*(3), 257-267.
Weeraratna, C. S. 1981. Effect of submergence on subsequent nitrification in a wetland cultivated rice soil. *Plant and Soil*, *59*, 407-414.
Wu, B., Xi, B., He, X., Sun, X., Li, Q., Ouche, Q., Zhang, H. and Xue, C. 2020. Methane emission reduction enhanced by hydrophobic biochar-modified soil cover. *Processes*, *8*(2), 162.
Wu, P., Xie, M., Clough, T.J., Yuan, D., Wu, S., He, X., Hu, C., Zhou, S. and Qin, S. 2023. Biochar-derived persistent free radicals and reactive oxygen species reduce the potential of biochar to mitigate soil N2O emissions by inhibiting nos. *Soil Biology and Biochemistry*, *178*, 108970.
Xu, Y., Yan, Y., Obadamudalige, N. L., Ok, Y. S., Bolan, N., and Li, Q. 2019. Redox-mediated biochar-contaminant interactions in soil. In *Biochar from biomass and waste* (pp. 409-419). Elsevier.
Yang, Z., She, R., Hu, L., Yu, Y., and Yao, H. 2022. Effects of biochar addition on nitrous oxide emission during soil freeze–thaw cycles. *Frontiers in Microbiology*, *13*, 1033210.
Yuan, Y., Kong, Q., Zheng, Y., Zheng, H., Liu, Y., Cheng, Y., Zhang, X., Li, Z., You, X. and Li, Y. 2022. Co-application of biochar and pyroligneous acid improved peanut production and nutritional quality in a coastal soil. *Environmental Technology and Innovation*, *28*, p.102886.
Yuan, H., Zeng, J., Yuan, D., Zhang, L., Qin, S., Wrage-Mönnig, N., Clough, T. and Zhou, S. 2020. Co-application of a biochar and an

electric potential accelerates soil nitrate removal while decreasing N2O emission. *Soil Biology and Biochemistry*, *149*, 107946.

Yuan, Y., Bolan, N., Prévoteau, A., Vithanage, M., Biswas, J. K., Ok, Y. S., and Wang, H. 2017. Applications of biochar in redox-mediated reactions. *Bioresource Technology*, *246*, 271-281.

Yue, Y., Lin, Q., Xu, Y., Li, G. and Zhao, X. 2017. Slow pyrolysis as a measure for rapidly treating cow manure and the biochar characteristics. *Journal of Analytical and Applied Pyrolysis*. https://doi.org/10.1016/j.jaap.2017.01.008

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Conflict of Interest

All authors declared that they do not have conflict of interest among them

NITROGEN MINERALIZATION FROM ORGANIC MANURES UNDER LABORATORY CONDITIONS IN SAMARU, NORTHERN GUINEA SANANNA OF NIGERIA

Ogunsola, E.O.,[1*], Oyinlola, E.Y.,[1] Arunah, U.L.,[2]Amapu,I.Y.[1] & Abdulkareem J.H.[1]
[1]*Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria*
[2]*Department of Agronomy, Ahmadu Bello University, Zaria, Nigeria*
Corresponding author email:ogunsholaelijah@yahoo.com

ABSTRACT
Soil microbes play an important role in the release of nutrients in soils. Nitrogen (N), a limiting nutrient in the soil is vital for plant growth. An incubation study was carried out at the Department of Soil Science, Institute for Agricultural Research Ahmadu Bello University, Zaria to determine the rate of N mineralization from three sources of organic manure. The treatments were four, farm yard manure (FYM), Compost manure (CM), Poultry manure (PM) and control (without manure) replicated four times. The experimental design was a complete randomized design (CRD). The incubation trial utilized an air-dried sieved (2 mm) soil taken from 0-20 cm under a fallow land from the Institute for Agricultural Research Farm, Ahmadu Bello University Zaria. Results showed that all manures had significantly higher concentration of total mineralized N than the control with farm yard manure having 43 %, CM 27 % and PM 23 %. The net rate of mineralization from manures ranged from 0.02 to 2.9, 0.12 to 2.8, 0.01 to 2.04 mg kg^{-1} day^{-1} for FYM, CM and PM respectively. From the results, farm yard manure mineralized faster than the other organic manures.
Keywords: Nitrogen mineralization, Soil microbes, Net rate of mineralization, Organic manures

Introduction

The efficiency of nitrogen (N) fertilizer utilization can be improved by knowing the exact amount of N supplied to a growing crop from mineralization of soil organic matter which in turns reduces the risk of polluting water resources**.** In northern Guinea savanna, nutrient depletion and nutrient balances are negative for many cropping systems owing to continuous cropping without external nutrient input (Yusuf *et al.*, 2008).The addition of organic materials to soil is the suitable solution to increase soil C storage (Powlson *et al.* 2012), enhance soil water holding capacity (Pandey and Shukla, 2006), decreased bulk density (Carter *et al.* 2004), and improved soil fertility (Mader *et al.* 2002). Organic amendment to soils recycles nutrients and organic matter to support crop productivity and maintain soil fertility (Whalen *et al.* 2001). However, the choice of organic material such as farmyard manure, poultry manure and compost as organic amendments will depend on the trade-offs in its various uses but also on its availability, quantity and especially its quality.

The quantity of manure accumulated by livestock would be a function of factors affecting the animal and factors related to the management. The amount can be determined by breed, species, age and size of the animal, number of animals, animal environment, animal productivity, the type and nature of food ingested, seasonal variation, length of kraaling time, and whether or not bedding. For an individual farmer, it is important to know approximately how much does each kind of domestic animal produce per day or per year (Lorimor 2004). Organic waste quality has been currently improved through several technologies. Composting converts the active organic portion in solid waste into a stabilized product, which can be used as a nutrient source for plant growth and/or as a conditioner to improve soil properties (Huang *et al*., 2006). Vermicompost is the microbial composting of organic wastes through earthworm activity to form organic fertilizer which contains high level of organic matter, organic carbon, total and available N, P, K and micronutrients, microbial and enzyme activities (Edwards and Bohlen, 1996; Ranganathan, 2006; Parthasarathi *et al*., 2007).

The management of rice residue through direct incorporation of straw in soil is associated with certain problems such as immobilization of plant nutrients particularly nitrogen and reduces germination of subsequent crops. Moreover, rice straw waste contains high C:N ratio about 80:1 and is rich in silica and lignin which make it difficult to be degraded (Kumar *et al*., 2006). Therefore, farmers resort to *in situ* burning of a part of the crop residues that remain scattered in the field and is difficult to collect, all over the world (Jacobs *et al*., 1997; Reinhardt *et al.,* 2001). The burning of crop residues is a great economic loss and burning is now being discouraged by Governments and Institutions. However, composting of rice straw is seen as a safe alternative option which results in reusability of the nutrients contained in the residue. Therefore, management of paddy straw through composting will avoid air pollution caused by residue burning and also prevent loss of plant nutrients and organic matter (Sidhu and Beri, 2008). Manures from farms have been used as a fertilizer for a long time (Rajan *et al*., 2023). Decomposition of organic manures also results in the production of nutritional agents like humic and fulvic acids, which improve the nutrients' mobility, solubility, and availability (Kaushal and Kaushal 2013). Farm yard manure consists of dung and urine of cattle and the litter, a bedding material like hay, straw used for cattle. FYM loses nutrients in the form of ammonia when it is constantly exposed to the scorching sun and heavy rain (Webb *et al.*, 2004). High temperatures accelerate the decomposition of cattle dung, converting the complex organic form of nutrients contained therein to available forms which might be lost easily (Reddy *et al*., 2010). A well-prepared FYM has nutrient composition pertaining to both macro as well micro-nutrients (Rajan *et al*., 2023). Poultry manure is another source of manure commonly used by farmers and is the set of waste resulting from the breeding of poultry. How poultry manure is managed, from the time of excretion through land application, strongly influences the kinds and amounts of nitrogen losses that may occur. Typical manure management activities include manure management in housing systems, during storage, and at time of land application (Oenema *et al*., 2014; De Vries *et al*., 2015). Information on the dynamics of N mineralization from organic manures is still scanty under a laboratory condition in the Northern Guinea Savanna of Nigeria. Therefore in this paper, three different organic materials i.e., farmyard manure; poultry manure and compost were evaluated to determine dynamics of N mineralization release under laboratory conditions.

Materials and methods

Location

The incubation research was conducted in the Department of Soil Science laboratory at the Institute for Agricultural Research (IAR) Samaru, Zaria, Nigeria located between latitude 11º 11'19.3''N and longitude 007º 37'02.16''E with an altitude of about 686m above sea level. The area is situated in the northern Guinea savanna ecology of Nigeria with a monomodal annual rainfall of about 1011 ± 161 mm concentrated almost entirely in the five months (May/June to September/October) and a mean daily temperature of 24^{o} C (Oluwasemire and Alabi, 2004).

Geology and soil

The soil used for the incubation study was a leached tropical ferruginous soil classified as Typic Haplustalf according to USDA soil taxonomy (Valette and Ibanga, 1984). The soil belongs to the order Acrisol in the FAO system (Valette and Ibanga, 1984) which has developed on deeply weathered pre-Cambrian Basement complex but overlain by aeolian drift of varying thickness (Shobayo, *et al*., 2015) . The soils are inherently low in fertility, due to low organic matter and cation exchange capacity, and dominance of low activity clays (Odunze, 2003).

Soil sampling and preparation

The soils were taken from a depth of 0-20 cm in a long term fallow (S2) soil at the Institute for Agricultural Research Farm, Ahmadu Bello University Zaria. The soil had not received manure for years. The soils were air-dried and sieved (2 mm).

Manure sampling and preparation

Three air-dried manures, Farm yard manure (FYM), Compost manure (CM) and Poultry manure (PM) were used for the study. Compost was made from rice straws harvested from farmer's field, while farmyard manure and poultry manure were obtained from farmer's household and the poultry manure was from a deep litter system.

Treatments and experimental design

The treatments were four, namely: Farm yard manure (FYM), compost manure (CM), poultry manure (PM) and a control (without manure). The treatments were a total of 4 replicated four times to give 16 jars. The design of the experiment was a Complete Randomised Design, (CRD).

Incubation study

Aerobic incubation procedure (Zarabi and Jalali 2013; Sistani *et al*. 2008; Cusick *et al*. 2006; Griffin *et al*. 2005) was used to study N mineralization of manure and soil mixture. Prior to incubation, 800 g of air-dried soil was added to a 1.2 L glass jar for each treatment (manure) plus controls (without manure) and deionized water was added to attain 50% water holding capacity (WHC) and packed to the bulk density of most plough layers (approximately 1.20 Mg m^{-3}) Li and Li (2014). The jars were pre-incubated at 25°C±2°C for 1 week Li and Li (2014). After pre-incubation, each manure which is about 450 kg ha^{-1} manure N in 0-20 cm surface soil, i.e. 15.24, 15.24, 22.86 g of FYM, CM, PM, respectively, was added to the soil. The soil and manure were mixed in the jar by stirring with a spatula, the mixtures were repacked to approximately bulk density (1.20 Mg m^{-3}), brought to 60% water holding capacity (WHC) with deionized water, and incubated at 25°C±2°C. The jars were covered with lids but aerated for 1 h each day. Moisture content was maintained at 60% WHC by weighing periodically.

A 10 g sample was taken from the mixture in each jar at 0, 3, 7, 14, 28, 42, 56, 84, 112 day of incubation. Soil moisture content, NH_4^+-N and NO_3^--N were determined. Nitrogen mineralization in manure soils was calculated as the difference between mineral N (NH_4^+-N + NO_3^--N) during incubation and its initial content prior to incubation. Nitrogen mineralization from manure was calculated by subtracting the amount of mineralized N in unamended soils from the mineralized N in manure soils.

$$N_{min} = N\text{-}NH_4^+ + N\text{-}NO_3 \quad (1)$$

Then, with the values of N_{min} and N_{tot} (Total N in the soil = total quantity of N added via organic fertilizers + total N quantity naturally occurring in the soil of each treatment)

Cumulative net nitrification (N_{cum}), soil concentration of manure-derived NH_4 (N_{amm}), and manure organic N mineralized (N_{org}) at each sampling time (t) was defined similar to Griffin and Honeycutt (2000):

$$N_{cum}(\text{mg kg}^{-1}\text{ soil})=\{[NO_3]_t - [NO_3]_{t=0}\}_{amended} - \{[NO_3]_t - [NO_3]_{t=0}\}_{unamended} \quad (2)$$

Accounting for changes in soil NO_3 concentration between t = 0 and t, and correcting for the N nitrified in the unamended soil. Similarly,

$$N_{amm}(\text{mg kg}^{-1}\text{ soil})=\{[NH_4]_t - [NH_4]_{t=0}\}_{manure} - \{[NH_4]_t - [NH_4]_{t=0}\}_{unamended} \quad (3)$$

$$N_{org}(\text{mg kg}^{-1}\text{ soil})=\{[N_i]_t - [N_i]_{t=0}\}_{manure} - \{[N_i]_t - [N_i]_{t=0}\}_{unamended} \quad (4)$$

where N_i is the sum of NO_3 and NH_4 at time, t.

The percentage of total N mineralized from each organic manure amended at each sampling time was calculated as described by Azeez and van Averbeke (2010) and Abbasi *et al*. (2007), as follows:

$$\% \text{ Mineralization} = \frac{\text{MN amended - MN control}}{\text{N Total applied}} \times 100 \quad (5)$$

where MN is total mineral N, and N total is total N in the applied organic manure.

Nitrogen mineralization models

Mineralization parameters was estimated from the cumulative amounts of leached N (NO_3^--N plus NH_4^+-N) (mean values of 3 samples) via non-linear regression, using the single and double exponential models below. Data was fitted into the models to evaluate the degree of fitting related to nitrogen mineralization.

a. $N_m = N_o [(1-\exp^{(-kt)})] + έ$…………………... Stanford and Smith, (1972) (6)
b. $N_m=N_oS(1-\exp^{-ht})+N_o(1-S)(1-\exp^{-kt})$………Molina *et al.,* (1980) (7)

Where Nm is the amount of N mineralized at time *t* [μg g^{-1}], N_o is the initial amount of potentially mineralizable N [μg g^{-1}], and *k* is the first-order rate constant [day^{-1}] with a value of 0.011 day^{-1} for the single exponential model (Benbi and Richter, 2002). The double exponential model considers two pools, where S and (1-S) represent the labile fraction and recalcitrant fraction of N_o, decomposing at a specific rate of h and k, respectively.

Physical and chemical analysis of soils

Soil physical and chemical properties were determined following standard laboratory procedures. These include; textural class by hydrometer method (Gee and Bauder, 1986), bulk density by core method at depth (Blake and Hartge, 1986), Soil pH with glass electrode (IITA, 2010), Cation Exchange Capacity (CEC) by Anderson and Ingram, (1989), Organic carbon by dichromate oxidation method (Nelson and Sommers, 1982), Total nitrogen by microbial kjeldahl digestion method (Bremner and Mulvaney, 1982), Soil available nitrogen, (NH_4^+ and NO_3^-) by colorimetric method (Hefferman, 1985); Nitrate N was determined as difference between total mineral N and ammonium N, Available Phosphorus by Bray 1 method as described by Nelson and Sommers, (1982), Exchangeable Bases (Anderson and Ingram, 1989), Electrical Conductivity (EC) where the extract was obtained from pH determination and was used for the EC determination procedure

Chemical analysis of organic manure

Subsamples of approximately 4 g were air-dried, crushed to pass through a 2-mm sieve, and analyzed for pH, organic carbon, total N, P and K and total P. Manure pH was determined with glass electrode (IITA, 1982), Organic carbon content was determined using the Walkley and Black dichromate wet oxidation method, total N by micro-Kjeldahl digestion with subsequent distillation and titration, while total P was assessed via wet digestion using a 25-5-5 mL mixture of HNO_3-H_2SO_4-$HClO_4$ (AOAC, 2000). Phosphorus was measured colorimetrically with the molybdate blue method in an autoanalyser and K by flame photometry. In addition to these, Carbon to nitrogen ratio (C:N) values were determined by calculation using division method to find their common ratio.

Statistical Analysis

Data were compiled and statistically analysed by using R-software version 4.2.0. Means was separated at 5 % level of significance, if the results vary significantly; Least Significant Difference (LSD) was used for comparing means.

Results

Physiochemical Properties of the Soil Used in the Incubation Study

The results of the physical and chemical properties of the soil are presented in Table 1. Soils of the study area were dominated with silt fractions (460 g kg^{-1}) followed by sand separates (420 g kg^{-1}) and clay (120 g kg^{-1}) to be classified as loam in texture. Bulk density of the soil was 1.20 Mg m^{-3}, particle density was 2.65 Mg m^{-3} for mineral soils, total porosity was 50 %.. Soil reactions pH (water) and pH ($CaCl_2$) was 6.2 and 5.1 respectively. Organic carbon, total nitrogen and available phosphorus were (8.02 g kg^{-1}), (0.014 g kg^{-1}) and (2 mg kg^{-1}), and Exchangeable bases (Ca, Mg, Na, and K) were found to have values of 0.89 $cmolkg^{-1}$, 0.84 cmol kg^{-1}, 0.78 cmol kg^{-1}, and 0.48 cmol kg^{-1}., and exchangeable acidity was 0.55 cmol kg^{-1}. Summation of exchangeable bases and exchangeable acidity (effective cation exchange capacity) was found to be 3.54 cmol kg^{-1} and the electrical conductivity was 0.14 dS m^{-1}.

Chemical Properties of the Manure Used Before the Experiment

Results of the chemical properties of the manures used for the experiment are presented in Table 2. The results revealed that pH ranges from 8.0 to 8.2, total nitrogen from 7.0 to 10.5 g kg^{-1}, total phosphorus from 19 to 48 mg kg^{-1}, total potassium from 5.5 to 16.25 gkg^{-1}, organic carbon from 120.1 to 428.9 gkg^{-1}, C:N ratio from 11.45 to 40.85, NH_4^+-N from 0.11 to 1.68 gkg^{-1}, NO_3^--N from 0.11 to 0.46 gkg^{-1} respectively.

Mineralization of organic manures

The manure effect was determined by taking the average value across the time (Table 3), which indicates that mineral N release from FYM (19 mg kg^{-1}) was significantly higher, followed by CM (17. mg kg^{-1}), PM (17 mg kg^{-1}) and lowest with the untreated soil (control) 14 mg kg^{-1} from the organic pool. All the manures had significantly higher concentration of mineral N than the control. The percentage increases were 43, 27, and 23 % for FYM, CM and PM respectively. However, FYM and CM releases 21 and 5 % more mineral N than PM. The effect of different incubation time on mineralization was determined by taking the average values of three manures at each incubation time (Fig. 1). Mineral N release (mineralization) from the organic pool increased over time, and the significant difference was observed at day 7 of incubation, where maximum mineralization (43 mg kg^{-1}) occurred.

Table 1. Physical and chemical properties of the soil used for incubation

Properties (0-20 cm)	Units	Values
Particle Size Distribution		
Sand	g kg^{-1}	420
Silt	g kg^{-1}	460
Clay	g kg^{-1}	120
Textural Class		Loam
Bulk density	Mg m^{-3}	1.20

Particle Density	Mg m^{-3}	2.65
Total Porosity	%	50
pH(Water) (1:1)		6.2
pH($CaCl_2$) (1:25)		5.7
Total Nitrogen	g kg^{-1}	0.014
Available P	mg kg^{-1}	2
EC	dS m^{-1}	0.14
Exchangeable Cations	cmol kg^{-1}	
Calcium		0.89
Sodium		0.78
Magnesium		0.84
Potassium		0.48
H + Al	cmol kg-1	0.55
ECEC	cmolkg^{-1}	3.54

EC=Electrical conductivity, ECEC=Effective cation exchange capacity

Table 2. Properties of manure used in incubation

	Manure		
Properties	Farmyard	Compost	Poultry
pH	8.14	8.20	7.99
Total N (g kg^{-1})	10.50	10.50	7.00
Total P (g kg^{-1})	19.00	48.00	44.00
Total K (g kg^{-1})	11.50	16.25	5.50
Organic C (g kg^{-1})	428.90	120.10	163.00
C:N	40.85	11.45	23.29
NH_4^+-N (g kg^{-1})	1.68	0.11	0.21
NO_3^--N (g kg^{-1})	0.11	0.46	0.17

Table 3. Manure effect

Manure	Total Mineral N over 112 days, (mg kg^{-1}) Soil average
Control	13.53c
FYM	19.38a
CM	17.21b
PM	16.59b
LSD($P<0.05$)	0.801

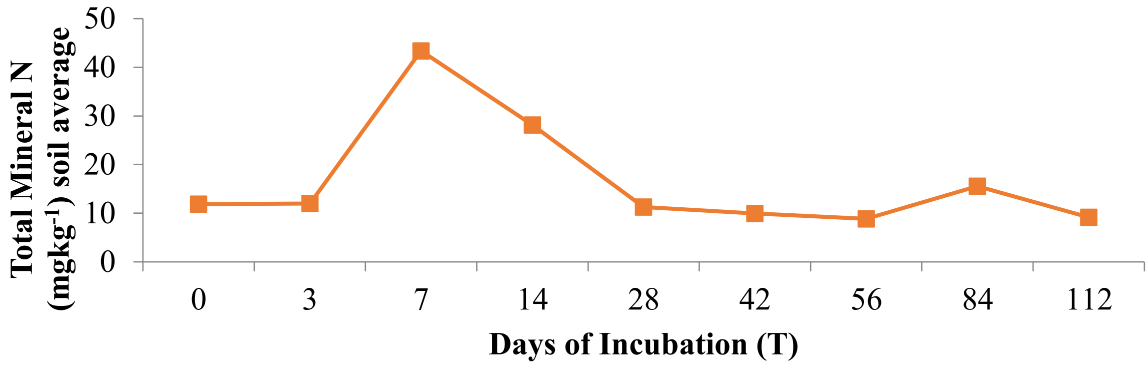

Fig. 1 Effect of days of incubation on total mineral N ($NH4^{+}$-N + NO_3^{-}N)

Fig. 2 showed the effects of various treatments on mineralization. At the end of 112 days of incubation, the concentration of inorganic N in the different manures and soil was 3-5 times higher than the concentration recorded at the beginning of the experiment at day 0. The extent of the release of mineral N over time was such that a slow release was observed at the beginning up to day 3, thereafter a significant increase in all treatments at day 7 and 14 and a decline at day 28, 42, 56, 84 and 112. The variation among treatments was inconsistent. Farm yard manure (FYM)/soil, recorded significantly higher values at day 3, 7, 14 and 42 which was significantly the same with CM and PM at day 7 and different from other treatments at day 3 and 14. More so, CM recorded significantly higher values at day 56 which was significantly not the same with the other treatments while PM recorded significantly higher values at day 0, 28, 84 and 112 which was significantly different from other treatments.

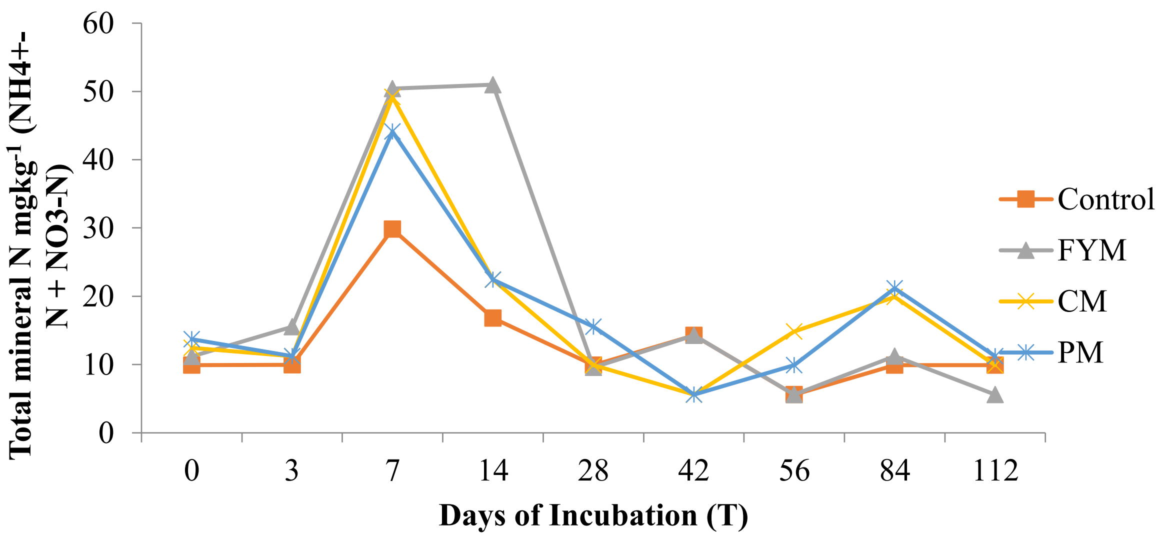

Fig. 2 Effect of Farm yard, poultry and compost manure on total mineral N ($NH4^{+}$-N + NO_3^{-}N)

The mineral N released from the organic pool of the manures (N_{org}) is shown in Fig. 3. The pattern of TMN over time is inconsistent (it increase and decrease with time). All the manure were able to release substantial amount of mineral N in the initial stage of the experiment with FYM recording the highest concentration at day 7 and 14 (19 and 33 mg kg^{-1}), followed by CM and PM at day 14 (17 and 10 mg kg^{-1}) whereas CM mineralized more at the later stage of incubation. On the basis of this maximum release of mineral N, net N release as percent of added N for FYM, CM and PM was 10, 8 and 5 % respectively. The net rate of mineralization from manures ranged from 0.02 to 2.9, 0.12 to 2.8, 0.01 to

2.04 mg kg^{-1} day^{-1} for FYM, CM and PM respectively (Fig. 4). All the manures also showed negative values at different timings. Taking averages (3-112 days), the daily rates of mineralization were 0.95, 0.50 and 0.41 mg kg^{-1} day^{-1} for FYM, CM and PM respectively.

The interaction of the manures and time is shown in Fig 5. Manure effect on total mineralized N is largely dependent on the level of days of incubation. At day 7 and 14, FYM had significantly higher concentration of total mineralized N which was statistically at par with CM at day 7 and significantly different from other treatment combinations. Farm yard manure (FYM) at 56 and 112 days, CM and PM at 42 day and control at 56 day gave significantly the lowest mineralized N

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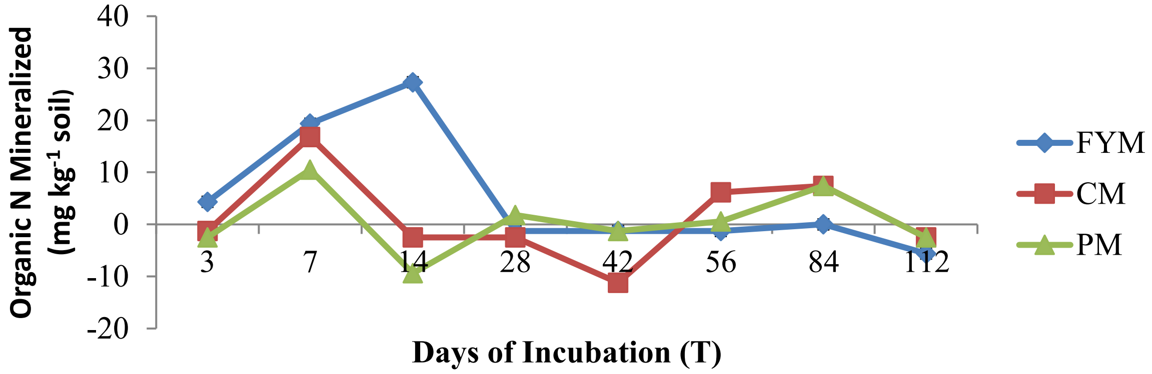

Fig. 3 Organic N mineralized (N_{org})

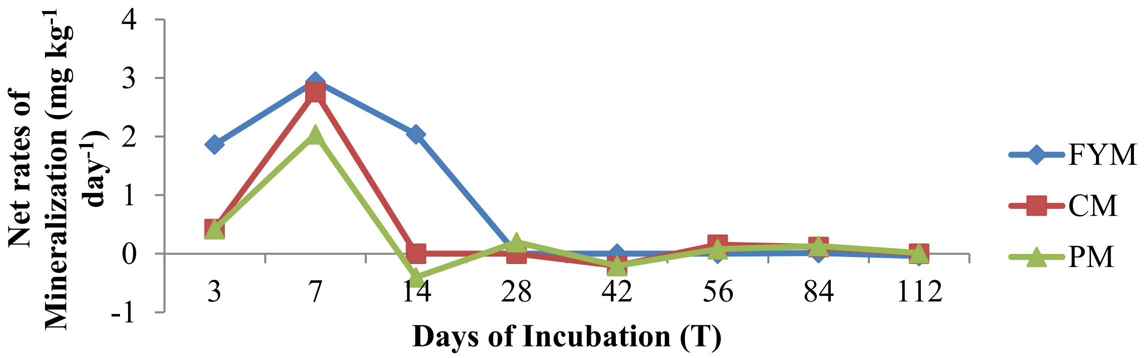

Fig. 4 Net mineralization rates

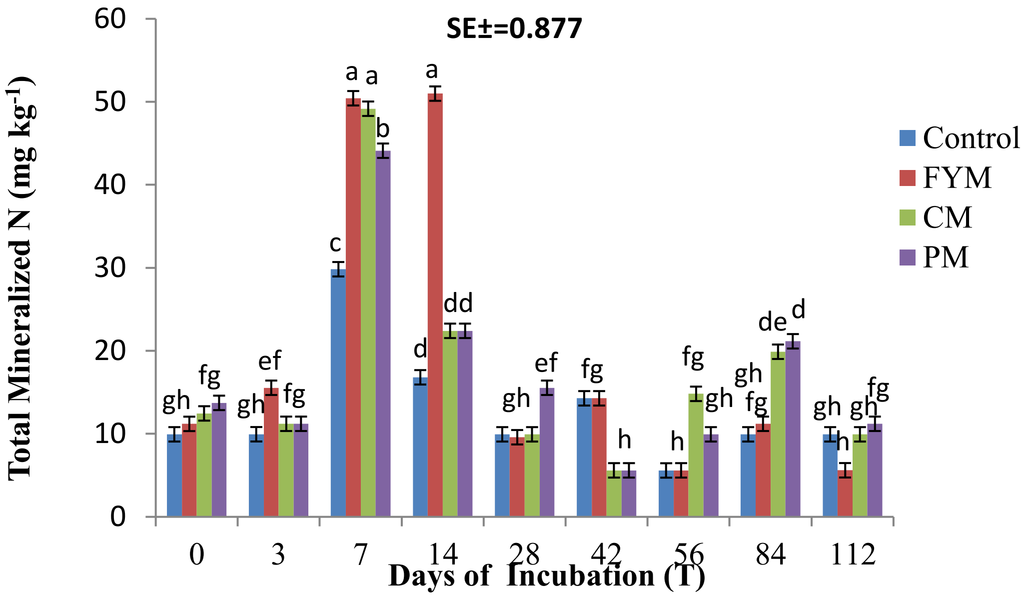

Fig. 5 Effect of manure and days after incubation on total mineralized N

Changes of NH_4^+-N and NO_3-N in manured Soils

The content of NH_4^+-N for various manures varied from one another. Farm yard manure was consistent during day 0 and 3 (3 mg kg^{-1}) and increases during day 7 (11 mg kg^{-1}) declined during day 14 and 28 (8 and 1 mg kg^{-1}) and increased during day 42 (13 mg kg^{-1}) and declined consistently from day 56 to 112 (5 to 1 mg kg^{-1}) (Fig. 6). Compost and poultry manure nearly followed the same pattern in the content of NH_4^+-N except during day 56 and 84 respectively (Fig. 6). There was a decline during day 0 to 3 and an increase during day 14. NH_4^+-N content decline during day 14 and 28, increases during day 42 and decline consistently from 56 to 112 day. Control was consistent during day 0, 3, 28, 42, 56, 84 and 112 and only increases during day 7 and 14 with incubation time and the decline was marked during the day 3, 28, 56 and 112 respectively. After day 3, NH_4^+-N content increased during day 7, 14 and 42. The NH_4^+-N content ranges from 1-15 mg kg^{-1} after day 112.

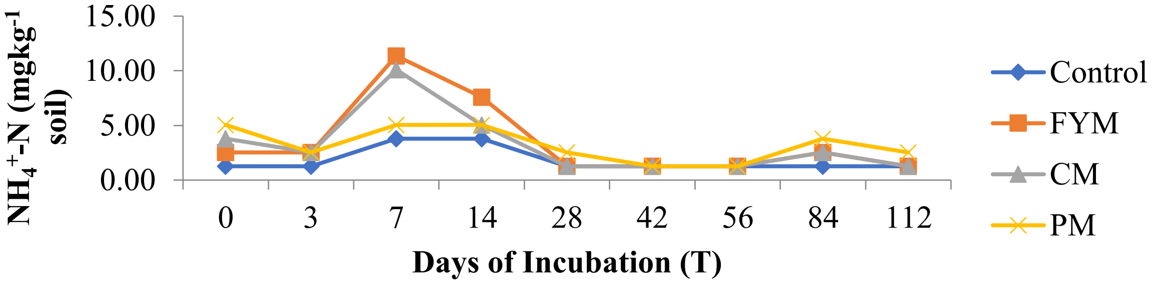

Fig. 4 Dynamics of NH4$^+$-N content

The overall effect of manure on nitrification showed all the manures accumulate more NO_3-N at day 7 and 14 than the control (Fig. 7). The level of increase was 33 % at day 7 for all the manure and 70 % for FYM and 25 % for CM and PM than the control. Among all the manures, FYM had the highest concentration of NO_3-N at day 14. Under FYM, NO_3-N had concentration from 4 to 43 mg kg^{-1}, CM and PM from 4 to 39 mg kg^{-1} and control from 4 to 26 mg kg^{-1}. More so, the net and cumulative net

NO_3-N followed the same pattern among all the manures (Figs. 8 and 9).

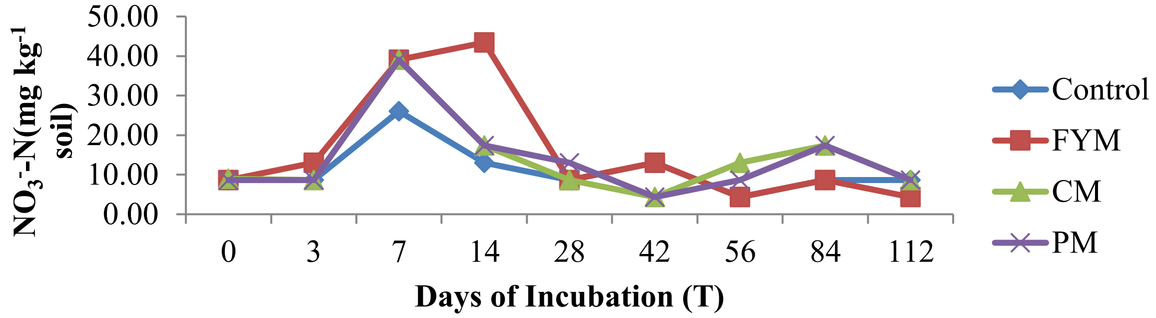

Fig. 5 Dynamics of NO_3^--N content

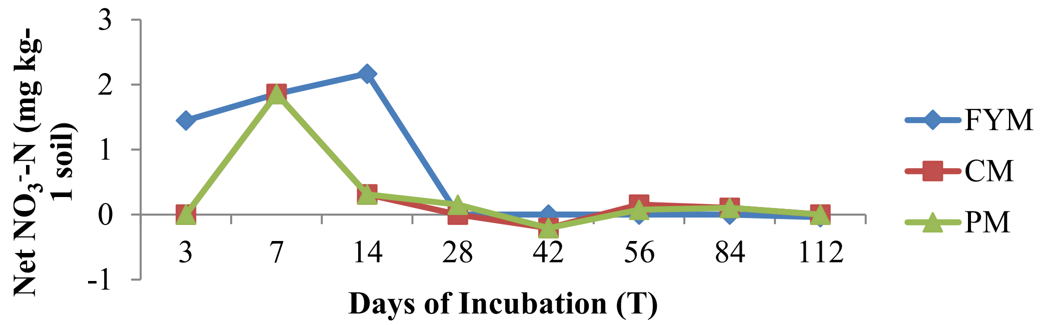

Fig. 6 Dynamics of net NO_3^- -N content

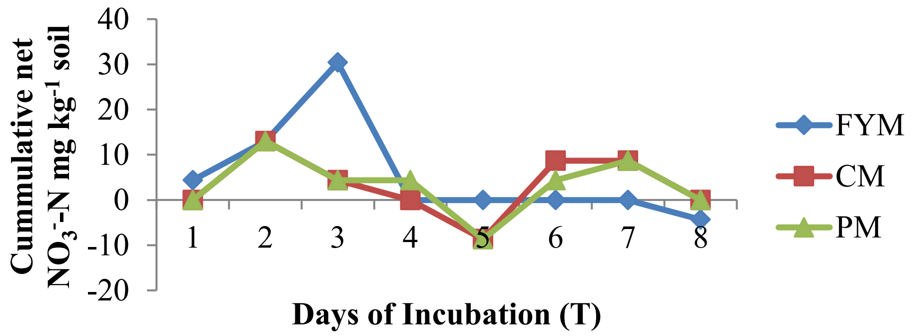

Fig. 7 Dynamics communlative net NO_3^- -N content

Parameter estimation of N mineralization

Nitrogen mineralization parameters of the incubated soils optimized with the double and the single model are shown in Table 5. In most cases, the double model resulted in a higher R^2 (0.965-0.9861) and greater model/error ratio (163.17-426.39) than the single model (0.9728-0.9729), (214.23-214.50). However, N mineralization in FYM was well simulated by the single model with the potentially mineralizable N, N_0 (21 mg kg^{-1}) being slightly higher than the mean measured value in 112 days (19 mg kg^{-1}), and a rate constant k (0.011 day^{-1}). Both CM and PM was well simulated with the double model with potentially mineralizable nitrogen N_o (35 and 36 mg kg^{-1}) twice the mean measured value in 112 days (17.21 and 16.59 mg kg^{-1}) as shown in Table 6 and a rate constant ka (0.1544 and 0.1538 day^{-1}), kr (0.0052 and 0.0062 day^{-1}). Farm yard manure had the highest organic carbon of 429 g kg^{-1}) compared to CM with 120 g kg^{-1}) and PM (163 g kg^{-1}).

Table 1. Optimized Mineralization model parameters using non-linear regression (double and single exponential model) of the incubation experiment

Treatments	Na (mg/kg)	Ka (day^{-1})	Nr (mg/kg)	Kr (day^{-1})	N_o (Na+Nr)	R^2	Ratio (Model/Error)	CV	RMSE
			Double exponential model						
FYM	11.20	0.0906	9.59	0.0079	20.79	0.9645	163.17	18.27	7.91
CM	12.46	0.1544	22.41	0.0052	34.87	0.9861	426.39	11.43	4.95
PM	13.73	0.1538	22.41	0.0062	36.14	0.9839	365.66	12.33	5.33
			Single exponential model						
		K (day^{-1})							
FYM		0.011			20.79	0.9729	215.47	15.98	6.91
CM		0.011			34.87	0.9728	214.23	16.02	6.93
PM		0.011			36.14	0.9728	214.50	16.01	6.92

N_o is the potentially potentially mineralizable N; Na and Nr represent the active and resistant pools decomposing at specific rates ka, and kr.

Discussion

Physical and chemical properties of the soil used for incubation

The texture of the soil was loamy with slight clay content which showed that the bulk density of the soil was within the range that was ideal for plant growth (<1.40 Mgm^{-3}) according to Arshad *et al.* (1996). Li *et al*., (2002) reported that increase in soil bulk density from 1.00 to 1.60 Mg m^{-3}, decreases the total numbers of bacteria, fungi and actinomycetes by 26–39 %. The value of total porosity affirms that the soil contains 50.19% of the pore space which indicate good water infiltration and permeability, aeration and growth and high water holding capacity. The low levels of total nitrogen, available phosphorus, organic carbon, ECEC, suggest that the soils are degraded and impoverished in quality and fertility status (Chidowe *et al*., 2017; Khan *et al*., 2010; Odunze, and Kureh, 2007). Further, low value of total nitrogen may be ascribed to high C: N ratio of the soil. The result of pH indicates that the soil is slightly acidic likely caused by the loss of basic cations from the top soil (Daudu, 2004). The low electrical conductivity value indicates they are non-saline and suggests low available nutrients (USDA, 2011). Low exchangeable acidity reflects increase in availability of nutrients, favourable condition for the activities of microorganism and reduction in the risk of aluminium toxicity in soils.

Chemical Properties of the Manure Used Before the Experiment

The results indicated that all the organic manures had moderately alkaline pH, high organic carbon, total nitrogen, phosphorus and potassium according to Enwezor *et al*., 1989; Esu, 2010; Chude *et al*., 2011; Hezelton and Murphy, 2011; Sasseville, 2013. This shows that all the manures have the tendency of improving soil conditions for agricultural production. Further, the pH will enhance high biological activities of micro-organism (Peter *et al*., 2020)

Mineralization of Organic Manures

The ability of the manures to have substantial amount of mineralized N over the control was expected because they contain higher concentration of total N and the variation in mineralization was due to more labile organic N compounds and high levels of microbial biomass and activity in manures. This finding was similar to that of Abbasi *et al*., (2007). It has been shown in a number of studies that the amount of N that is mineralized and immobilized by manures can vary as function of the availability of organic C (Van Kessel *et al.*, 2000). More so, the differences of N mineralization among organic materials were probably related to animal diets (Azeez and Van Averbeke, 2010). In this present study, untreated soil (control) released a maximum of 29.83 mg mineral N kg^{-1}soil at day 7, whereas the initial concentration at the start of the experiment was 9.94 mg mineral N kg^{-1}, showing a threefold increase in mineral N. This increase in mineral N was due to the mineralization of organic materials present in the soil. It showed that the soil under study has substantial potential for mineralization.

The effect of days of incubation and various treatments on mineralization suggests that three different phases of mineralization were noted in this study (slow N release (0-3 day), followed by an accumulation (maximum mineralization) (7-14 day) and finally by the decline (loss of N) (28, 42, 56, 84 and 112 day). This conforms to the report of several authors that three phases of mineralization were observed: an accumulation phase followed by a phase of N release and finally by the loss of N phases (Kachaka *et al.,* 1993; Eneji *et al*., 2002). Mineralization of organic matter was maximum during initial incubation periods due to the consumption by soil organisms of the most easily decomposable organic compounds and on account of the factors which may accelerate organic matter decomposition such as handling and preparations of the samples (drying, grinding and wetting). The decline phase may be due to immobilization. Abbasi *et al.,* (2007) in their study reported four phases (initial rapid release, slow, maximum mineralization and decline phase), that the initial rapid-release pattern of mineralization was primarily because of the drying and wetting of soil. The decline phase was most probably because of immobilization. The C/N ratio of 4:1 indicated relatively more C than N resulted in immobilization of added manures. When applied to soils, manure increases the energy or food supplies available to the soil microbial population. This energy supply stimulates soil microbial activity, which consumes more available N than the mineralization processes release. Thus, high microbial activity during initial mineralization can cause a reduction of available N. In this study, all the manure resulted in net N mineralization as early as 7 and 14 day which would meet the early N demand of the crop. So if the manure was to be applied, it should be applied with appropriate rate at planting.

The mineral N released from the organic pool of the manures suggests that N availability of FYM was higher than CM and PM. The lower N availability in PM may ascribe to lower total nitrogen and type of material found in the manure (contain more bedding materials). The result disagrees with what Alizadeh *et al*., (2012) reported that PM treated soils had significantly higher total N mineralization than cow manure treated soils after 110 day of field incubation using the buried bag technique. The interaction effect of the manures and days of incubation suggests that days of incubation is an important factor in determining the rate of mineralization

Changes of NH_4^+-N and NO_3-N in manured soils

The highest NH_4^+-N content under CM at Day 42 suggests higher total N. The finding is similar to that of Melo *et al*., (2008) who reported that contents of NH_4^+-N are higher in residue with greater content of total N and with lower degree of maturation. Decline of soil NH_4^+-N within the periods of days can be ascribed to rapid immobilization combined with nitrification/denitrification as also reported by Li and Li (2014). It has been found that microorganism prefer NH_4--N for their growth and utilize NO_3^--N when NH_4^+-N content is lower than 1 μg N g^{-1}soil (Gioacchini *et al*., 2007). Additions of C in soil promote multiplications of microorganism and then increase NH_4^+-N immobilization and/or nitrification. Other studies on N mineralization of chicken manure (Aoyama and Nozawa, 1993), pig manure (Bernal and Kirchmann 1992) and cattle manure (Calderón *et al*., 2005) also found the rapid decline of soil NH_4^+-N in a short period after incubation.

In this study, the content of NO_3^- measured gave higher dynamics than NH_4^+-N with incubation time. This was because NH_4^+ was prone to losses through volatilization, immobilization, fixation and nitrification. Low C/N of organic materials cause mineralization of N as they are decomposed, whereas the high C/N of organic materials cause immobilization of mineral N because available N is utilized by soil microbial biomass (Schimel *et al.* 1992; Mary *et al.* 1996). Calderón *et al*., (2004) studied N mineralization of 107 dairy cattle manures and reported that net mineralization occurred when $C/N < 16.0$, but net immobilization occurred when $C/N > 19.0$. In our study, the C/N ratio of farm yard and poultry manures was more than 20, while C/N ratio of CM was less than 16. Therefore, it is expected that CM should mineralize faster than FYM and PM. But in our case, FYM and CM mineralise faster than PM. Results obtained with CM and PM support the findings of Calderon *et al*., (2004) and Van Kessel *et al*., (2000), while the result obtained with FYM disagrees with their report. Other factors like organic

N fraction or other physical and chemical characteristics of manures might be responsible for the differences (Burger and Venterea 2008; Fangueiro *et al*. 2010). Our results are consistent with Chen *et al.,* (2019) who reported that chicken manure, with high N concentration and low C/N ratio, decomposed more slowly than pig manure, highlighting the important role of manure chemical composition for decomposition. Previous studies have found that manure decomposition could be regulated by their main structural components such as cellulose (Movan *et al*., 2006; Chen *et al.,* 2019), as cellulose was found to be the primary substrate for glucan depolymerisation at a later stage of decomposition after more labile C compounds such as sugars and starch had been depleted (Leitner *et al.,* 2012). This regulation of decomposition rate by cellulose may probably explain why FYM in this study decomposed more quickly than other manures even though it had higher C/N ratio. Cellulose in manure can decompose very fast because it is already rich in cellulolytic bacteria from the rumen (Lia *et al*., 2005).

Parameter estimation of N mineralization

The results from this study suggests that both models produced good predictions for all the manured soil but because soil organic matter has heterogeneous components with varying degrees of degradability, models having two components are generally more accurate than a single component model for simulating N mineralization (Dou *et al*., 1996; Benbi and Richter, 2002). Occasionally, single model can be better than the double model and one possible reason is that more than two fractions of organic N are contributing to N_0.

Conclusion

In this study, all the manure resulted in net N mineralization as early as 7 and 14 day. Farm yard manure had the highest daily rates of mineralization, highest concentration of NO_3-N at day 14 while CM had the highest NH_4^+-N content after day 112 respectively. Furthermore, the content of NO_3^- measured gave higher dynamics than NH_4^+-N with incubation time. Carbon to nitrogen ratio of farm yard and poultry manures was more than 20, while C/N ratio of CM was less than 16. Fram yard manure and CM mineralise faster than PM. Both models produced good predictions for all the manured soil. In most cases, the double model resulted in a higher R^2 and greater model/error ratio than the single model. Nitrogen mineralization in FYM was well simulated by the single model with the potentially mineralizable nitrogen N_o being slightly higher than the mean measured value in 112 days. Both CM and PM were well simulated with the double model with potentially mineralizable nitrogen N_o twice the mean measured value in 112 days.

References

Abbasi, M.K., Hina, M., Khaliq, A., and Khan, S.R. (2007). Mineralization of three organic manures used as nitrogen source in a soil incubated under laboratory conditions. *Community of Soil Science and Plant Analysis.* 38, 1691–1711.

Alizadeh, P., Fallah, S., and Raiesi, F. (2012). Potential N mineralization and availability to irrigated maize in a calcareous soil amended with organic manures and urea under field conditions. *International Journal of Plant Production*, 6, 493-512.

Anderson, J, M. and Ingram, J. S. I. (1989). Tropical Soil Biology and Fertility: A Handbook of Methods (2nd ed.). C.A.B. Intemation Wallingford, U.K. pp. 221.

AOAC. (2000). Official methods of analysis of the association of official analytical chemists. 17th Edition, Association of OfficialAnalytical Chemists International, Gaithersburg, MD, USA.

Aoyama, M., and Nozawa, T. (1993). Microbial biomass nitrogen and mineralization immobilization processes of nitrogen in soils incubated with various organic materials. Soil Science and Plant Nutrition, 39, 23-32.

Arshad, M. A., Lowery, B., and Grossman, B. (1996). Physical Test for Monitoring Soil Quality. In: Doran, J. W and Jones, A. J., Editors. Methods for Assessing Soil Quality WI.PP.123141.Retrieved on October 23, 2011, from

http://soilquality.org/indicators/bulkdensity.html.

Azeez, J.O., and Van Averbeke, W., (2010). Nitrogen Mineralization potential of three animal manure applied on a sandy clay loam soil. *Bioresoure Technology*. 101, 5645- 5651.

Benbi, D.K., and Richter, J. (2002): A critical review of some approaches to modeling nitrogen mineralization. *Biology and Fertility of Soils* 35, 168-183.

Bernal, M P., and Kirchmann, H. (1992). Carbon and nitrogen mineralization and ammonia volatilization from fresh, aerobically and anaerobically treated pig manure during incubation with soil. *Biology and Fertility of Soils*, 13, 135-141.

Blake, C.R. and Hartge, K. H. (1986). Bulk density methods of soil analysis, part 1, physical and mineral method (Ed. A Klute). Pp 363-382.

Bremner, J.M. and Muvaney, C.S. (1982). Total nitrogen. In: Methods of soil analysis. Page, A.L., R.H. Miller and D.R. keeping (Eds.) of soil part 2. *American Society of Agronomy*. Madison Wisconsin. 595-624.

Burger, M., and Venterea, R. T. (2008). Nitrogen immobilization and mineralization kinetics of dairy, hog, and turkey manure applied to soil. *Soil Science Society of America Journa*l, 72, 1570-1579.

Calderón, F. J., McCarty, G. W., and Reeves, J. B. (2005). Analysis of manure and soil nitrogen mineralization during incubation. *Biology and Fertility of Soils*. 41, 328–336.

Calderón, F. J., McCarty, G. W., van Kessel, J. A S., and Reeves, J. B. (2004). Carbon and nitrogen dynamics during incubation of manured soil. *Soil Science Society of America Journal,* 68, 1592-1599

Carter, M. R.; Sanderson, J. B.; MacLeod, J. A. (2004). Influence of compost on the physical properties and organic matter fractions of a fine sandy loam throughout the cycle of a potato rotation. Canadian Journal of Soil Science, 84(2), 211–218. doi:10.4141/S03- 058.

Chen, Z., Yehong, X., Daniela, F. C., Michael, J. C., and Weixin, D. (2019) Molecular insights into the inhibitory effect of nitrogen fertilization on manure decomposition. Elsevier Volume 353, 1 November 2019, Pages 104-115.

Chidowe, O.A., Musa, Y.D., and Abdulkadir, A. (2017) Soil Quality, Carbon Sequestration and Yield of Maize (Zea mays L.) under Maize/Legume Cropping System in Alfisols of a Savanna Zone, Nigeria. *American Journal of Climate Change*, 6, 622-642.

Chude, V.O., Olayiwola, S.O., Osho, A.O. and C.K. Daudu (2011). Fertilizer Use and Management Practices for Crops in Nigeria. Fourth edition. Federal Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria, pp. 1-59.

Cusick, P. R., Powell, J. M., Kelling, K. A, Hensler, R. F., and Muňoz, G R.

(2006). Dairy manure N mineralization estimates from incubations and litterbags. *Biology and Fertility of Soils*, 43, 145-152.

. Daudu, C. K. (2004).An evaluation of different sources of organic matter on the fertility and productivity of an Alfisol in the Nigerian savanna. Ph. D. Thesis. Department of Soil Science, ABU, Zaria Nigeria.

De Vries, J.W., Groenestein, C.M. and Schroder, J.J. (2015). Integrated manure management to reduce environmental impact: II. Environmental impact assessment of strategies. Agric. Syst. 138, 88e99. https://doi.org/10.1016/j.agsy.2015.05.006.

Dou, Z., John, D. Toth, J. D., Jabro, R. H. Fox and Daniel, D. F. (1996). Soil Nitrogen Mineralization During Laboratory Incubation: Dynamics And Model Fitting. *Soil Biology and Biochemistry Vol. 28, No. 415, pp. 625-632, 1996.*

Edwards, C.A. and Bohlen P.J. (1996). Biology and Ecology of Earthworms. 3rdEdn., Chapman and Hall, London.

Enesi, A.E., Honna, T., Yamamoto, S., Saito, T., Masuda, T., (2002). Nitrogen transformation in four Japanese soils following manure + urea amendment. *Commununity of Soil Science of Plant Analysis.* 33, 53–66.

Enwezor, W.O., E.J. Udo, N.J. Usoro, K.A. Ayotade, J.A. Adepetu, V.O. Chude and C.I. Udegbe, (1989). Fertilizer use and management practices for crops in Nigeria. Series 2.Federal Ministry Agriculture and Water Resources. Lagos. 18pp.

Esu, I.E. (2010). Soil characterization, classification and survey. HEBN Publishers, Plc, Ibadan, Nigeria, 232pp.

Fangueiro D, Gusmaõ M, Grilo J, Porfírio G, Vasconcelos E, Cabral F. (2010). Proportion, composition and potential N mineralisation of particle size fractions obtained by mechanical separation of animal slurry. *Biosystems Engineering*, 106, 333-337.

Gee, G.W. and Bauder, J. W. (1986). Particles size analysis. In: A. Klute (ed) Methods of soil analysis 2nd No. ASA Inc. Madison, Washington D.C. 383-409.

Gioacchini P, Manici L M, Ramieri N A, Marzadori C, Ciavatta C. (2007). Nitrogen dynamics and microbial response in soil amended with either olive pulp or its by-products after biogas production. *Biology and Fertility of Soils*, 43, 621-630

Griffin, T.S. and Honeycutt, C.W. (2000) Using growing degree days to predict nitrogen availability from livestock manure. *Soil Science Society of America Journal*, 64: 1876–1882.

Hefferman, B. (1985). A handbook of method on inorganic chemical analysis for forest soils, forages and water. Division of forest research, CSIRO, Canberra, Australia 281pp.

Huang, G.F., Wu, Q.T., Wong, J.W.C., and Nagar, B.B. (2006). Transformation of organic matter during co-composting of pig manure with sawdust. *Bioresource Technology*, 97 (15), 1834- 1842 doi.org/10.1016/j.biortech.2005.08.024.

Hezelton P. and B. Murphy, (2011). Interpreting soil test results. CSIRO Publisher, Australia. 152pp.

IITA-International Institute of Tropical Agriculture.(2010). Automated and semi-automated Analysis.Manual series No. 12 IITA. Ibadan, Nigeria. Pp 72.

Jacobs, J., R. Kreutzer and D. Smith, (1997). Rice burning and asthma hospitalizations Butte County, California, 1983-1992. Environ. Health Perspect., 105: 980-985.

Jeff Lorimor (2004). Manure Characteristics (Manure Management Systems Series). Mild west plan service (MWPS). Pp 1-24.

Kachaka, B., Vanlauwe, B., and Merckx, R. (1993). Decomposition and nitrogen mineralization of pruning of different quality. In Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture; Mulongoy, M. and Merckx, K. (eds.); John Wiley and Sons: Chichester, UK, Pp.199–208.

Kaushal, M and Kaushal, R. (2013). Screening and characterization of rhizobacterial strains of Bacillus spp. isolated from rhizosphere of cauliflower (Brassica oleracea var. botrytis L.). African J Microb. Res. 2013;7(3):1657-1663.

Khan, Z. R., Charles, A. O., Midega, T., Bruce, J. A., Hooper, A. M. and Pickett, J. A. (2010) Exploiting Phytochemicals for Developing a "Push-Pull" Crop Protection Strategy for Cereal Farmers in Africa. *Journal of Experimental Botany*, 61, 4196-4196. https://doi.org/10.1093/jxb/erq229.

Leitner, S., Wanek, W., Wild, B., Haemmerle, I., Kohl, L., Keiblinger, K.M., Zechmeister- Boltenstern, S., and Richter, A. (2012) Influence of litter chemistry and stoichiometry on glucan depolymerization during decomposition of beech (Fagus sylvatica L.) litter. *Soil Biology Biochemistry.* 50:174–187. https://doi.org/10.1016/j.soilbio.2012.03.012.

LI Ling-ling and LI Shu-tian (2014). Nitrogen Mineralization from Animal Manures and Its Relation to Organic N Fractions. *Journal of Integrative Agriculture* 2014, 13 (9): 2040-2048.

Li, C. H., Ma, B. L. and Zhang, T. Q. (2002). Soil bulk density effects on soil microbial populations and enzyme activities during the growth of maize (*Zea mays L.*) planted in large pots under field exposure. *Canadian Journal of Plant Science*. 82: 147–154.

Mader, P. (2002). *Soil Fertility and Biodiversity in Organic Farming. , 296(5573), 1694–1697.* doi:10.1126/science.1071148

Mary, B., Recous, S., Darwis, D., Robin, D. (1996). Interactions between decomposition of plant residues and nitrogen cycling in soil. *Plant and Soil*, 181, 71-82.

Melo, L.C.A., Silva, C. A., Dias, B, O. (2008). Characterization of the organic matrix of residues from different origins. Revista Brasileira de Ciência do Solo*, 32(1), 101–110.* doi:10.1590/s0100-06832008000100010

Molina, J. A. E., Clapp, C. E., and Larson, W.E. (1980). Potentially mineralizable nitrogen in soil: the simple exponential model does not apply for the first 12 weeks of incubation. *Soil Science Society of America Journal*, Madison, v.44, p.442-443.

Morvan, T., Nicolardot, B., and Péan, L. (2006) Biochemical composition and kinetics of C and N mineralization of animal wastes: a typological approach. *Biology and Fertility of Soils* 42:513–522. https://doi.org/10.1007/s00374-005-0045-6.

Nelson, D.W., and Sommers, L.E. (1982). Total carbon, organic carbon and organic matter. In: Page, A.L., Miller, R.H., and Keeney, D.R. (eds). Methods of soil Analysis no.9, part 2, Chemical and microbiological properties. *American society of Agronomy. Madison, Wisconsin*. Pp 539-579.

Odunze, A.C. and Kureh, I. (2007) Land Use Limitations and Management Option for a Savanna Zone Alfisol. *Nigerian Journal of Soil and Environmental Research*, 7, 70-81.https://doi.org/10.4314/njser.v7i1.28420.

Oenema, O., Ju, X. and de Klein, C. (2014). Reducing nitrous oxide emissions from the global food system. Curr Opin Environ Sustain 9 (10), 55e64. https://doi.org/10.1016/j.cosust.2014.08.003.

Oluwasemire, K. O. and Alabi, S. O (2004). Ecological impact of changing rainfall pattern, soil processes and environmental pollution in the Nigerian Guinea Savvana Agro- ecological zones. *Nigerian Journal of Soil Research*.5:23-31.

Pandey, C. and S. Shukla. 2006. Development and evaluation of soil moisture based seepage irrigation management for water use and quality. Journal of Irrigation and Drainage Engineering. In press.

Parthasarathi, K., L.S. Ranganathan, V. Anandi and J. Zeyer. (2007). Diversity ofmicroflora in the gut and casts of tropical composting earthwormsreared on different substrates. J. Environ. Biol., 28, 87-97 (2007).

Peter, A. L., Daniela, D., Oded, L., Ott, S., Nuno, P. M., Zeynep, C., 6, Estefanía, N. F., Sara, B., Rebecca, H., Michael and Conor O'B. (2020). Understanding How Microorganisms Respond to Acid pH Is Central to Their Control and Successful Exploitation. Frontiers in Microbiology. 2020 Sep 24;11:556140. doi: 10.3389/fmicb.2020.556140

Powlson; D. S., A. Bhogal; B.J. Chambers; K. Coleman; A.J. Macdonald; K.W.T. Goulding; A.P. Whitmore (2012). The potential to increase soil carbon stocks through reduced tillage or organic material additions in England and Wales: A case study. , 146(1), 23–33. doi:10.1016/j.agee.2011.10.004.

Rajan, B., Naresh, R.K., Himanshu, T., Singh, P.K., Dhritiman, D., Manoj, K., Rahul, B and Gaurav, T. (2023). Farm-yard manure as a resource for integrated nutrient management.The Pharma Innovation Journal 2023; 12(4): 672-681.

Ranganathan, L.S.: Vermibiotechnology - From Soil Health to Human Health.Agrobios., India (2006).

Reinhardt, T.E., R.D. Ottmar and Castilla, C. (2001). Smoke impacts from agricultural burning in a rural Brazilian town. J. Air Waste Manage. Assoc., 51: 443-450.

Sasseville, D.N. 2013. Better Performance, Better Quality and Better Profits. Agriguadian Jefferson City, MO / Athens, GA, USA 573-690-2150. Lecture delivered at the 37th Conference of SSSN, Lafia, Nassarawa State, Nigeria.

Schimel, J. P, Helfer, S, and Alexander, I. J. (1992). Effects of starch additions on N turnover in Sitka spruce forest floor. *Plant and Soil*, 139, 139-143.

Shobayo, A. B., Aliyu, J., Malgwi, W. B., and Jimoh A.I (2015). Characterization and classification of soils of the Institute of Agricultural Research (IAR) Horticultural Garden, Zaria. Paper presented at the 39th Annual Conference of the Soil Science Society of Nigeria at Landmark university Omu-aran, Kwara State, Nigeria. March 2015.

Sidhu, B.S. and Beri, V. (2008). Rice residue management: Farmer's perspective. Indian J. Air Pollut. Control, 8: 61-67.

Sistani, K. R., Adeli, A., McGowen, S. L, Tewolde, H., and Brink G E. (2008). Laboratory and field evaluation of broiler litter nitrogen mineralization. *Bioresource Technology*, 99, 2603-2611.

Stanford, G., and Smith, S.J. (1972). Nitrogen mineralization potentials of soils. *Soil Science Society of America Journal*, Madison, v.36, p.465-472, 1972.

Valette, J. and Ibanga, I. J. (1984). Detailed Soil Survey Report of Institute for Agricultural Research Farm, Samaru. Page 1-64.

Van Kessel, J. S., Reeves, J. B., and Meisinger, J. J. (2000) Nitrogen and carbon mineralization of potential manure components. *Journal of Environmental Quality* 29:1669–1677.

Webb, J., Chadwick, D., Ellis, S. (2004). Emissions of ammonia and nitrous oxide following incorporation into the soil of farmyard manures stored at different densities. Nutrient Cycling in Agroecosystems. 2004;70:67–76.

Yusuf, A. A., Iwuafor, E. N. O., Abaidoo, R. C., Olufajo, O. O., and Sanginga, N. (2008). Grain legume rotation benefits to maize in the northern Guinea savanna of Nigeria: fixed-nitrogen versus other rotation effects. Nutrient Cycling in Agroecosystems, 84(2), 129–139. doi:10.1007/s10705-008-9232-9.

Zarabi, M., and Jalali, M. (2013). Nitrogen mineralization in two calcareous soils treated with raw organic amendments. *Clean Technologies and Environmental Policy*, 15, 317- 331

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INFLUENCED OF CONSERVATION AGRICULTURE ON SOIL PHYSICAL, CHEMICAL QUALITY INDICATORS AND YIELD IN SAMARU, NORTHERN GUINEA SAVANNA OF NIGERIA

Ogunsola, E.O.,[1*], Abdullahi, M.Y.,[1] Sule, B.A.,[2] , Christian. A.T.,[3] and Olaoye O.J.[4]
[1]Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria
[2]Plantation Department, SIAT Nigeria Limited, Ubima, Port Harcourt, Cross River State
[3]Africa Rice Center (AfricaRice) Nigeria, Kano Regional Office
[4]ThriveAgric Limited, GRA, Zaria
Corresponding author email: ogunsholaelijah@yahoo.com

ABSTRACT
The capacity of soil to function can be reflected by measured soil physical, chemical and biological properties. Continuous cultivation alters soil structural units, increases the loss of soil organic matter and change pore distribution. Conservation Agriculture (CA) as an approach to managing agro-ecosystem for improved and sustained productivity is essential in the northern Guinea savanna of Nigeria. The study was carried out to determine the effect of CA treatments on soil physical, chemical quality indicators and yield during the 2013 and 2014 rainy seasons at the research farm of the Institute for Agricultural Research, Ahmadu Bello University Zaria. The treatments consisted of Desmodium inortum, Macrotyloma uniflorum and Centrosema pubescen, each intercropped with Maize (SAMMAZ 14), food legume; cowpea (SAMPEA 8)/groundnut (SAMNUT 24) and fodder cowpea (SAMPEA 11) as associated crops laid out in randomized complete block design and replicated three times. Disturbed and undisturbed soil samples were collected at 0-15 and 15-30 cm, 0-5 cm and 5-15 cm depth respectively both prior to trial establishment and at harvest. Results in 2013 showed that highest positive correlation was obtained for air capacity (AC) versus macroporosity (Pmac) (r > 0.60) and highest negative correlation was obtained for relative field capacity (RFC) versus air capacity (AC) (r > 0.70). First seven principal component (PCs), eigenvalues >1, accounted for 66% of variability in measured soil physical, chemical indicators and grain yield while in 2014, highest positive correlation were obtained for structural index (SI) versus organic carbon (OC) (r > 0.90) and highest negative correlation was obtained for relative field capacity (RFC) versus air capacity (AC) (r > 0.90). The six PCs, eigenvalues >1, accounted for 80% of variability in measured soil physical, chemical indicators and grain yield. Air capacity (AC) was found to be the most dominant in both years measured attributes.
Keywords: *Conservation Agriculture, Conventional Tillage, Factor analysis, Physical and chemical quality indicators.*

Introduction

Soil quality is often perceived as an abstract characteristic of soils, which cannot be defined because it depends on external factors, such as land use and soil management practices, ecosystem and environmental interactions, and socioeconomic and political priorities (Pankhurst *et al.,* 1997). Soil quality is assessed with respect to specific soil functions (Larson and Pierce, 1994). However, soil functions themselves cannot be directly measured. Selected physical, chemical, and biological properties of soil are used instead to quantify soil quality functions related to specific goals. Those soil properties are called soil quality indicators (USDA, 2015).

Conventional tillage (CT) as a management practice can alter soil quality positively or negatively. Conventional tillage causes disruption of soil structure, reduces soil organic matter and increase loss of soil erosion (Prodipto *et al*., 2023). An approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment called conservation agriculture (CA), is needed to maintained and improve soil quality (FAO, 2014). Conversation agriculture is characterized by the practical application of three linked principles, along with other complementary good agricultural practices of crop and production management, namely (FAO, 2014): (1) Continuous no or minimal mechanical soil disturbance (implemented by the practice of no-till seeding or broadcasting of crop seeds, and direct placing of planting material into untilled soil; and causing minimum soil disturbance from any cultural operation, harvest operation or farm traffic); (2) Maintenance of a permanent biomass soil mulch cover on the ground surface (implemented by retaining crop biomass, root stocks and stubbles and cover crops and other sources of ex situ biomass); and (3) Diversification of crop species (implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, including a balanced mix of legume and non-legume crops).

Global literatures are well stocked with positive impacts of CA adoption on soil quality improvement (Naab *et al*., 2017; Friedrich *et al.,* 2012; Wang *et al.,* 2010; Sombrero and de Benito, 2010; Thierfelder and Wall, 2009; Fernandez-Ugalde *et al.,* 2009; Rockstrom *et al.,* 2009). The soil quality improvements are around enhancement of soil organic carbon (SOC) content, water infiltration capacity, water holding capacity and microbial activities, and thereby arresting decline in total factor productivity of applied inputs (Dejene *et. al*., 2020) Moreover, it was reported to have contributed to protection of the top fertile soil from wind and water erosion (Dumanski *et al.,* 2006). Its contribution was indicated in build-up of effective nutrient recycling and enhancement of nutrient use efficiency by creating conducive rhizosphere for soil micro-flora and fauna (Sombrero and de Benito, 2010; Bessam and Mrabet, 2003). In addition to reducing the evaporation losses and non-point pollution of water bodies, CA contributed to reducing vulnerability against impacts of climate change on crop production and mitigation by reducing emissions and improving carbon sequestration in soils (Bessam and Mrabet, 2003; West and Post, 2002). Ogunsola *et al*., (2022) reported that in the northern Guinea savanna of Nigeria, CA improves soil physical quality such as total porosity, hydraulic conductivity, plant available water capacity and structural stability index which are within the optimal ranges that helps to maintain and improve soil resource base. However, ‘‘optimal’’ soil quality parameter values for maximum field-crop production with minimum environmental degradation under CA are still largely unknown in the northern Guinea savannah of Nigeria. Therefore, the objective of this paper is to determine soil quality indicator(s) mostly influenced by CA.

Materials and Methods

Experimental Site

The research was carried out at the Research Farm of the Institute for Agricultural Research (IAR) Samaru, Ahmadu Bello University, Zaria, Nigeria. The site is located on Latitude 11º 10’60.0’’North and Longitude 007º36’64.06’’East on an altitude of about 686 m above sea level. The area is situated in the Northern Guinea Savanna ecology with a mono-modal rainfall pattern and means annual rainfall of ±1039 mm concentrated entirely in six months (April/May to September/October) at the metrological station (IAR Metrological Station, 2013). Soil is classified as Typic Haplustalf by the USDA soil taxonomy (Valette and Ibanga, 1984). The history of the field for the past 10 years was fallow in 2003 and 2004; sole maize in 2005 to 2007; sole yam in 2008; yam/sweet potatoes in 2009 to 2011 and cowpea in 2012.

Treatments and Experimental Design

The treatments are Conservation Agriculture (CA) principles which include *Desmodium inortum*, *Macrotyloma* *uniflorum* and *Centrosema pubescens* as permanent cover crops, cowpea (SAMPEA 8), (SAMPEA 11) and groundnut (SAMNUT 24) represents the diversification of locally adapted crop rotations and were all planted on a no-till soil. Each of the cover crop was intercropped with maize (SAMMAZ 14) as the test crop, cowpea (SAMPEA 8) /groundnut (SAMNUT 24) as associated crop and (SAMPEA 11) as fodder cowpea, making a total of six treatment combinations; (*Desmodium inortum*- SAMMAZ 14 - SAMPEA 8- SAMPEA 11, *Desmodium inortum*- SAMMAZ 14 - SAMNUT 24 - SAMPEA 11, *Macrotyloma uniflorum* - SAMMAZ 14 - SAMPEA 8- SAMPEA 11, *Macrotyloma uniflorum* - SAMMAZ 14 - SAMNUT 24 - SAMPEA 11, *Centrosema pubescens* - SAMMAZ 14 - SAMPEA 8- SAMPEA 11, *Centrosema pubescens* - SAMMAZ 14 - SAMNUT 24 - SAMPEA 11. All treatments were replicated three times which gave a total of 18 treatment plots. The experiment was laid out in a randomised complete block design.

Land Preparation and Planting Activities

At two weeks prior to land preparation, the whole experimental field was sprayed with herbicide (Glyphosate), at the rate of 6 litres per hectare irrespective of the type of tillage operation adopted. Further, pedimenthalin, a pre-emergence herbicide was applied immediately after planting of cover crops, at the rate of 6 litre per hectare.

Land preparation and planting of cover crops was carried out with respect to the previously mentioned treatments. The experimental plots were marked out; each gross plot measured 5.0 m in length and width (5 x 5 m = 25 m^2), distance between each plot was 2 m along rows and 1 m along columns of each replication. It consisted of six ridges spaced 0.75 m apart, while the net plot (3 m by 1.5 m) consisted of four inner ridges.

In order to establish cover crops at the beginning of each season, weeds were slashed and controlled using the aforementioned chemicals namely: Glyphosate and Pedimenthalin. Cover crops were established immediately after the first rain to provide cover for the soil. They were planted by drilling in rows having shallow furrow of about 5 cm deep and spaced 0.75 m apart.

After four weeks, maize which is the test crop was intercropped on the rows sowing two seeds per hole at a depth of 5 cm, 0.75 m × 0.25 m inter and intra row spacing and later thinned to one plant per stand at two weeks after emergence. The plant population per hectare was 53,333.3 plants. After four weeks of planting maize, the associated crops (Cowpea/Groundnut) were intercropped on the row with maize followed by fodder cowpea four weeks after. Cowpea and groundnut were sown manually at the rate of two seeds per hole, along each row using an inter-row spacing of 0.2 m. It followed the order in the ratio 1:1:1:1 that is cover crop – maize - cowpea/groundnut - fodder cowpea at a distance of 5 cm each (Figure 1.).

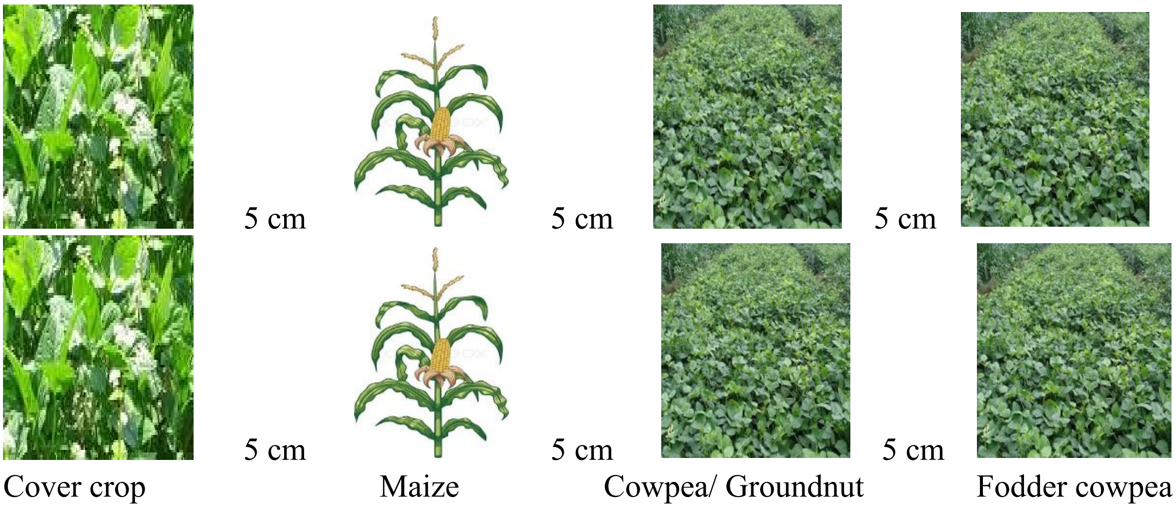


Figure 1: Field arrangements of cover crop-maize-cowpea/groundnut-fodder cowpea

Cultural Practices

Fertilizer application

Inorganic fertilizer was applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} to the maize crop, nitrogen was however applied in two equal split doses (at 2 and 6 weeks after sowing (WAS). One-third of the N and all of the P and K were applied using NPK (15:15:15) at 2 WAS while two-third of N was applied using urea at 6 WAS by top dressing.

Weeding

Weeding was done at 2 and 6 WAS, by hand pulling. Weeds cut were left on the soil surfaces Subsequent weeding was done by roughing.

Soil Sampling

Disturbed and undisturbed soil samples were obtained prior to the establishment of the various treatments. A simple random sampling technique was adopted. Disturbed soil samples were collected at two depths (0-15 cm and 15-30 cm). The collected samples were air-dried, crushed and sieved through 2 mm mesh size sieve to determine particle size distribution by standard hydrometer method (Gee and Or, 2002). More so, undisturbed soil samples were taken at two depths (0-5 cm and 5-15 cm) to determine bulk density by gravimetric method (Blake and Hartge, 1986), total porosity from the moisture characteristic curve as the moisture content at saturation (0 kPa), particle density from the standard pycnometer method as described by Blake and Hartge (1986) and soil penetration resistance by cone index method using a Farnell hatfield England (Farnell A2451) soil penetrometer. At harvest, undisturbed core soil samples were taken to determine soil bulk density, soil penetration resistance, total porosity, air capacity, macroporosity, relative field capacity, saturated hydraulic conductivity and soil water retention characteristics.

Measurement of Physical Properties

Particle size distribution and soil texture

The particle size analysis was determined by the standard hydrometer method (Gee and Or, 2002).

Soil Physical Quality Indicators

Air capacity

Air capacity of undisturbed field soil was determined from the moisture retention measurement by (White, 2006)

$$AC = \theta s - \theta FC \quad (i)$$

Where;

θs ($cm^3\ cm^{-3}$) = saturated volumetric water content

θFC ($cm^3\ cm^{-3}$) = volumetric water content corresponding to the field capacity at h=100 cm (Reynolds *et al*., 2002).

Plant available water capacity

The plant-available water capacity (PAWC) (cm^3 cm^{-3}) was determined from soil moisture retention data as:

$PAWC = \theta FC - \theta PWP$ (White, 2006) (ii)

□PWP (cm^3 cm^{-3}) is the volumetric water content corresponding to permanent wilting point (at h=-15,000 cm).

Macroporosity

The macroporosity (P_{mac}) (m^3 m^{-3}), is defined here by (Jarvis *et al*., 2002; Dexter and Cyz, 2007; Dexter *et al*., 2008 and Reynolds *et al*., 2008):

$Pmac = \theta s\ (\Psi = 0) - \theta m\ (\Psi = 0.1\ m): 0 \leq Pmac \leq \theta s$ (iii)

Relative field capacity

The relative field capacity (RFC) (dimensionless) was determined as

$RFC = \frac{\theta FC}{\theta s}$ (Reynolds *et al*., 2008) (iv)

Structural stability index

The formula of Pieri, (1992) proposed for measuring structural stability index (SI) was employed to determine SI as:

$SI = \frac{1.724 \text{ x OC}}{(Silt+Clay)} \times 100$ (v)

S-Value

The 'S-value' (''S_{gi}'') was estimated directly from raw release curve data according to van Genuchten (1980) and (Dexter, 2004).

Van Genuchten (1980) water release function, θ (h), can be written as

$\theta g = (\theta gs - \theta gr) [1 + (\alpha h)^n]^{-m} + \theta gr$: h≥ 0 (hpa or cm) (vi)

Where;

θg (kg kg^{-1}) = gravimetric water content

θgs (kg kg^{-1}) = saturated gravimetric water content,

θgr (kgkg^{-1}) = residual gravimetric moisture content,

θ (-) = normalized water content or degree of saturation

α (hpa^{-1}), (-) and m (-) are empirical curve fitting parameters

$Sgi = \frac{d\ (\theta gi)}{(\ln hi)} = [-n\ (\theta gs - \theta gr)\ [1 + 1/m]^{-(m+1)}]$ (vii)

Where;

Sgi = magnitude of the release curve slope at the inflection point

θgi = water content at the inflection point (kg kg^{-1})

hi = tension head at the inflection point (hpa or cm)

Bulk density

Undisturbed core samples were collected from the plots at 0 - 5 cm up to 20 cm depth at harvest for bulk density determination using the core method (Blake and Hartge, 1986).

Total porosity

Total porosity (*f*) was determined from the moisture characteristic curve as the moisture content at saturation (0 kPa).

Saturated hydraulic conductivity (Ks)

The saturated hydraulic conductivity was determined with undisturbed soil cores by the constant permeameter method (Klute and Dirksen, 1986) using the ICW laboratory permeameter (Eijikelkamp Agrisearch N0. 08.10.).

Infiltration measurements

Infiltration was measured *insitu* on the field, using double ring infiltrometer (Bouwer, 1986).

Soil strength

A Farnell hatfield England (Farnell A2451) soil penetrometer was used to measure the soil strength at 0 - 5 cm up to 20 cm depth at harvest. The soil moisture was also determined each time the soil strength was measured.

Soil Chemical Quality Indicators

Soil pH

Soil pH was measured at 1:2.5 soil to solution ratio with water and 0.01M calcium chloride ($CaCl_2$) using a glass electrode (IITA, 2010).

Organic carbon

Organic carbon was determined by dichromate oxidation method (Nelson and Sommers, 1982).

Total nitrogen

Total nitrogen was determined by micro kjeldahl digestion method as described by Bremner and Mulvaney (1982).

Available phosphorus (AP)

Available phosphorus was determined by Bray 1 method as described by Nelson and Sommers (1982).

Yield

Grain Yield (kg/ha)

Harvesting was carried out at 110 days after sowing maize when they have fully attained physiological maturity. Each net plot of 3 m by 1.5 m (4.5 m^2) was harvested, shelled, winnowed, weighed and the yield was expressed in kilogram per hectare basis.

Statistical Analysis

Data obtained were subjected to factor analysis using SAS (Statistical Analysis System) software version 9.3 (2011).

Results

Physical properties of soil used

Initial results of the physical properties of the soil used for the experiment are presented in Table 1. The results showed that, sand fraction of 71 % and 69 % at 0 - 15 cm and 15 - 30 cm depths respectively dominated the soil particle distribution, followed by silt having recorded 20 % and 20 % at 0 - 15 cm and 15 - 30 cm depths. Conversely clay separate was the least representing only 9 % and 11 % at the respective depths. Thus, the soil was classified as sandy loam. Soil bulk density was 1.58 Mg/m^3 at both depths Particle density was 2.34 Mg/m^3 and 2.41 Mg/m^3 at depths 0 - 5 cm and 5 - 15 cm respectively. Total porosity was 32 % and 35 % at respective depths. Soil strength recorded a value of 1.61 and 1.70 MPa at 0 - 15 cm and 15 - 30 cm respectively,

Table 1. Soil Physical Properties of the Study Area

	Depth (cm)	
Properties	**0-15**	**15-30**
Sand (%)	71	69
Silt (%)	20	20
Clay (%)	9	11
Textural Class	Sandy loam	Sandy loam
	0-5cm	**5-15cm**
Bulk density (Mg/m^3)	1.58	1.58
Particle density (Mg/m^3)	2.34	2.41
Total porosity (%)	32	35
Soil strength (MPa)	1.61	1.70

Soil physical, chemical quality indicators and yield mostly influenced by CA in 2013 and 2014

In 2013, correlation analysis of soil attributes representing soil physical, chemical quality indicators and grain yield resulted in significant correlation ($p < 0.05$) in 33 out of the 136 soil attribute pairs (Table 2). Highest positive correlation were obtained for Air capacity (AC) versus Macroporosity (Pmac) ($r > 0.60$) and highest negative correlation were obtained for relative field capacity (RFC) versus air capacity (AC) ($r > 0.70$).

Factor analysis (FA) was done using a correlation matrix on the standardized values of the measured soil physical, chemical quality indicators and grain yield with each variable having a zero mean and unit variance with total variance = number of variables. The first seven principal components (PCs), eigenvalues >1, accounted for 66% of variability in measured soil physical, chemical indicators and grain yield (Table 3). The principal components (PCs) with eigenvalue >1 were retained, since eigenvalue < 1 indicated that the factor could explain less variance than an individual attribute (Sharma, 1996).

A high communality estimate suggests that a high portion of variance was explained by the factor; therefore, it would get higher preference over a low communality estimate (Johnson and Wichern, 1992). Thus, PHOS was the least important attribute due to the lowest communality estimates. The magnitude of the eigenvalues was used as a criterion for interpreting the relationship between soil attributes and factors. Soil attributes were assigned to a factor for which their eigenvalues was the highest.

Factor 1 explained 16% of variance (Table 3) with a high positive loading (> 0.80) from AC, (> 0.60) from Pmac, T.P. It also had negative loading (-0.58) from RFC (Table 4). This result from the significant correlations among RFC, AC and Pmac (Table 2). Factor 2 explained 13% of variance (Table 3). It had highest positive loading of 0.72 from pH ($CaCl_2$), (0.61) from GY, moderate positive loading from SI (0.51). It also had highest negative loading from NIT (-0.70) Table 4. Factor 3 explained 12% of variance (Table 3) with high positive loading from PAWC (0.64), moderate positive loading from PHOS (0.53), RFC (0.49) and T.P (0.45) Table 4. Factor 4 explained 9% of variance (Table 3) with high positive loading (0.54) from Sgi, moderate positive loading (0.45) from IR. In addition, it had highest negative loading from pH water (-0.73) (Table 4). Factor 5 had highest positive loading from PR (0.63) and a moderate negative loading from PAWC (-0.55) Table 4. 9% of variance was explained by factor 5 (Table 3). Factor 6 explained 8% of variance (Table 3) with high negative loading from OC (-0.73), and a moderate positive loading from Ks (0.47) (Table 4). For factor 7, It explained 8% variance (Table 3) with a moderate positive laoding of (0.56) from BD (Table 4).

In 2014 cropping season, soil attributes representing soil physical, chemical quality indicators and grain yield resulted in significant correlation ($p < 0.05$) in 60 out of the 136 soil attribute pairs (Table 5). Highest positive correlation were obtained for structural index (SI) versus organic carbon (OC) ($r > 0.90$) and highest negative correlation were obtained for Relative field capacity (RFC) versus Air capacity (AC) ($r > 0.90$).

Six factor scores explained > 90% of variance in AC > 80% in RFC, BD, SI, Sgi, Ks, IR, OC, NIT, PAWC, PR, > 70% in Pmac, pH (water), pH ($CaCl_2$) and TP; > 60% in PHOS; > 50 % in GY (Table 6). Thus, GY was the least important attribute due to the lowest communality estimates (Table 6). Factor 1 explained 39% of variance (Table 6) with a high positive loading (0.90) from AC, (> 0.80) from SI, PAWC, and OC, (> 0.70) from TP and PHOS, (> 0.60) from Pmac. It had high negative loading from BD, PR, and RFC (> 0.75) Table 7. Factor 2 explained 13% of variance (Table 6) with high positive loading from NIT and pH (water) (> 0.70). It also had high negative loading from GY (-0.65) (Table 7). Factor 3 explained 9% of variance (Table 6) with high positive loading from pH ($CaCl_2$) (> 0.60) and a moderate negative loading from IR (-0.48) (Table 7). Factor 4 explained 7% of variance (Table 6) with high positive loading from Sgi (> 0.60) and a moderate loading from Ks and IR (> 0.50) (Table 7). Factor 5 explained 7% of variance (Table 6) with a moderate positive loading from Sgi (> 0.60) and moderate loadings from IR (>0.50) (Table 7). Factor 6 explained 6% of variance (Table 6) with a high positive loading from Ks (> 0.80) (Table 7).

Table 2. Correlation Matrix for soil physical, chemical quality indicators and yield in 2013.

	RFC	AC	Pmac	BD	SI	Sgi	Ks	IR	GY	OC	PHOS	NIT	pHwater	pHCaCl2	PAWC	TP	PR
RFC	1																
AC	-0.74****	1															
Pmac	-0.37**	0.60***	1														
BD	0.09NS	-0.04NS	-0.05NS	1													
SI	-0.11NS	0.15NS	0.17NS	-0.07NS	1												
Sgi	0.11NS	-0.03NS	0.20*	-0.08NS	0.06NS	1											
Ks	0.16NS	-0.01NS	-0.12NS	-0.01NS	-0.03NS	-0.01NS	1										
IR	0.07NS	0.18NS	0.16NS	-0.11NS	0.18NS	0.14NS	0.04NS	1									
GY	0.02NS	-0.20*	0.05NS	-0.06NS	0.04NS	0.27*	-0.18NS	-0.02NS	1								
OC	0.06NS	-0.08NS	-0.03NS	-0.04NS	0.24*	-0.09NS	-0.21*	-0.08NS	-0.14NS	1							

PHOS	0.21*	-0.06^{NS}	-0.15^{NS}	-0.20*	0.17^{NS}	0.10^{NS}	0.15^{NS}	0.14^{NS}	-0.02^{NS}	0.01^{NS}	1						
NIT	0.10^{NS}	-0.01^{NS}	0.05^{NS}	-0.27*	-0.41***	-0.29*	-0.02^{NS}	-0.001^{NS}	-0.34**	0.10^{NS}	-0.19^{NS}	1					
pHwater	-0.04^{NS}	0.12^{NS}	-0.09^{NS}	0.09^{NS}	0.13^{NS}	-0.15^{NS}	0.31**	-0.12^{NS}	0.06^{NS}	0.02^{NS}	0.06^{NS}	-0.16^{NS}	1				
pHCaCl$_2$	-0.02^{NS}	-0.11^{NS}	-0.01^{NS}	-0.14^{NS}	0.18^{NS}	0.12^{NS}	-0.13^{NS}	0.23*	0.39**	0.02^{NS}	0.22*	-0.33**	0.46***	1			
PAWC	0.17^{NS}	0.06^{NS}	-0.28*	-0.24*	-0.02^{NS}	0.12^{NS}	0.06^{NS}	-0.02^{NS}	-0.23*	0.15^{NS}	0.05^{NS}	0.16^{NS}	0.21*	0.03^{NS}	1		
TP	0.01^{NS}	0.56***	0.40***	0.09^{NS}	0.09^{NS}	0.22*	0.06^{NS}	0.26*	-0.30**	0.05^{NS}	0.16^{NS}	0.05^{NS}	0.15^{NS}	-0.19^{NS}	0.37**	1	
PR	-0.09^{NS}	0.17^{NS}	0.07^{NS}	0.03^{NS}	0.07^{NS}	-0.15^{NS}	0.14^{NS}	0.35**	-0.36**	0.19^{NS}	0.004^{NS}	-0.03^{NS}	-0.10^{NS}	-0.21*	-0.13^{NS}	0.19^{NS}	1

* = Significant at 0.05 level of probability, ** = Significant at 0.01 level of probability, ***=Significant at 0.001 level of probability, ****=Significant at 0.0001 level of probability, RFC = relative field capacity, PAWC = plant available water capacity (m^3m^{-3}), AC = air capacity (m^3m^{-3}), Pmac = macroporosity (m^3m^{-3}), BD = dry bulk density (Mg/m^3), SI = structural stability index (%), Sgi = (S-index) inflection point slope of gravimetric soil water release curv (-), Ks= Saturated hydraulic conductivity (cm/hr), IR = Infiltration rate (mm/hr), GY= Grain yield (kg/ha), OC = Organic carbon (g kg^{-1}), PHOS = Available phosphorus (mg kg^{-1}), NIT = Total nitrogen (g kg^{-1}), PH(Water), PH($CaCl_2$), TP = Total soil porosity (%), PR = Soil penetration resistance (MPa).

Table 3. Eigenvalue, Proportion and Cumulative Varaiance explained by Factor Analysis using Correlation Matrix (standardized data) at harvest in 2013

Factors	Eigenvalue	Difference	Proportion	Cumulative
1	2.66	0.37	0.16	0.16
2	2.29	0.33	0.13	0.29
3	1.96	0.44	0.12	0.41
4	1.52	0.04	0.09	0.49
5	1.48	0.09	0.09	0.58
6	1.38	0.17	0.08	0.66
7	1.21	0.17	0.08	0.66

7 factors were retained by the Mineigen criterion

Table 4 Proportion of Variance using Varimax Rotation and Communality Estimates for Soil Attributes or each of the Retained Factors at harvest in 2013.

Attributes	Factor1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality estimate
RFC	-0.58	-0.19	0.49	0.31	0.15	0.17	0.20	0.80
AC	0.90	0.15	-0.11	-0.19	-0.21	0.06	-0.08	0.94
Pmac	0.69	0.24	-0.33	0.19	-0.11	0.06	0.05	0.70
BD	-0.03	-0.05	-0.19	-0.35	0.42	0.38	0.56	0.79
SI	0.22	0.51	0.19	-0.06	0.29	-0.35	0.16	0.59
Sgi	0.01	0.43	0.10	0.54	-0.18	0.36	0.29	0.74
Ks	-0.01	-0.06	0.44	-0.29	0.21	0.47	-0.35	0.67
IR	0.32	0.23	0.28	0.45	0.29	-0.02	-0.31	0.62
GY	-0.39	0.61	-0.35	0.16	-0.15	0.06	-0.02	0.70
OC	0.06	-0.12	0.19	-0.01	0.07	-0.73	0.44	0.79
PHOS	0.08	0.29	0.53	0.17	0.13	-0.02	-0.19	0.46
NIT	0.08	-0.70	0.02	0.16	-0.38	-0.14	-0.26	0.76
PHwater	0.02	0.34	0.37	-0.73	-0.18	0.03	-0.04	0.82
$PHCaCl_2$	-0.24	0.72	0.14	-0.12	-0.14	-0.26	-0.19	0.73
PAWC	0.03	-0.14	0.64	-0.03	-0.55	-0.06	0.20	0.78
TP	0.68	0.008	0.45	0.09	-0.16	0.26	0.32	0.87
PR	0.43	-0.22	0.17	0.05	0.63	-0.16	-0.14	0.71

RFC = relative field capacity, PAWC = plant available water capacity (m^3m^{-3}), AC = air capacity (m^3m^{-3}), Pmac = macroporosity (m^3m^{-3}), BD = dry bulk density (Mg/m^3), SI = structural stability index (%), Sgi = (S-index) inflection point slope of gravimetric soil water release curv (-), Ks= Saturated hydraulic conductivity (cm/hr), IR = Infiltration rate (mm/hr), GY= Grain yield (kg/ha), OC = Organic carbon (g kg^{-1}), PHOS = Available phosphorus (mg kg^{-1}), NIT = Total nitrogen (g kg^{-1}), PH(Water), PH($CaCl_2$), TP = Total soil porosity (%), PR = Soil penetration resistance (MPa).

Table 5. Correlation Matrix for soil physical, chemical quality indicators and yield in 2014.

	RFC	AC	Pmac	BD	SI	Sgi	Ks	IR	GY	OC	PHOS	NIT	PHwater	PHCaCl$_2$	PAWC	TP PR	PR
RFC	1																
AC	-0.93****	1															
Pmac	-0.59***	0.69***	1														
BD	0.66***	-0.76****	-0.54***	1													
SI	-0.43***	0.57***	0.42***	-0.69***	1												
Sgi	-0.03^{NS}	0.08^{NS}	0.08^{NS}	-0.19^{NS}	0.07^{NS}	1											
Ks	-0.05^{NS}	0.02^{NS}	0.04^{NS}	0.18^{NS}	-0.08^{NS}	-0.11^{NS}	1										
IR	-0.07^{NS}	0.06^{NS}	-0.22*	-0.13^{NS}	0.07^{NS}	-0.01^{NS}	0.02^{NS}	1									
GY	0.05^{NS}	0.02^{NS}	0.18NS	-0.05^{NS}	-0.20*	-0.09^{NS}	-0.08^{NS}	-0.11^{NS}	1								
OC	-0.45***	0.58***	0.48***	-0.69***	0.97****	0.11^{NS}	-0.02^{NS}	0.02^{NS}	-0.22*	1							
PHOS	-0.55***	0.54***	0.38**	-0.67***	0.58***	0.15^{NS}	0.03^{NS}	0.09^{NS}	-0.22*	0.64***	1						
NIT	-0.01^{NS}	0.06^{NS}	0.05^{NS}	-0.24*	0.30*	0.19^{NS}	-0.01^{NS}	-0.20*	-0.35**	0.33**	0.42***	1					
PHwater	0.09^{NS}	-0.10^{NS}	-0.15^{NS}	0.06^{NS}	0.18^{NS}	-0.11^{NS}	0.07^{NS}	-0.04^{NS}	-0.31**	0.18^{NS}	0.12^{NS}	0.51***	1				
PHCaCl$_2$	-0.10^{NS}	0.02^{NS}	-0.09^{NS}	0.11^{NS}	-0.14^{NS}	-0.05^{NS}	-0.02^{NS}	-0.07^{NS}	0.05^{NS}	0.13^{NS}	0.10^{NS}	0.15^{NS}	0.09^{NS}	1			
PAWC	-0.83****	0.85****	0.55***	-0.63***	0.57***	-0.09^{NS}	-0.03^{NS}	-0.09^{NS}	-0.19^{NS}	0.58***	0.55***	0.32**	0.15^{NS}	0.02^{NS}	1		
TP	-0.65***	0.79****	0.58***	-0.51***	0.55***	-0.02^{NS}	-0.09^{NS}	0.06^{NS}	0.07^{NS}	0.56***	0.43***	0.07^{NS}	0.14^{NS}	-0.01^{NS}	0.49***	1	
PR	0.52***	-0.65***	-0.53***	0.72****	-0.72****	0.08^{NS}	0.21*	-0.08^{NS}	0.12^{NS}	-0.73****	-0.54***	-0.04^{NS}	0.08^{NS}	0.27*	-0.22*	-0.56***	1

* = Significant at 0.05 level of probability, ** = Significant at 0.01 level of probability, ***=Significant at 0.001 level of probability, ****=Significant at 0.0001 level of probability, RFC = relative field capacity, PAWC = plant available water capacity (m^3m^{-3}), AC = air capacity (m^3m^{-3}), Pmac = macroporosity (m^3m^{-3}), BD = dry bulk density (Mg/m^3), SI = structural stability index (%), Sgi = (S-index) inflection point slope of gravimetric soil water release curv (-), Ks= Saturated hydraulic conductivity (cm/hr), IR = Infiltration rate (mm/hr), GY= Grain yield (kg/ha), OC = Organic carbon (g kg^{-1}), PHOS = Available phosphorus (mg kg^{-1}), NIT = Total nitrogen (g kg^{-1}), PH(Water), PH($CaCl_2$), TP = Total soil porosity (%), PR = Soil penetration resistance (MPa).

Table 6. Eigenvalue, proportion and cumulative variance explained by factor analysis using correlation matrix (standardized data) in 2014.

Factors	Eigenvalue	Difference	Proportion	Cumulative
1	6.64	4.52	0.39	0.39
2	2.13	0.69	0.13	0.52
3	1.45	0.18	0.09	0.60
4	1.27	0.15	0.07	0.68
5	1.12	0.09	0.07	0.74
6	1.02	0.21	0.06	0.80

6 factors were retained by the Mineigen criterion.

Table 7. Proportion of variance using varimax rotation and communality estimates for soil attributes or each of the retained factors in 2014

Attribute	Factor1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communality Estimate
RFC	-0.79	0.25	-0.25	-0.12	-0.29	-0.09	0.85
AC	0.89	-0.27	0.15	0.10	0.16	0.07	0.93
Pmac	0.68	-0.34	-0.11	0.33	-0.17	0.24	0.78
BD	-0.86	0.07	0.19	-0.02	-0.09	0.13	0.81
SI	0.83	0.25	-0.18	-0.18	-0.17	-0.01	0.84
Sgi	0.09	0.11	-0.57	0.36	0.41	0.01	0.64
Ks	-0.08	0.11	0.36	-0.12	0.27	0.82	0.92
IR	0.06	-0.03	-0.01	-0.66	0.58	-0.29	0.86
GY	-0.09	-0.65	0.17	0.26	-0.22	-0.16	0.60
OC	0.85	0.26	-0.18	-0.12	-0.14	0.06	0.86
PHOS	0.75	0.28	-0.01	0.09	0.25	-0.003	0.71
NIT	0.25	0.77	-0.09	0.37	-0.05	0.001	0.80
PHwater	0.07	0.74	0.37	-0.06	-0.22	-0.09	0.76
PHCaCl_2	-0.07	0.14	0.42	0.53	0.36	-0.34	0.73
PAWC	0.42	0.03	0.69	-0.13	-0.10	-0.13	0.71
TP	0.78	-0.15	0.28	0.02	-0.09	-0.09	0.72
PR	-0.81	0.13	0.20	0.28	0.21	0.05	0.84

RFC = relative field capacity, PAWC = plant available water capacity (m^3m^{-3}), AC = air capacity (m^3m^{-3}), Pmac = macroporosity (m^3m^{-3}), BD = dry bulk density (Mg/m^3), SI = structural stability index (%), Sgi = (S-Index) inflection point slope of gravimetric soil water release curve (-), Ks = Saturated hydraulic conductivity (cm/hr), IR = Infiltration rate (mm/hr), GY= Grain yield (kg/ha), OC = Organic carbon (g kg^{-1}), PHOS= Available phosphorus (mg kg^{-1}), NIT = Total nitrogen (g kg^{-1}), PH(Water), PH($CaCl_2$), TP = Total soil porosity (%), PR = Soil penetration resistance (MPa).

Discussions

Soil Physical and Chemiical Properties of the Study Area in 2013.

Results obtained from the analysis of soil at the experimental site showed that the soil textural class was a sandy loam, bulk density was between the range that is ideal for plant growth (< 1.40 Mg/m^3) and (1.63

Mg/m^3) that affect plant growth as reported by Arshad *et al*. (1996). Particle density was low not close to the range (2.65 Mg/m^3) reported by Marshall and Holmes, (1979), total porosity of 32 % and 35 % at respective depths, are below the 10 % critical limits (Baver *et al.,* 1976) necessary for enhanced root growth. Soil strength values fall below the range that cannot limit plant growth Munkholm *et al*. (2008).

Soil pH (H_2O) was moderately acidic and pH ($CaCl_2$) was strongly acidic, organic carbon, total nitrogen and available phosphorus values were very low (Chude *et al.,* 2011). This confirms the views odunze *et al.,* (2002) that soils of the northern Guinea savanna of Nigeria are low in fertility status.

Soil Physical, Chemical Quality Indicators and Yield mostly influence by Conservation Agriculture at harvest.

During 2013 cropping season, factor one was named soil aeration as most of the attributes were important component or functions of soil air capacity, factor two was termed 'yield determinant; as all the four attributes were functions of crop yield, factor three was called 'moisture status' as the attributes were functions of soil pores.

We named factor four 'soil structure pores' because it explains the shape of soil water release curve at tension heads between saturation and inflection point and are important component of inter-aggregate, micro cracks and fracture. Reynold *et al*. (2009) revealed essential premise of S-Index value (Sgi) that soil physical or structural quality is determined primarily by management induced structure pores rather than texture-induced matrix pores. Factor five was termed 'soil strength' because it addressed soil resistance to root penetration, factor six was called 'Soil aggregation' because organic carbon content influences soil structural formation and affects both pore volume and water. We named the factor seven 'Pore volume' because soil bulk density is an obvious function of pore volume.

Further in 2014, factor 1 was called soil water release characteristics because it explains variations in pore characteristics. This agrees with what Reynolds *et al.* (2008) reported; that air capacity (AC), relative field capacity (RFC) depends on soil porosity and soil water characteristics. Structural Index (SI) relates indirectly to pore space function through organic carbon and texture. Soil bulk density (BD) and macroporosity (Pmac) are obvious function of pore volume and organic carbon content. Factor two was named 'yield determinant' because the attributes are factors that can influence yield. We called factor three 'water transmission' because it explained transmission properties of the soil. We named factor four 'structure pores'. We called factor five 'water transmission and factor six 'soil pore connection'. This explains function of steady water flow through the soil profile.

In conclusion, air capacity (AC) was the most dominant in both years measured attributes which constitutes factors that influence structural pores and water transmission properties of soil.

References

Arshad, M. A., Lowery, B and Grossman, B. (1996). Physical Test for Monitoring Soil Quality. In: Doran, J. W and Jones, A. J., Editors. Methods for Assesing Soil Quality WI. PP. 123-141.Retrieved on October 23, 2011, from

http://soilquality.org/indicators/bulkdensity.html

Baver, L. D., H. W. Gardener, and Gardner, W. R. (1976). Soil physics. 4th edition. Wiley Eastern Ltd. New Delhi, India, p.498.

Bessam F, and Mrabet R. (2003). Long-term changes in soil organic matter under conventional tillage and no-tillage systems in semiarid Morocco. Soil Use and Management, 19:139─143

Blake, C.R. and Hartge, K. H. (1986). Bulk Density Methods of Soil Analysis, part 1, Physical and Mineral Method (Ed. A Klute). Pp 363-382.

Bouwer, H. (1986). Intake rate: cylinder infiltrometer. In: Klute, A. (Ed). Methods of soil Analysis, part 1 physical, and Mineralogical properties, monograph 9. ASA, Madison, WI, pp. 363-376.

Bremner, J. M., and Mulvaney, C. S. (1982). Nitrogen - Total. *In* A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of soil analysis. Part 2. Chemical and microbiological properties.2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI. p. 595-624.

Chude, V.O., Olayiwola, S.O., Osho, A.O. and C.K. Daudu (2011). Fertilizer Use and Management Practices for Crops in Nigeria. Fourth edition. Federal Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria, pp. 1-59.

Dejene, A. Bedru, B. and Feyera, M. L. (2020). The Role of Conservation Agriculture for Soil Quality Improvement: A Review. Ethiop. J. Agric. Sci. 30(4) 197-222 (2020).

Dexter, A. R. Czyz, E. A., Richard, G. and Reszkowska, A. (2008). A user friendly water retention function that takes account of textural and structural pores in soil. *Geoderma,* **143**: 243-253.

Dexter, A. R. and Czyż, E. A. (2007). Applications of S-theory in the Study of Soil Physical Degradation and its Consequences. *Land Degradation and Development,* **18**: 369- 381.

Dexter, A. R. (2004). Soil Physical Quality: Part II. Friability, tillage, Tilth and Hard-setting. *Geoderma,* **120**: 215-225.

Dumanski J, Peiretti R, Benites JR, McGarry D, and Pieri, C. (2006). The Paradigm of Conservation Agriculture. In: Proceedings of World Association of Soil and Water Conservation Paper. pp 58─64

FAO, (2014) What is conservation agriculture? FAO CA website (http://www.fao.org/ag/ ca/1a.html) (accessed 15 May 2018).

Fernandez-Ugalde O, Virto I, Bescansa P, Imaz MJ, Enrique A, Karlen DL. (2009). No- tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils. Soil & Tillage Research, 106: 29–35.

Friedrich T, Derpsch R, and Kassam A. (2012). Overview of the Global Spread of Conservation Agriculture, Field Actions Science Reports, Special Issue 6 2012. URL: http://factsreports.revues.org/1941. Accessed on 14, December 2013.

Gee, G.W., and Or, D. (2002). Particle-size analysis. In: J.H. Dane, and C.G. Topp, editors, Methods of soil analysis. Part 4. Physical methods. SSSA Book Ser. 5.4. SSSA, Madison, WI. p. 255– 293.

IAR Metrological station (2013). Annual Rainfall in the Northern Guinea Savanna

IITA-International Institute of Tropical Agriculture.(2010). Automated and semi-automated Analysis.Manual series No. 12 IITA. Ibadan, Nigeria. Pp 72.

Jarvis, N.J., Zavattaro, L., Rajkai, K., Rey nolds, W.D., Olsen, P.A., and McGechan, M. (2002). Indirect estimation of near-saturated hydraulic conductivity from readily available soil information. *Geoderma* **108**: 1–17.

Johnson, R. A. and Wichern, D. W. (1992). Applied multivariate statistical analysis. Prentice-Hall, Englewood Cliffs, NJ.

Klute, A. and Dirksen, C. (1986). Hydraulic conductivity and diffusivity. In: Method of soil Analysis Part 1. Physical and Minerological Methods, Klute, A (Eds). ASA and SSSA, Madison, WI, pp.687-734.

Larson, W.E., and Pierce, F.J. (1994). The dynamics of soil quality as a measure of sustainable management. In Doran et al. (eds.) Defining Soil Quality for a Sustainable Environment, pp. 37-52. SSSA Special Publication 35:37-52.

Marshall, T. J and Holmes, J.W. (1979). Composition of soil. In soil physics, Cambridge University press: Cambridge. pp 10.

Munkholm, L. J., Hansen, E. M. and Olesen, J. E. (2008). The effect of tillage intensity on soil structure and winter wheat root/shoot growth. *Soil Use Manage*ment, **24**: 392–400.

Naab, J.B., Mahama, G.Y., Yahaya, I., and Prasad, P.V.V. (2017). Conservation Agriculture Improves Soil Quality, Crop Yield, and Incomes of Smallholder Farmers in North Western Ghana. Frontiers in Plant Science. 8: 996. doi: 10.3389/fpls.2017.00996

Nelson, D. W. and Sommers, L. E. (1982). Total carbon, organic carbon, and organic matter. In A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd ed. *Agronomy,* **9**: 539-579.

Odunze, A.C., Iwuafor, E.N., and Chude, V.O. (2002). Maize/Harbaceous legume inter crop Properties in the Northern Guinea Savanna Zone , Nigeria Journal of Sustainable Agriculture. 20:1, 15-25.

Pankhurst, C.E., Doube, B.M., and Gupta, V.V.S.R (1997). Biological indicators of soil health: Synthesis. In C.E. Pankhurst, B.M. Doube, and V.V.S.R. Gupta (eds.) Biological Indicators of Soil Health.

Pieri, C. J. M. G. (1992). Fertility of Soils: A future of Farming in the West African Savannah. Springer-Verlag, Berlin, Germany.

Prodipto, B. A., Nafisa, A., Mst, M.A., Shreejana, K.C., Rucksana, P. S., and Sadia, J. (2023). An Overview of the Impact of Tillage and Cropping Systems on Soil Health in Agricultural Practices. Hindawi. Advances in Agriculture Volume 2023, Article ID 8861216, 14 pageshttps://doi.org/10.1155/2023/8861216.

Reynolds, W. D., Drury, C. F, Tan, C. S, Fox, C. A and Yang, X.M. (2008). Optimal soil physical quality inferred through structural regression and parameter interactions. *Geoderma*, **116**: 466-474.

Reynolds, W. D., Drury, C. F, Tan, C. S, Fox, C. A and Yang, X. M. (2007). Land management effects on the near-surface physical quality of a clay loam soil. *Soil and Tillage Research*, **96**: 316-330.

Reynolds, W, D., Bowman, B. T., Drury. C. F., Tan, C. S., Lu, X. (2002). Indicators of good soil physical quality: density and storage parameters. *Geoderma,* **110**:131- 146.

Rockstrom J, Kaumbutho P, Mwalley J, Nzabi AW, Melesse Temesgen, Mawenya L, Barron J, Mutua J, and Damgaard-Larsen S. (2009). Conservation farming strategies in East and Southern Africa: yields and rainwater productivity from on-farm action research. Soil and Tillage Research, 103:23–32.

Sharma, S. (1996). Applied Multivariate Techniques. JohnWiley and Sons, New York.

Sombrero, A, and de Benito A. (2010). Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. *Soil and Tillage Research.* 107:64–70.

Thierfelder, C., and Wall, P.C. (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research, doi:10.1016/j.still.2009.07.007.

Valette, J. and Ibanga, I. J. (1984). Detailed Soil Survey Report of Institute for Agricultural Research Farm, Samaru. Page 1-64.

USDA Natural Resources Conservation Service, (2014). Soil Quality Indicators. Chemical indicators and soil function. Pp. 1-3.

Wang, Y, Xu J, Shen J, Luo Y, Scheu S, and Ke X. (2010). Tillage, residue burning and crop rotation alter soil fungal community and water-stable aggregation in arable fields. Soil and Tillage Research, 107:71–79.

West, T.O, and Post, W.M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation. Soil Sci. Soc. Am. J., 66:1930–1946.

White, R.E. (2006). Principles and Practice of Soil Science. 4th edition. Blackwell

IMPACT OF FARMYARD MANURE AND MINERAL FERTILIZERS ON SOIL AGGREGATE STABILITY

Girei A. H.[1*], Nabayi, A[1]., Abubakar, F.J.[2], Abdullahi, M.Y[3], Alasinrin S. Y.[4], Abdulkadir, A.[2]

[1]*Department of Soil Science, Faculty of Agriculture, Federal University, Dutse, Nigeria.*
[2]*Department of Soil Science, Institute for Agricultural Research Samaru, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria.*
[3]*Department of Soil Science, Faculty of Agriculture, Federal University, Dutsinma, Nigeria.*
[4]*Department of Agronomy, Faculty of Agriculture, University of Ilorin.*
gireihalilu@yahoo.com

ABSTRACT

Soil physical quality indicators are greatly influenced by land use and soil management practices, which in turn influence its structural composition and water transmission properties. Ten plots of DNPKdefine DNPK trial field of Samaru were analyzed to assess the effects of farmyard manure (D) and mineral fertilizers (N, P, K) on soil aggregate stability at two depths (0-15 cm and 15-30 cm) after a long period of cultivation and fallow. The plots were subjected to different fertilization regimes since 1950.   These fertilization regimes include inorganic fertilizers such as Nitrogen (N) state fertilizer carrier, Phosphorus (P) state carrier, Potassium (K) state carrier in combination with organic fertilizer Dung define the dung (D) that is (D+NPK), (D+N), (D+P), (D+K), NPK only and a control receiving neither NPK nor D. Sand fractions were found to be more dominating than any other fraction. On the surface soil, plots treated with N (1.29%) indicate the source of N, DNPK (1.24%) and DP (1.23%) were found to contain higher values of total soil organic carbon than the rest. Wet mean weight diameter (MWDW) and dry mean weight diameter (MWDD) were measured to evaluate soil stability. In the wet state, the DNPK treatment exhibited the highest aggregate stability, with MWDW values ranging from 45.98 to 90.93 mm across soil fractions (<0.05 mm to 0.5 mm). Conversely, in the dry state, the DNPK treatment also showed superior stability in larger aggregates, with MWDD values ranging from 17.65 to 66.45 mm. Overall, the application of farmyard manure and mineral fertilizers significantly influenced soil aggregate stability, indicating the potential for enhanced soil structure and resilience to environmental stressors. These findings underscore the importance of integrated soil management practices for sustainable agricultural systems.

Key Word: *Mean weight Diameter, Farmyard manure, NPK, Aggregate Stability*

Introduction

The stability of soil aggregates is an important factor in determining the overall health of soil and its capacity to sustain agricultural output. Soil aggregates refer to an assemblage of soil particles that exhibit stronger connections with each other than with neighboring particles (Tisdall and Oades, 1982). These aggregates play an important role in regulating water infiltration, root growth, resistance to erosion, and microbial processes (Six *et al.,* 2004). Application of farmyard manure (FYM) and mineral fertilizers are widely acknowledged as typical methods to enhance soil fertility and crop production (Whalen and Chang, 2002). Nevertheless, their effects on soil structure, specifically soil aggregate stability, may differ considerably. Recognizing these effects is crucial for devising successful soil management approaches that foster long-term soil health and agricultural sustainability.

Farm animal dung combined with straw or bedding material forms farmyard manure as a form of organic amendment. This type of manure contains a high amount of organic matter, which is vital for enhancing soil structure (Haynes and Naidu, 1998). The organic matter in farmyard manure aids in developing stable aggregates, thereby improving the soil's physical properties (Celik*et al.,*2004). It also enhances microbial activity and the production of substances like polysaccharides that bind soil particles together, ultimately increasing aggregate stability (Rillig *et al.,*2002). Furthermore, farmyard manure enhances soil moisture retention and aeration, creating favorable conditions for root growth and nutrient uptake (Manna *et al.,*2007).

Inorganic compounds known as mineral fertilizers facilitate the supply of essential nutrients such as nitrogen, phosphorus, and potassium directly to the soil (Sutton *et al.,* 1986). Despite their ability to significantly increase crop productivity, the long-term effects of mineral fertilizers on soil structure are intricate (Bastida *et al.,* 2008). Overuse of mineral fertilizers can result in soil acidification, reduction in organic matter, and disturbance of soil microbial communities (Zhao *et al.,* 2010). These alterations may have adverse effects on soil aggregate stability, rendering the soil more susceptible to erosion and compaction (Zhang *et al.,* 2014).

The interaction between farmyard manure (FYM) and mineral fertilizers in influencing the stability of soil aggregates is a topic of great interest in the field of soil science. When used together, these inputs have the potential to provide combined advantages (Bhattacharyya *et al.,*2008). For example, the organic content from FYM can alleviate some of the adverse impacts of mineral fertilizers, such as soil acidification and reduction of organic material (Lal, 2006). Additionally, the nutrients provided by mineral fertilizers can supplement the gradual nutrient release from FYM, resulting in balanced and consistent soil fertility (Bationo *et al.,*2012).

Evaluating the impact of FYM and mineral fertilizers on soil aggregate stability requires a comprehensive understanding of various factors, including soil type, climatic conditions, cropping systems, and management practices (Bronick and Lal, 2005). Studies have shown that the beneficial effects of FYM on soil structure are more pronounced in soils with low organic matter content (Kay, 1998). In contrast, the impact of mineral fertilizers can vary depending on their composition, application rate, and frequency (Geisseler and Scow, 2014).

Therefore, integrating both inputs in a balanced manner, tailored to specific soil and crop needs, can lead to improved soil health and sustainable agricultural practices. This research is therefore carried out to evaluate the long-term impacts of combined application of farm yard manure and mineral fertilizer on soil aggregate stability and overall soil health (Schjønning *et al.,*2004).

Materials and Methods

Location

The experiment was carried out on the long-term dung (D) and mineral fertilizer (NPK) trial field (i.e. DNPK) of the institute for Agricultural Research, Samaru (11^0 16’ N, 07° 64’ E. 686m altitude) in the Northern Guinea Savanna ecology of Nigeria. The soils are leached tropical Ferruginous classified as Typic Halplustalf according to USDA soil taxonomy (Jones and Wilds,1975). The long-term DNPK trial field at Samaru is about the oldest manure and fertilizer experimental site in West Africa. The field plots consist of 81 treatment combinations randomly arranged in nine plots of 220 m^2 sizes. Each plot has been fertilized with FYM, N, P, and K or their combinations.

In the selected plots for this study (Table 1), dung was applied at the rate of 2500-5000 kg/ha, nitrogen 67.5-135.0 kg/ha, phosphorus 13.5-27.0 kg/ha and potassium 29-58 kg/ha. The trial had been under natural fallow since 2009. Urea, single super phosphate and muriate of potash were source of N, P, and K respectively where applicable (Lawal and Girei, 2011).

Soil Sample Collection, Preparation and Analysis

selected plots. Each plot was divided into three equal-sized sub-plots, and disturbed soil samples were taken in triplicates from each sub-plot. These samples were then combined to create

S/N	Treatment combination	Acronym	Rates (kg ha^{-1} yr^{-1})
1	Dung + Nitrogen +Phosphorus + Potassium	DNPK	Dung = 5000; N = 48-135; P = 18-54; K = 29-58
2	Dung +Nitrogen	DN	D = 5000; N = 48-135
3	Dung + Phosphorus	DP	D = 5000; P = 18-54
4	Dung + Potassium	DK	D = 5000; K = 29-58
5	Nitrogen + Phosphorus + Potassium	NPK	N = 48-135; P = 18-54; K = 29-58
6	Nitrogen	N	N = 48-135
7	Phosphorus	P	P = 18-54
8	Potassium	K	K = 29-58
9	Dung	D	D = 5000
10	Control	CT	NIL

Surface soil samples were collected at depths of 0-15 cm and 15-30 cm from ten three composite replicate samples per soil depth and plot. Additionally, undisturbed soil samples were collected from the same ten plots (as detailed in Table 1). All samples were appropriately labelled for easy identification, and a brief description of the fertilizer history for each study plot is provided in

Table 1.
Table 1. Fertilizer combination histories of the selected study plots

The collected soil samples were air-dried and divided into two portions. One portion was passed through a 5 mm mesh sieve and stored in polyethylene bags for bulk soil aggregate stability determination. The second portion was ground and passed through a 2 mm sieve for subsequent routine physical and chemical analyses. Hydrometer method (Gee and Bauder, 1986) was used in determining particle size distribution in the soil. The textural classes of the soil were obtained from the textural triangle of SPAW define at first instance hydrology model (Version 6.02.72) by computing percentage clay and sand fractions. Soil organic carbon was determined by dichromate oxidation method (Nelson and Sommers, 1982).

Results and Discussion
Result of the particle size distribution and soil organic carbon measurement are presented in Table 2. Average values of percentage clay, silt and sand shows that the soils are sandy loam/sandy clay loam in texture in all the plots investigated (0-15cm), with the clay content increasing with depth while sand and silt content reduced with depth. This observation is in accordance with the findings of Jones and Wild's (1975) characteristic for most savanna soil. The increase in clay content with depth was often associated to illuvial deposition from the surface to subsoil (Ogunwole *et al*., 2001). Generally, effect of the treatments on particle size distribution was highly significant ($p<0.01$) on all the particle sizes except on clay content (Table 2). Highest sand content was observed in dung + potassium (DK)

(58.36%) and dung (D) (56.03%) plots followed by dung + nitrogen (DN), nitrogen+phosphorus+potassium (NPK) and dung+phosphorus (DP) with lowest content in dung+nitrogen+phosphorus+potassium (DNPK) (42.36%). Similarly, higher silt content was found in plots treated with dung+nitrogen+phosphorus+potassium (DNPK) (50.32%) than the other treatments. The latter might be as a result of the effect of mechanical implement disturbance and the grazing of animals as well as abrasion effect with time there by reducing sand fraction to silt (Ibrahim, 1995).The general low clay content of all the treatments may probably be due to losses associated with frequent cultivation from the past histories of these plots (Ogunwole and Ogunleye 2004).The implication of having more sand content in almost all the plots than any other fraction is that such plots are expected to have an exponential increased in permeability with an increase in particle size as reported by Abdulkadir (2000). It is also expected that such plots permit rapid infiltration because of their higher permeability and effective porosity as observed in Table 2. This expectation is in conformity with the findings of Babaji (1982). Jones and Wild (1975) classified most of the clay found in savanna soils as low activity clay with low water holding capacity, low to moderate CEC and low nitrogen content thus implying low fertility status of such soils. Crop production is not profitable without soil nutrition hence the use of soil conditioners and amendments (Lawal and Girei, 2013).

There was no significant difference on the effect of soil depth, and the interaction of soil depth and the treatment on the particle size distribution of all the plots investigated (Table 2).

Table. 2. Effect of farmyard manure and mineral fertilizer on soil particle size distribution and soil organic carbon

	%			
DEPTH	SILT	CLAY	SAND	OC
1	40.99	6.49	52.16	1.1
2	41.72	6.79	50.86	0.98
SE ±	0.783	0.219	1.087	0.0 81
	NS	NS	NS	NS
Trt				
CONTROL	46.65^{ab}	6.65^{abc}	46.69^{dc}	0.97
D	37.65^{d}	6.32^{abc}	56.03^{a}	1.05
DK	35.65^{d}	5.65^{bc}	58.36^{a}	1.03
DN	36.65^{d}	5.32^{c}	54.69^{ab}	0.83
DNPK	50.32^{a}	7.32^{a}	42.36^{d}	1.24
DP	40.65^{dc}	6.32^{abc}	54.53^{ab}	1.23
K	39.32^{dc}	6.99^{ab}	53.69^{abc}	0.75
N	45.99^{ab}	7.32^{a}	46.69^{dc}	1.29
NPK	36.65^{d}	6.99^{ab}	54.69^{ab}	0.99
P	43.99^{bc}	7.49^{a}	47.36^{bcd}	1.03
SE ±	1.751	0.489	2.431	0.181
	**	*	**	NS
DEPTH*TRT	NS	NS	NS	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *,

**=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium.

No significant effect was recorded between the treatments applied to the study plots on soil organic carbon content (Table 2). However, plots treated with N, DNPK and DP recorded high values relative to the other plots. Plots treated with K only and no organic amendment had the least value of TOC. The high organic C levels observed in this plot (K and control) might be as a result of increased soil fertility and moisture retention from dung addition which resulted in increased weed growth and ground cover. Accumulated plant biomass contributed to the high TOC content over the years from plant and litter deposition from long fallow that the plots were subjected to (Lawal and Girei, 2013). Agbenin and Goladi (1997) also recorded high organic matter content with addition of farmyard manure as organic nutrient inputs.

Though no significant effect was observed on the influence of soil depth on the total organic carbon content of all plots, higher values were observed on the surface soil than the sub soils, which may be attributed to accumulation of plant litter on surface soil (Singh and Ghoshal, 2011). A substantial increase in organic matter levels on surface soils of grassland ecosystems was also observed by Esu (1999) because of presence of plant litter.

The high availability of organic carbon as a result of additions of fertilizers in the form of organic manure or mineral or both, is viewed to improve soil fertility because of their potential in modifying soil physical condition by improving water holding capacity, aeration, drainage, friability and ability to provide energy for microbial activity (Goladi and Agbenin, 1997).

Aggregate stability of selected DNPK plots

Water Stable Aggregate and Wet Mean Weight Diameter

No significant effect was observed on the effect of depth on water-stable aggregate in this study (Table 3). However, stability of macro aggregates was found to increase with depth probably due to the increase in clay content with increase in depth (Table 3). This result confirm the findings of Abdulkadir and Habu (2013) who reported decrease in stability of water stable macroaggregates with depth.

The influence of treatments on stability of water stable aggregates was highly significant ($p<0.01$) as observed from the values obtained (Table 3). For the small macroaggregates (>0.5mm), N, control and DK had the most stable aggregates. This might be due to the accumulation of organic matter through litter deposition and root biomass that greatly enhanced the formation and stabilization of soil aggregates (Silva and Mielniczuk, 1997). Increase in water stable aggregates with increase in the application of mineral fertilizer N was also observed by N'Dayegamiye *et al*. (2010). The lowest proportion of small macroaggregates was observed in the NPK treatment which is statistically similar to DNPK and P. However, Hades *et al*. (1990) reported an improvement in the stability of macro aggregates with application of phosphorus fertilizer. The DNPK and Control plots recorded the highest water stable microaggregates (Table 3). This might not be unconnected with the influence of calcium present in the mineral fertilizer in the formation of clay-polyvalent cation – organic matter complexes which exerts a stabilizing effect on the level of micro aggregation (Clough and Skjemstad, 2000).

Also, in terms of wet MWD define at first instance, the treatment was found to play a significant role on the stability of macro aggregates. Higher proportion of water stable aggregates was recorded in plots treated with N and DNPK while DN plots recorded the least values (Table 3).

The high wet MWD recorded in the fertilizer and dung-treated plots might be as a result of increase in organic materials from increased organic manure additions as reported by Ogunwole (2008). Another possible reason for the high value may be associated to the lower amounts of monovalent cations accompanied in the integrated application of manure and inorganic fertilizer. A reason for the low wet MWD recorded in some of the plots may be associated to the degradation of the large macro aggregates fraction in the dry soil when immersed in water (Unger, 1997), a situation consistent with natural wetting by intense rain. The presence of large quantities of ions present as a result of complimentary application of manure and inorganic fertilizer could also de-stabilize the soil by dispersing larger soil aggregates (Ogunwole, 2008).

Significant effect was recorded in the influence of depth on the wet MWD of the study plots and soil depth of 15-30cm recorded the highest mean. This is probably due to the cementing effect of clay particles that increased with depth and which played an important role in the formation of micro aggregates. The interaction between soil depth and treatments on wet MWD was not significant.

Generally, the addition of organic matter to the soil in the form of either farmyard manure or decomposed plant residues over a long period of time played a significant role in the stability of aggregates in water or wind. This improves the soils capability for withstanding water erosion (Ogunwole, 2008).

Table 3. Effect of farmyard manure and mineral fertilizer on soil water stable aggregates and wet mean weight diameter

DEPTH	**MWDW**	0.5mm	0.25mm	0.05mm	<0.05mm
1	0.97^{b}	3.76	69.18	78.34	42.75
2	1.13^{a}	3.34	65.59	80.17	45.53
SE ±	0.051	0.493	1.377	1.478	1.685
SL	*	NS	NS	NS	NS
Trt					
CONTROL	1.18^{ab}	6.9^{a}	57.23^{cd}	77.4^{a}	52.25^{a}
D	1.17^{ab}	3.02^{b}	68b	82.25^{bcd}	39.8^{bcd}
DK	1.11^{abc}	3.97^{ab}	81.2^{a}	76.43^{b}	33.53^{d}
DN	0.77^{c}	3.03^{b}	82.2^{a}	73.65^{b}	37.55^{cd}
DNPK	1.248^{a}	2.3^{b}	45.98^{e}	90.93^{a}	52.68^{a}
DP	0.96^{abc}	3.17^{b}	64.95^{bc}	83.27^{ab}	40.4^{abcd}
K	0.85^{bc}	2.58^{b}	78.8^{a}	77.23^{b}	40.43^{abcd}
N	1.26^{a}	7.02^{a}	54.12^{de}	77.77^{b}	51.27^{ab}
NPK	1.01^{abc}	1.28^{b}	73.33^{ab}	75.48^{b}	46.57^{abc}
P	0.95^{abc}	2.22^{b}	68.03^{b}	78.15^{b}	46.92^{abc}
SE ±	0.115	1.101	3.080	3.306	3.768
SL	*	**	***	*	**
DEPTH*Trt	NS	NS	**NS**	**NS**	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *, **=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium; MWDW=wet mean weight diameter;SL=significant level.

Dry stable aggregates and dry mean weight diameter

The Distribution of large macro aggregates (>2mm), macroaggregates (>0.025mm) and microaggregates (>0.05) fractions were significantly affected ($p<0.05$) along the study depth (Table 4) while the small macroaggregate (>0.5) and the silt+clay (<0.05) fractions were not significantly affected by the depth. The stability of aggregates increased with depth except for microaggregates, a scenario that can be attributed to the strong effect of clay as a cementing agent. This finding is in line with the findings of Guber *et al*., (2005) and implies that minimum use of heavy machinery in the field is required to avoid further degradation of the stable aggregates as well as the formation of hard pan in the subsurface soil.

Among the treatments, stability of macro aggregates was significantly affected ($p< 0.05$). However micro aggregates and silt+clay fractions were not influenced by fertilizer application (Table 4). High proportions of large and small macro aggregates were recorded in DNPK, N, control and NPK and DK plots, respectively. This might be attributed to the addition of organic matter in the form of farmyard manure or accumulation of litter material resulting from the death of grasses during the fallow period or the influence of well-established symmetrical roots in the enmeshment of particles as a result of adequate nutrients (Reubens *et al.*, 2010).The availability of N and NPK in the plots may have also stimulated the activity of fungi and other microbes that play important roles in binding of particles through secretion of binding agents (Haynes and Francis,1993).The chances of reduction in the amount of macroaggregates from these plots cannot be ruled out because long term cultivation may likely reduce aggregation (Tisdall and Oades, 1982). The non-significant influence of different fertilization regimes on soil microaggregates and silt+clay fractions further suggests that fertilizer application significantly affected formation of the macroaggregates in these plots (Shehu, 2013).

The dry mean weight diameter of the plots studied was not significantly affected by the combination of farm yard manure and mineral fertilizer application over a long period of time (Table 4). However, plots receiving N, DN and no fertilization obtained the highest dry MWD than other treatments with the exception of DNPK, which has the least dry MWD (Table 4). This result corresponds to the findings of Ogunwole (2008) who reported high dry MWD in DP plot but differ in DNPK plots. Hades *et al*. (1990) observed that nitrogen and zero fertilizer application affect and stabilize the sizes of larger structural units at air dryness. The implication of this is that, plots with highest mean value of dry MWD will have better stable aggregates that can withstand wind erosion than other treatments, while those with low mean values like DNPK plot may be most prone to wind erosion due to the low dry stable aggregates. One probable reason for reduction in MWD with fertilization compared with that of the control under the long-term trial, may be due to the disruptive forces that resulted from the long-term cultivation and incorporation of fertilizer (Ogunwole *et al*., 2008).

Soil depth and the interaction effect between depth and treatment showed no significance on the dry MWD in the study plots (Table 4).

Table 4. Effect of farmyard manure and mineral fertilizer on dry soil aggregate stability and dry mean weight diameter

DEPTH	MWDD	2mm	0.5mm	0.25mm	0.05mm	<0.05mm
1	0.32	27.54^{b}	59.40	26.30^{a}	77.83^{a}	7.96
2	0.32	38.382^{a}	58.72	26.30^{a}	69.775^{b}	6.46
SE ±	0.011	2.288	0.879	0.546	2.575	0.829
SL	NS	*	NS	*	*	NS
Trt						
CONTROL	0.34	42.4^{ab}	54.18^{d}	19.4^{e}	75.95	7.42
D	0.30	39.28^{abc}	60.77^{abc}	24.25^{cd}	68.82	6.07
DK	0.33	24.88^{cd}	62.58^{ab}	28.88^{ab}	75.75	7.12
DN	0.34	25.84^{cd}	61.58^{abc}	29.15^{ab}	76.01	6.34
DNPK	0.26	50.77^{a}	58.37^{bcd}	17.65^{e}	66.45	6.15
DP	0.32	28.42^{bcd}	55.68^{cd}	25.5^{bc}	77.97	11.43
K	0.30	19.03^{d}	58.93^{bcd}	29.22^{ab}	74.33	6.93
N	0.34	43.18^{ab}	56.92^{bcd}	20.88^{de}	72.07	6.33
NPK	0.33	27.97^{bcd}	66.17^{a}	30.9^{a}	68.42	5.43
P	0.33	27.83^{bcd}	55.42^{cd}	25.37^{bc}	82.27	8.85
SE ±	0.024	5.115	1.965	1.220	5.758	1.853
SL	NS	*	*	***	NS	NS
DEPTH*Trt	NS	NS	NS	NS	NS	NS

†Mean with the same alphabets within the same column are not significantly different at 5% level of probability. NS=not significant; Trt=treatment; *, **=significant at 5% and 1% level of probability, respectively; D=dung; N=nitrogen; P=phosphorus, K=potassium; MWDD=dry mean weight diameter; SL=significant level.

Conclusion

Result from the study shows that the application of farmyard manure (D) and mineral fertilizers (N, P, K) significantly improves soil aggregate stability, with the combination treatment (DNPK) showing the most pronounced effects. This indicates that integrated nutrient management practices can effectively enhance soil structure. The positive effects of combining farmyard manure with mineral fertilizers provide a viable pathway for enhancing soil structure and ensuring long-term soil health and productivity.

References

Abdulkadir, A. (2000). Prediction of infiltration rate of a Typic Haplustalf in Samaru, Northern Guinea Savanna, Nigeria. Under Graduate Project Work. pp. 3-17.

Abdulkadir, A. and Habu, S.T. (2013). Soil properties of a fallow field under long-term cultivation and fertilization regimes in Northern Guinea savanna, Nigeria. *African Journal of Agricultural Research*. 8(42)5211-5220.

Agbenin J.O. and Goladi J. T. (1997). Long-Term soil fertility trend in the savanna as influenced by farm yard manure and inorganic fertilizer. *Proceeding Soil Fertility Management*.21-29

Babaji, G.A. (1982). Some underlying reasons for changes in infiltration in cultivated savanna soils of Northern Nigeria. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria. PP. 129.

Bastida, F., Zsolnay, A., Hernández, T., and García, C. (2008). Past, present and future of soil quality indices: A

biological perspective. Geoderma, 147(3-4), 159-171.
Bationo, A., Waswa, B., Kihara, J., and Kimetu, J. (2012). Sustainable Agriculture Volume 2: Perspectives on Growth and Development. Springer.
Bhattacharyya, R., Prakash, V., Kundu, S., and Gupta, H. S. (2008). Effect of organic manures and chemical fertilizers on soil organic carbon storage, soil quality, and yield sustainability under a rainfed soybean–wheat cropping system in the Indian Himalayas. Soil and Tillage Research, 103(2), 343-349.
Bronick, C. J., and Lal, R. (2005). Soil structure and management: a review. Geoderma, 124(1 2), 3-22.
Celik, I., Ortas, I., and Kilic, S. (2004). Effects of compost, mycorrhiza, manure, and fertilizer on some physical properties of a chromoxererert soil. Soil and Tillage Research, 78(1), 59 67.
Clough, A., and Skjemstad, J.O. (2000). Physical and chemical protection of organic carborn in three agricultural soils with different contents of calcium carbonate. *Australian Journal of Soil Research*, 38, 1005-1016.
Drinkwater, L. E., Wagoner, P., and Sarrantonio, M. (1998). Legume-based cropping systems have reduced carbon and nitrogen losses. Nature, 396(6708), 262-265.
Esu, I. E. (1999). Fundermental of pedology. Stirling-Horden Publishers (Nig) Ltd.PP.66.
Gee, G.W. Bauder JW (1986). Particle size analysis. In: Klute A (Ed.). Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, Monograph No. 9. American Society of Agronomy. Madison, WI.
Geisseler, D., and Scow, K. M. (2014). Long-term effects of mineral fertilizers on soil microorganisms–A review. Soil Biology and Biochemistry, 75, 54-63.
Goladi, J. T. (1997). Carbon,nitrogen and phosphorus dynamics induced by long-term cultivation and management. M. Sc Thesis Ahmadu Bello University, Zaria, Nigeria, pp: 89.
Guber, A.K., Parchepsky, Ya A., Levkovsky, E.V. (2005).Fractall mass size scalling of wetting soil aggregates.*Ecological Model* 182(2-3):317-322.
Hades, A., Hadas, A., and Quinton, J. (1990). Long-term effects of high application rates of NPK fertilizer on tensile strength and stability of the soil structure. *Geoderma*, 47:381-392.
Haynes, R. J., and Naidu, R. (1998). Influence of lime, fertilizer and manure applications on soil organicmatter content and soil physical conditions: a review. Nutrient Cycling in Agroecosystems, 51(2),123-137.
Haynes, R.J. and Francis, G.S. (1993). Change in microbial C,soil carbohydrate composition and aggregate stability induced by selected crop and forage species under field condition. *Journal of Soil Science,* 44:665-675.
Ibrahim A. Okai (1995). Irrigation effect on the physical properties of soils at Kadawa iirigation project Kano state. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.
Jones, M.j. and Wild, A. (1975). *Soil of the West African Savanna*. PP.52-57.
Kay, B. D. (1998). Soil structure and organic carbon: a review. Soil Processes and the Carbon Cycle, 169.
Kemper, W.D. and Rosenau, R.C. (1986). Aggregate stability and size distributions. In: *Methods of soil analysis*. Part 1, 2nd Ed. A. Klute (Ed.). Agronomy monorgraph. ASA and SSSA, Madison,WI, 425-442.

Lal, R. (2006). Enhancing crop yields in developing countries through restoration of the soil organic carbon pool in agricultural lands. Land Degradation and Development, 17(2), 197-209.

Lawal H.M. and **Girei H. A. 2013.** Infiltration and organic carbon pools under the Long-Term Use of Farm Yard Manure and Mineral Fertilizer. International Journal of Advance Agricultural Research. 92-101

Manna, M. C., Swarup, A., Wanjari, R. H., Mishra, B., and Shahi, D. K. (2007). Long-term fertilization, manure, and liming effects on soil organic matter and crop yields. Soil and Tillage Research,94(2), 397-409.

N'Dayegamiye, A., Drapeau, A., Nduwamungu, C. (2010). Fresh and composted paper sludge sustain soil productivity. *International Journal of Agronomy* 1-10.DOI: 10. 1155/2010/132080.

Nelson DW, Sommers LE (1982). Total Carbon, Organic Carbon and Organic Matter. In: Page AL, Miller RH, Keeny DR (Eds.). Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Am. Soc. Agron. pp. 539-579

Ogunwole, J.O. (2008). Soil aggregate characteristics and organic carborn concentrations after 45 annual application of manure and inorganic fertilizer. *Biological Agriculture and Horticulture*. 25(3):223-233.

Ogunwole, J.O. and Ogunleye, P.O. (2004). Influenced of long-term application of organic and mineral fertilizers on quality of savanna Alfisol. *Journal of Sustainable Agriculture*.26(3) 5-13.

Ogunwole, J.O., Chaudhary, D.R., Ghosh, A., Daudu, C.K., Chikara, J. and Patola, J.S. (2001). Contribution of *Jatropa curcas* to soil quality improvement in a degraded Indian entisol. *Soil and Plant Science.* 58:245-251.

Reubens, B., Achten,W.M.J., Maes, W.H., Danjon, F., Alerts, R., Poesen, J. and Muys, B.(2010). Morethan Biofuel? *Jathropa curcas* L. root system symmetry and potential for soil erosion control. *Journal of Arid Environment*, doi:10.1016/j.Jaidenv.2010.09.011.

Rillig, M. C., Wright, S. F., Shaw, M. R., and Field, C. B. (2002). Artificial climate warmingpositively affects arbuscular mycorrhizae but decreases soil aggregate water stability in an annual grassland.Oikos, 97(1), 52-58.

Schjønning, P., Elmholt, S., and Christensen, B. T. (2004). Managing Soil Quality: Challenges in Modern Agriculture. CABI Publishing.

Shehu, B.M. (2013). Physical quality of an alfisols as influenced by cultivation of *Jatropha curcas* L. at Samaru, Northern Nigeria. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Silver,I.F. and Mielniczuk, J. (1997). Acao do sistema redicular de plantas na formacao e estabilizacao de agregados do solo. *Rev. Bras.Ci. Solo*, 21:113-117

Sing M.K. and Ghoshal N. (2011). Impact of land used change on soil organic carborn content in dry tropics. *Plant Archives*.11(2);903-906.

Six, J., Bossuyt, H., Degryze, S., and Denef, K. (2004). A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil and Tillage Research, 79(1), 7-31.

Sutton, A. L., Kephart, K. B., Verstegen, M. W. A., Canh, T. T., and Hobbs, P. J. (1986). Potential for reduction of odorous compounds in swine manure through diet modification. Journal of Animal Science, 74(12), 439-446.

Tisdall, J. M., and Oades, J. M. (1982). Organic matter and water-stable aggregates in soils. Journal of Soil Science, 33(2), 141-163.

Tisdall, J.M., Oades, J.M. (1982). Organic matter and water stable aggregates in soils. *Journal of Soil Science.* 33(2):141-163.

Unger, P.W. (1997). Aggregate and organic concentration inter-relationships of torrerttic paleustoll. *Soil Tillage Research*. 42:95-13.

Whalen, J. K., and Chang, C. (2002). Macroaggregate characteristics in cultivated soils after 25 annual manure applications. Soil Science Society of America Journal, 66(5), 1637-1647.

Zhang, S., Li, Q., Lü, Y., Zhang, X., and Liang, W. (2014). Contributions of soil biota to C sequestration varied with aggregate fractions under different tillage systems. Soil Biology and Biochemistry, 72, 72-81.

Zhao, Q., Zhou, X., and Luo, Y. (2010). Effects of inorganic nitrogen fertilization on microbial communities and carbon sequestration in paddy soil in China. Soil Biology and Biochemistry, 42(1), 144-152.

CHARACTERIZATION, CLASSIFICATION AND SUITABILITY ASSESSMENT OF SOILS ALONG A TRANSECT FOR RAIN FED RICE CULTIVATION IN NIMO, ANAMBRA STATE, NIGERIA

[1]Ajoagu, G.M., [2]Onwudiwe, E.E. and [1]Unagwu, B.O.
[1]University of Nigeria, Nsukka, Enugu State, Nigeria
[2]Federal College of Education (T), Asaba, Delta State, Nigeria
Corresponding author email:ekynet09@gmail.com

ABSTRACT
A growing number of communities in Anambra State have been identified as rice growing communities. Despite these numbers of rice growing communities, the rice production in Anambra State is afar from what is expected when compared to other rice producing states in Nigeria. The present study was carried out to characterize, classify and evaluate the suitability of soils along a transect in Nimo, Anambra State for rice cultivation. Three slope positions (upper, middle and lower slopes) were identified along the transect using a free survey while a profile pit was dug for each slope position. The pits were described in situ following FAO guidelines and soil samples were collected from the identified generic horizon for laboratory analyses. The soils were strongly to slightly acidic with low CEC, total nitrogen, organic matter and exchangeable bases. The soils were classified as Grossarenic Kandiudults at the upper slope and Typic Kandiudults at the middle and lower slopes. The current aggregate suitability evaluation indicated that the soils were marginally suitable (S3) for rice production but have the potential of being moderately suitable (S2) if the limitations are managed properly. The major limitations identified were drainage,wetness CEC, calcium and available phosphorus.
Keywords: *characterization, transect, classification, suitability, evaluation*

Introduction

Soil plays a pivotal role in the agricultural ecosystem. Sustainability of soils hinges largely on the knowledge of its potential maximal utility and effective maintenance of soil's invaluable natural resources. As soils differ in properties due to differences in parent materials (Law-Ogbomo and Nwachokor, 2010), soil characterization and evaluation is very vital to sustainable crop production (Okonkwo and Nsor, 2015). Sustainability in agricultural production is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 2007). Ande (2011) noted that soil suitability evaluation involves characterizing the soils of a given area for specific land use types. Land evaluation is not only expedient but crucial because often, soil classification, soil maps, and the accompanying legends do not meet the needs of farmers and other land users (Ogunkunle, 2016).

Soil characterization and evaluation help in identifying limiting factors associated with a parcel of land for a particular crop production and enable decision-makers to develop a crop management system for sustainably land productivity (Halder, 2013). Soil characterization provides information on the morphological, physical, and chemical properties of soils as well as insights into their behavioural patterns (Basavaraju et al., 2005). This is essential for utilizing and maximizing soil properties (Kumar *et al*., 2013). Hence, periodic assessment of soils and their suitability for defined uses and management practices is inevitable. Soil information can be used for a more realistic land use recommendation (Nsor *et al*., 2014), thus, promotes suitable use and proper management of soil natural resources.

Rice is one of the fastest-growing food commodities in Nigeria with a likelihood of continued growth; its increase in demand is associated with the rapid population growth, urbanization and consumer's preference for rice as convenience food (Akande, 2003; Obianefo *et al*., 2019; USDA, 2014). Rice production in Anambra State, Nigeria, has seen significant growth over the years (Obianefo *et al*., 2022). However, the increment is marginal as most of the naturally endowed areas are left untapped due to paltry or no information on soil properties. To increase rice production, suitable areas and ecological conditions must be identified (Heumann *et al*. 2011). Such important tasks of increasing rice production can be addressed through spatial analyses of soil characteristics and land use suitability. Characterization, classification, and suitability evaluation of soils will not only establish a relationship between soil properties and the landscape parameters but also provide preliminary information on the soil nutrient status, potentials and constraints for a particular use. Therefore, this study tends to characterize, classify, and evaluate the suitability of soils along a transect in Nimo for rain fed rice cultivation.

Materials and Methods

Description of the study area

Nimo in Njikoka Local Government Area, Anambra State Nigeria lies within latitudes 6° 8' 0'' N and 6° 14' 0'' N and longitudes 6° 56' 0'' E and 7° 2' 0'' E. The area is characterized by two seasonal climatic conditions: rainy and dry season with most rain falling from March to October; and a short break in either July ending or August known as August break. The dry season extends from November to February with harmattan occurring between the months of December and January. The mean annual rainfall is above 1450 mm. It has an average temperature of 27°C with daily minimum and maximum temperatures in ranges of 22°C to 24°C and 30°C to 34°C, respectively. The relative humidity ranges from 75 to 95% (Hydrometeorological Department, Awka, 2022). The native vegetation of area was originally rainforest characterized by very tall, big trees with thick undergrowth and numerous climbers (Ezeigwe, 2015). However, due to human interferences, the vegetation now consists of bush regrowth, arable crop farms and tree crops. Agriculture, hunting and cottage industries are predominant means of livelihood in the area (Orji-Uzor and Obasi, 2012). The major crops along the selected toposequences include: cassava (*Manihot spp*); cocoyam (*Colocasia esculentus*); yam (*Discorea spp*); maize (*Zea mays*), plantain (*Musa spp*.), oil palm (*Elaeis guinensis*) and mango (*Mangifera indica*). The soils of the area are developed on sandstone parent material (Ezeigwe, 2015).

Field studies

A sloping portion of an arable land, adjoining River Oshoku, was selected for the study. The slope was partitioned at 200 m intervals and designated as upper, middle and lower slopes. In each segment, a representative profile of dimension 2 × 1.5 × 2 m was dug and described according to Food and Agriculture Organization (FAO) guidelines for soil profile descriptions (FAO, 2014). Soil samples (core and auger samples) were collected from generic horizons for laboratory analysis.

Soil analyses

The soil samples were air dried, crushed and sieved using a 2 mm sieve size. Particle size distribution was determined by Bouyocous hydrometer method using sodium hydroxide as a dispersant (Gee and Or, 2002). Silt clay ratio was obtained by dividing the value of silt with that of clay. Bulk density was determined using core method after oven drying the soil samples to a constant weight at temperature 105°C for 24 hours (Grossman and Reinsch, 2002). Saturated hydraulic conductivity was measured by core method as described by Klute and Dirksen (1986). Pore size distribution was determined using water retention data as follows: macroporosity as water drained at 60 cm tension/volume of bulk soil: microposity as water retain at 60 cm tension /volume of bulk soils and total porosity from the sum of macroporosity and microporosity (Brady and Weil, 2002).

Soil pH was determined both in water and 0.1N potassium chloride solution at the soil/liquid ratio of 1:2.5 using Beckman Zerometic pH meter (Van Reeuwijk, 1992). Organic carbon content was determined by the dichromate wet oxidation method (Jackson, 1973) and multiplied by 1.724 to obtain organic matter. Total nitrogen was determined by the Kjeldahl digestion, distillation and titration procedure as described by Bremner (1965). Available phosphorus was determined using Bray II method as described by Olsen and Sommers (1982). Cation Exchange Capacity was determined using the ammonium acetate method (Chapman, 1965). Exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were extracted using 1N ammonium acetate; calcium and magnesium was determined by titration method (Chapman, 1965) while sodium and potassium was determine using flame photometer as described by Rhoades (1982). Exchangeable hydrogen and aluminium were determined by titrimetric method using potassium chloride extract (Mclean, 1965). Exchangeable Acidity was calculated by summing the values of exchangeable aluminium and hydrogen. Base Saturation was calculated as thus in equation (1):

$$\mathrm{PBS} = \frac{\mathrm{TEB}}{\mathrm{CEC}} * \frac{100}{1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where TEB = total exchangeable bases and CEC = Cation exchange capacity.

Land Evaluation Procedure

The suitability of the soils for rice production was assessed using the parametric linear additive model as stated in Ezeaku and Tyav (2013):

$$\mathrm{LI} = A + \frac{B}{100} + \frac{\mathrm{C}}{100} + \frac{\mathrm{D}}{100} + \cdots \frac{\mathrm{F}}{100}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

where LI is the Land Suitability Index (%), A is the overall lowest characteristics ratings (%) and B, C, D..... F are the ratings for each property (%). The value of the land suitability index was used to determine the aggregate suitability class. The detailed land and soil requirements for rice are presented in the Table 1 below.

Table 1: Land/Crop requirements for rain-fed rice cultivation

Land qualities	Land Characteristics	Unit	S_1 (100-85)	S_2 (84-60)	S_3 (59-40)	N_1 (39-20)	N_2 (19-0)
Climate (c)	Annual Rainfall	Mm	> 1400	1200-1400	950-1100	850-900	< 850
Soil physical characteristics (s)	Soil Depth	Cm	> 20	10-20	5-10	< 5	any
	Clay	%	45-25	25-15	15-5	<5	any
	Texture	-	Loam	Clay loam	Clay	Sandy clay	any
Wetness (w)	Drainage	-	VPD	PD	MD	MWD	WD
	F.D	Months	> 4	3-4	2-3	< 2	any
	G.W.T	Cm	0- 15	15-30	30-60	> 60	Any
Fertility status (f)							
	pH(H_2O)	-	5.5-7.5	5.2-5.5	≤ 5.2, ≥ 8.2	≤ 5.2, ≥ 8.2	Any
	Total Nitrogen	g kg^{-1}	> 0.2	0.1-0.2	0.05-0.1	< 0.05	Any
	Organic carbon	g kg^{-1}	5-6	3-4	1-2	<1	Any
	Available Phosphorus	mg kg^{-1}	> 20	15-20	10-15	< 10	Any
	Exchangeable Ca	cmolkg^{-1}	10-15	5-10	1-5	< 1; > 15	Any
	Exchangeable Mg	cmolkg^{-1}	2-5	1-2	< 1	< 1; > 5	Any
	Exchangeable K	cmolkg^{-1}	> 0.2	0.1-0.2	< 0.1	< 0.1	Any
	CEC (Soil)	cmolkg^{-1}	> 16	10-16	5-10	< 5	Any

Key: F. D: Flooding Duration, G. W. T: Ground Water Table; VPD: Very poorly drained; PD: Poorly drained; MD: Moderately drained; MWD: Moderately well drained WD: Well drained; CEC: Cation exchange capacity Ca: Calcium; Mg: Magnesium K: Potassium; S1: highly suitable, S2: moderately suitable: S3: marginally suitable, N1: currently not suitable, N2: permanently not suitable

Adapted from Sys (1985)

Results and Discussion

Soil morphological properties

The soils were very deep greater than 150 cm (SSS, 1999) (Table 2). Soil colour ranged from dark reddish brown (10R 3/3); reddish brown (10R 4/3) and red (10R 6/6) for the upper, middle and lower slopes for the surface horizons while the subsurface horizons range danged from reddish brown (10R 4/4) and red (10R 4/6 and 10R 4/8), respectively. The soils were dominated by reddish colouration, which could be attributed to high iron content of the parent material and the oxidation state of the soils (Esu, 2010; Nsor, 2017). Soils of upper slope ranged from sand in the surface to sandy loam and loamy sand in subsurface horizons. Middle slope soils were sand at the surface soils and sandy loam at subsurface horizons. Lower slope soils were sandy loan at both surface and subsurface horizons. The surface soils were weak single grained granular structure underlain by weakly developed medium sub angular blocky structures at the upper slope soils. At the middle and lower slopes, the structure was fine massive granular structure at the surface underlain by moderately developed medium sub angular blocky structure. The weak to moderate developed sub angular blocky might be attributed to the degree of soil formation in profiles (Gisilanbe, *et al*., 2020).

The soils were loose to friable (moist) and non-sticky to slightly sticky (wet) in the Ap horizons and very friable to friable (moist) and not sticky to slightly sticky (wet) in the subsurface horizons. Roots varied from very fine to coarse and few to very many in size and relative abundance respectively. Ants and pores were observed in subsurface horizons. The presence of the roots, ants and pores were indications of considerable amount of biological activities in the soils. Pottery was observed in the 'B1' horizon, which suggested an evidence of human settlement in the past (Esu, 2010). Gravels were present at the subsurface soils of the lower slope. Generally, horizon differentiation between Ap horizons and the B horizons was quite clear across the profiles, which might be due to melanization from humification of organic matterials added to the Ap horizons as form of organic materials added to the Ap horizons as form of manure (Esu, 2010). In B horizons, differentiation ranged from gradual and smooth in the middle and lower slopes to diffuse smooth in the upper slope.

Soil physical properties

The particle size distribution data for the soils is presented in Table 3. Sand dominated the particle size fraction of the fine earth (<2 mm) portion of the soils. The sand content varied from 802 to 903 g kg^{-1} in the Ap horizons while the values for the sand content in the underlying horizon were between 742 and 882 g $kg^{-1.}$ Clay content ranged from 65 to 265 g kg^{-1} in the Ap horizons and 85 to 205 g kg^{-1}in subsurface horizons, respectively. The silt content was 33 g kg^{-1} in Ap horizon and varied between 33 and 39 g kg^{-1} in the subsurface horizons. Generally, sand content of the surface horizons was slightly higher than the subsurface horizons. Clay fraction was next to sand in abundance with an increasing pattern of distribution down the profiles and slope. The higher clay content often observed in subsurface horizons of many soils may be ascribed to illuviation processes (Malgwi *et al*., 2000). This confirms the presence of either kandic or argillic B horizons in the profiles. The texture of the soils varied between sand, sandy loam and loamy sand.

Table 2: Morphological properties of soils

Depth (cm)	HD	Colour		T	Structure	Consistency moist	wet	Roots	Hb	Other features
						Upper slope				
0-30	Ap	10R (DRB)	3/3	S	w sg g	l	ns	M vf	Cs	-
30-116	B_1	10R (RB)	4/4	SL	w m sab	vfr	ns	F vf	Ds	-
116-200	B_2	10R (R)	4/8	LS	w m sab	vfr	ss	-	-	-
						Middle slope				
0-27	Ap	10R (RB)	4/3	S	f ma g	vfr	ns	M vf; F f	Cw	-
27-114	B_1	10R (R)	4/6	SL	mod m sab	fr	ss	VF f	Gs	Very few medium pores, very few pottery
114-200	B_2	10R (R)	4/6	SL	mod m sab	vfr	ns	-	-	-
						Lower slope				
0-40	Ap	10R (R)	4/6	SL	f ma g	fr	ss	M f	Cs	-
40-125	B_1	10R (R)	4/8	SL	mod m sab	fr	ss	F f	Gs	very few gravel
125-200	B_2	10R (R)	4/8	SL	mod m sab	fr	ss	-	-	very few gravel, many ants

HD: horizon designation; T: texture; Hb: horizon boundary; RB; reddish brown; R: red; DRB: dark reddish brown; LS: loam sand; S: sand; SL; Sandy loam; f: fine; ma: massive, g: granular; vf: very fine; m: medium; mod: moderate, ab: angular blocky; sab: sub angular blocky; fr: friable; vfr: very friable; fi: firm; ns: not sticky; ss: slightly sticky; s: sticky; p: perfect; F: few; ; M: many; cs: clear smooth; ds: diffuse smooth; cw: clear wavey; -: absent

The silt to clay ratio ranged from 0.20 to 0.51 in surface soils and 0.16 to 0.39 in the subsurface soils. Silt to clay ratios were relatively higher in the surface soils and decreased with depth suggesting that subsurface soils were more weathered than the surface soils (Fasina *et al*., 2015). The values of bulk densities for upper, middle and lower slopes ranged from 1.61 to 1.74 g cm^{-3}; 1.63 to 1.74 g $cm^{-3}$and 1.64 and 1.82 g cm^{-3}, respectively with increasing trend down the profiles due to compaction caused by the overlying horizons. Generally, the soils have high bulk density which might be attributed to the sandy nature of the soils (Nsor, 2017). The values of the saturated conductivity varied between 11. 80 and 69.72 cm hr^{-1}. The upper slope soils had the highest values of ksat relative to other slope positions due its moisture content. This is in line with the findings of Antiono *et al*. (2001) and Bagaireaello and Lovino (2003). They reported high ksat on the upper slope due to higher water content and smaller pores. The high bulk density could be attributed to the sandy nature of the soil. The macro, micro and total porosity of soils varied from 5.13 to 5.70%, 34.29 to 39.08% and 39.68 to 44.46%, respectively.

Soil chemical properties

The soils were strongly to slightly acidic with pH in H_2O and KCl ranging from 4.80 to 5.60 and 4.40 to 5.00, respectively as shown in Table 4. This might be attributed to continuous cultivation, application of commercial fertilizers and leaching of exchangeable bases (Brady and Weil, 2002; Havlin et al., 2006). The organic matter (OM) values for surface horizons were 3.45 to 8.96, 3.65 to 6.72, and 2.76 to 8.89, g kg^{-1} for upper, middle and lower slope soils respectively. The soil OM content decreased with depth and was rated low irrespective of soil depth and slope positions. The low values of OM inferred that the studied site have been under continuous or intensive cultivation. This is because high agricultural activities deplete soil organic matter content (Fedaku *et al*., 2018). The OM decreased down the profiles, which may be linked to decrease in organic materials with depth. The total nitrogen values varied from 0.30 to 0.80; 0.20 to 0.70 and 0.10 to 0.40 g kg^{-1} for soils of upper, middle and lower slopes, respectively. Total N was low due to low OM, high N mineralization and crop removal (Njoku, 2012; Uzoho *et al*., 2014). The available phosphorus varied from 11.90, 5.60 and 0.93 mg kg^{-1} in the Ap horizon to 1.87, 1.87 and 3.73 mg kg^{-1}, respectively in the underlying horizon. The low level of available P may be due to low apatite content of the soil forming materials as well as low OM. Amhakhian and Osemuota (2012) opined that tropical soils are generally low in available P due to low apatite content of the soil forming materials. The trend in dominance of the exchangeable bases at the colloid is $Ca^{2+} > Mg^{2+} > K^+ > Na^+$. Exchangeable calcium (0.20 to 1.00 cmol kg^{-1}), magnesium (0.20 to 0.40 cmol kg^{-1}), sodium (0.05 to 0.09 cmol kg^{-1}) and potassium (0.08 to 0.92 cmol kg^{-1}) were considered to be low. This might be attributed partly to the dominance of 1:1 clay minerals and partly to the leaching loss of nutrients (Orji Uzor and Obasi, 2012; Chikere-Njoku, 2015). Total exchangeable bases ranged from 0.61 to 2.01 cmol kg^{-1} at the surface horizons and 0.53 to 2.04 cmol kg^{-1} at the subsurface soils. The values of cation exchange capacity (CEC) were 4.00, 4.80, and 3.20 cmol kg^{-1} for upper, middle and lower slope in the Ap horizon while 4.00 to 8.80, 4.80 to 8.80 and 5.60 to 6.00 cmol kg^{-1} were the values at the subsurface horizons, respectively. Low CEC values were reported to be an indication of dominance of sesquioxide and

Table 3: Physical properties of the soils

Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	Bd (g cm^{-3})	Ksat (cm hr^{-1})	Map (%)	Mip (%)	Tp (%)
Upper slope										
0-30	902	33	65	S	0.51	1.61	68.01	5.62	38.74	44.36
30-116	882	33	85	LS	0.39	1.65	69.72	5.58	36.40	41.98
116-200	862	33	105	LS	0.31	1.74	65.45	5.39	34.29	39.68
Mean	882	33	85	S	0.40	1.67	67.73	5.52	36.48	42.01
Middle slope										
0-27	903	33	65	S	0.51	1.63	33.43	5.70	38.14	43.84
27-114	742	53	205	SL	0.29	1.68	11.80	5.58	37.09	42.67
114-200	762	33	205	SL	0.16	1.74	17.33	5.49	34.26	39.75
Mean	803	39	158	SL	0.32	1.68	20.85	5.59	36.50	42.09
Lower slope										
0-40	802	33	165	SL	0.20	1.65	23.61	5.38	39.08	44.46
40-125	782	33	185	SL	0.18	1.82	31.59	5.23	37.06	42.29
125-200	762	33	205	SL	0.16	1.82	17.02	5.13	34.62	39.75
Mean	782	33	185	SL	0.18	1.76	24.07	5.25	36.92	42.17

TC: textural class; S: sand; SL: sandy loam; LS: loam sand; SCR: silt clay ratio; Bd: bulk density; Ksat: saturated hydraulic conductivity; Map: macroporosity; Mip: microporosity; Tp: total porosity

Table 4: Chemical properties of soils

Depth (cm)	pH (H_2O)	pH (KCl)	OM (g kg^{-1})	TN	Av. P (mg kg^{-1})	H^+ (cmol kg^{-1})	Al^{3+}	EA	Ca^{2+}	Mg^{2+}	Na^+	K^+	TEB	CEC	BS (%)
Upper slope															
0-30	5.30	4.90	8.96	0.80	11.90	0.40	0.80	1.20	0.60	0.40	0.09	0.92	2.01	4.00	62.62
30-116	5.00	4.60	4.14	0.40	5.60	0.40	1.20	1.60	0.80	0.20	0.07	0.43	1.30	4.00	44.83
116-200	4.90	4.70	3.45	0.30	1.87	0.80	1.60	2.40	1.00	0.40	0.07	0.55	1.41	4.80	39.83
Mean	5.07	4.73	5.52	0.50	6.46	0.53	1.20	1.73	0.80	0.33	0.08	0.63	1.57	4.20	49.40
Middle slope															
0-27	5.30	5.00	6.72	0.70	5.60	0.80	0.20	1.00	0.20	0.20	0.08	0.13	0.61	4.80	37.89
27-114	4.80	4.40	6.55	0.40	1.87	2.80	0.40	3.20	0.40	0.40	0.09	0.55	2.04	6.40	38.93
114-200	5.10	4.60	3.62	0.20	4.66	1.00	0.80	1.80	1.00	0.40	0.09	0.09	0.78	8.80	30.23
Mean	5.07	4.67	5.63	0.43	4.04	1.53	0.47	2.00	0.53	0.33	0.09	0.27	1.14	6.67	35.68
Lower slope															
0-40	5.00	4.60	8.89	0.40	0.93	0.80	1.20	2.00	0.40	0.40	0.04	0.09	0.93	3.20	31.74
40-125	5.60	4.70	4.48	0.20	4.66	0.20	1.60	1.80	0.40	0.20	0.06	0.09	0.75	5.60	29.41
125-200	4.90	4.70	2.76	0.10	3.73	0.80	2.00	2.80	0.20	0.20	0.05	0.08	0.53	6.00	15.94
Mean	5.17	4.67	5.37	0.23	3.11	0.60	1.60	2.20	0.33	0.27	0.05	0.09	0.74	4.93	25.69

OM: organic matter; TN: total nitrogen; Av. P available phosphorus; H^+: exchangeable hydrogen; Al^{3+}: exchangeable aluminum; Ca^{2+}: exchangeable calcium; Mg^{2+}: exchangeable magnesium; Na^+: exchangeable sodium; K^+: exchangeable potassium; EA: exchangeable acidity; TEB: total exchangeable bases; CEC: cation exchange capacity; BS: base saturation;

kaolinitic clays in the fine earth fractions (Tan, 2000). The increase in CEC values with depth in the profiles was as a result of increase in clay content (Abubukar *et al*., 2019) as it had similar trend with the clay content. The percentage base saturation (BS) varied from 39.83 to 62.62%; 30 to 38.93% and 15.94 to 31.74% in the upper, middle and lower slope soils respectively. The higher BS values at the surface horizons and upper slope might to be due to higher exchangeble bases when compared with the subsurface horizons and other slope position.

Soil classification

The soils of all the slope positions were classified as Order Ultisols as they had kandic horizons and base saturations <50% throughout the entire horizons (Soil Survey Staff, 2014). An udic moisture regime was inferred for all the soils as they are not dry in any part for more than 90 cumulative days in a normal and this placed the soils at Sub order Udults (Soil Survey Staff, 2014). The presence of kandic horizon with no densic, lithic, paralitic or petrolithic contacts with 150 cm of mineral soils and a clay increase of 3% or more in the fine earth fractions qualified the soils as Great group Kandiudults (Soil Survey Staff, 2014). At the Sub group level, the soils of the upper slope were classified as Grossarenic Kandiudults as they had Sandy skeletal particle size throughout the layers extending from the mineral soil surface to the top of the kandic horizon at the depth of 100 cm and more. Whereas the soils of the middle and lower slopes qualified as Typic Kandiudults (Soil Survey Staff, 2014)

According to FAO's World Resource Base (WRB), all the soils were correlated with Acrisols as they had agric horizons, CEC values of <24 and exchangeable bases of <50% within the upper 100 cm depth (FAO, 2014) (Table 5). The soils of the upper and lower slopes were further classified as Arenic Acrisols while the lower slope soil was were further correlated as Loamic Acrisols owing to the presence of sandy and loamy sand textures respectively in a layer ≥30 cm thick within <100 cm (FAO, 2014) respectively.

Table 5: Soil Classification

	USDA SOIL TAXONOMY				WRB
	Order	Sub order	Great group	Subgroup	
Upper slope	Alfisols	Udalfs	Kandiudults	Grossarenic Kandiudults	Arenic Acrisols
Middle slope	Ultisols	Udults	Kandiudults	Typic Kandiudults	Arenic Acrisols
Lower slope	Ultisols	Udults	Kandiudults	Typic Kandiudults	Loamic Acrisols

Land suitability assessment

The study showed that the climate data: rainfall and temperature were ideal for rice production scoring 95% (Table 6). Soil texture was highly suitable scoring 85% whereas clay was marginally (upper and middle slopes) to moderately suitable (lower slope) 50 to 70%. Soil chemical characteristics such as total nitrogen and organic matter were rated highly suitable (95%) for all the pedons. The pH of the soils was moderately suitable (70%) for the upper and middle slopes but marginally suitable (50%) for the lower slope. CEC and calcium were marginally suitable (35%) in all the pedons. Exchangeable magnesium was moderately suitable scoring 70%. Exchangeable potassium was highly suitable (95%) in the upper slope, moderately suitable (70%) in the middle slopes and marginally suitable (50%) in the lower slope. Available phosphorus rated from marginally suitable (35%) in all the slope position. wetness were rated marginally suitable (25%) for rice production in all the slope positions.

Aggregate suitability evaluation: current and potential indicated that the soils of the slope positions were marginally suitable and moderately suitable for rice production respectively. The major limitation was drainage, wetness, CEC, calcium and available phosphorus. The wetness and drainage limitations can be overcome through irrigation and mulching to conserve enough moisture in the soils. Soil management strategies such as spreading of crop residue on the soils after harvesting, inclusion of grasses and legumes during fallow should be practiced so as to boost the fertility of the soils. The pH of the soils can be raised by liming. This will also increase the available P, supply Ca and Mg, and eliminate any toxic substances like iron, aluminum and manganese ions. Periodic soil tests are also recommended to ascertain pH levels at a time in order to avoid over-limming.

Table 6: Land suitability assessment for rain fed rice production

Land qualities	Upper slope	Middle slope	Lower slope
Climate			
Annual rainfall (mm)	S1(95)	S1(95)	S1(95)
Temperature (°C)	S1(95)	S1(95)	S1(95)
Physical characteristics			
Depth (cm)	S1(95)	S1(95)	S1(95)
Clay (%)	S3 (50)	S3 (50)	S2 (70)
Texture	S1(85)	S1(85)	S1(85)
Wetness			
Drainage	S3(25)	S3 (25)	S3 (25)
Flooding duration	S3 (25)	S3 (25)	S3 (25)
Ground water table	S3 (25)	S3 (25)	S3 (25)
Fertility Status			
pH	S2 (70)	S2 (70)	S3 (50)
Total N	S1(95)	S1(95)	S1(95)
Organic C	S1(95)	S1(95)	S1(95)
Available P	S3 (50)	S3 (35)	S3 (35)
Exchangeable K	S1 (95)	S2 (70)	S3 (50)
Exchangeable Ca	S3 (35)	S3 (35)	S3 (35)
Exchangeable Mg	S2 (70)	S2 (70)	S2 (70)
CEC	S3 (35)	S3 (35)	S3 (35)
Aggregate Suitability (current)	S3 (35.67)	S3 (35.67)	S3 (35.67)
Aggregate Suitability (potential)	S2 (50. 33)	S2 (50. 33)	S (50.33)

S1: highly suitable, S2: moderately suitable: S3: marginally suitable, N1: currently not suitable, N2: permanently not suitable

According to suitability ranking of Sys *et al*. (1991), land suitability index from 0 to 12.5% connotes permanently not suitable (N2), 12.5 to 25% is currently not suitable (N1), 25 to 50% is marginally suitable (S3), 50 to 75% is moderately suitable (S2) and 75 to 100% is highly suitable (S1).

Conclusion

The soils of the study area were strongly to slightly acidic with low CEC, total nitrogen, organic matter and exchangeable bases. The soils were classified as Grossarenic Kandiudults at the upper slope and Typic Kandiudults at the middle and lower slopes. The soils were marginally suitable for rice production but have potentials to be moderately suitable if properly managed. Hence, there is the need to continually monitor the drainage, wetness and fertility status of the soils for effective optimization of its potentials for rice production. Management practices such as irrigation, cover cropping, mulching and organic manuring should be adopted so as to provide and conserve moisture in the soils as well as enhance the fertility.

References

Amhakhian, S. O. and Osemwota, I. O. (2012). Physical and chemical properties of soils in KogiState, Guinea savanna zone of Nigeria. *Nigeria Journal of Soil Science* 22(1), 44-52

Ande, O. T. (2011). Soil suitability evaluation and management for cassava production in the derived Savanna Area of Southwestern Nigeria. *International Journal of Soil Science*, *6*(2), 142.

Antonio, C.D.A., Angulo-Jaramilo, R., deSouza, E.S., Netto A.M., Cameiro C.J.G. and Montenegro, A.A.A. (2001). Determinants of hydraulic conductivity and sorptivity of soils using a disk infitrometer. *Br. Journal of Agriculture and Environmental Engineering* 1802-1899

Bagiaraello, V. and Lovino, M. (2003). Field testing parameter sensitivity of the two-term infiltration equation using differentiated linearization. *Soil Science Society of America Journal* 2:358-367

Basavaraju, D., Naidu, M. V. S., Ramavatharam, N., & RAA, K. G. (2005). Characterization, classification and evaluation of soils in Chandragiri mandai of Chittoor district, Andhra Pradesh. *Journal of Agropedology*, *15*(1), 55-62

Brady, N.C. and Weil R.R. (2002): The nature and properties of soils. 4th Ed. Prentice Hall Inc. New Jersey, U.S.A.

Brady, N.C. and Weil, R.R. (2006). Elements of the nature and properties of soils. Prentice Hall Inc. New York, USA. 95p

Bremner, J.M. (1965). Total nitrogen in C.A. Black (Eds.). Methods of soil analysis. Agronomy. No 9. Part II. American society of Agronomy, Maidson, Wisconsin. USA. 1149-1178

Chapman, H.D (1965). Cation exchange capacity In: C.A. Black, L.E Ensminger and F.E. Clark (Eds.). Methods of soil analysis. Agronom 9. American Society of Agronomy, Maidson, Wisconsin. USA. 891-901

Chikere-Njoku, C. (2015). Characterization and classification of soils along a toposequence for agronomic use in Obaidemili South L.G.A. of Anambra State, Southern Nigeria. *FUTO Journal Serie* 1(2): 103-110

Esu I.E. (2010). Soil characterization, classification and survey. HEBN Publishers, Plc, Ibadan, Nigeria. 73-99

Ezeaku, P.I and Tyav C. (2013). Fuzzy and parametric methods for land evaluation along Kastina-Ala flood plains in Central Region of Nigeria: Application to rice production. *Elixir International Journal* 61:173033-173039

Ezeigwe, P.C. (2015). Investigation of the characteristics of the soils behind the proposed governor's lodge, Ekwueme Square Awka and the environmental hazards prevalent in the area. *Journal of Natural Science Research* 5(20): 43-51

FAO (2007). Land evaluation: Towards a revised framework. Land and waterdiscussion paper no. 6. Food and Agriculture Organization of the United Nations, Rome, Italy. 108p. http://www.fao.org/nr/lman/docs/lman_070601_en.pdf

FAO (2014). World reference base for soil resources. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/3/a-i3794e.pdf

Fasina, A.S., Raji, A., Oluwatosin, G.A., Omoju, O.J. and Oluwadare, D.A. (2015). Properties, genesis, classification, capability and sustainable management of soils from South-Western Nigeria. *International Journal of Soil Science*, 10: 142-152

Fekadu, A., Kibebew, K.A, Bobe, B.A. and, Asmare, M.B. (2018). Characterization and classification of soils of Yikalo Subwatershed in Lay Gayint District, Northwestern Highlands of Ethiopia Endalkachew. *Eurasian Journal of Soil Science* 7(2): 151-166

Gee, G.W. and Or, D. (2002). Particle size analysis. In: Dane, J.H., Topp, G.C. (Eds). Methods of soil analysisPart 4, Physical Methods.Soil Science Society of AmericaBook series; No 5 ASA and SSSA Madison WI. 255-295

Gisilanbe, S.A., Ibrahim, I.S., Akwoga, J.A., Olayinka, O.S and Abdulhamid, B.B. (2020). Profile Characteristics and Soil classification, their Management practices for Crop cultivation in Jalingo, Taraba State. *Taraba Journal of Agricultural Research,* 978-978-923-450-9. https://www.researchgate.net/publication/378342990.

Grossman, R.B. and Reinsch, J.G. (2002). Bulk Density and linear extensibility in methods of soil analysis part 4. Physical Methods. Book Series. No. 5. ASA and SSA Madison, WI. 201-228

Halder, J.C. 2013. Land suitability assessment for crop cultivation by using remote sensing and GIS, *Journal of Geography and Geology*, 5(30)65-74

Havlin, J.L., Beaton, J.D., Tisdale, S. and Nelson, W.L. (2006). Soil fertility and fertilizers. An introduction to nutrient management. 7th Ed. Prentice Hall of India private limited, New Delhi. 110001. 633p

Heumann BW, Walsh SJ, McDaniel PM (2011) Assessing the application of a geographic presence-only model for land suitability mapping. *Ecological Inform* 6(5):257–269. https://doi.org/10.1016/j.ecoinf.2011.04.004

Hydrometeorological Department (2018). Anambra State Ministry of Environment, Awka

Jackson, M.L. (1973). Soil chemical analysis. Prentice Hall, New Delhi. 489p

Klute, A. and Dirksen, C. (1986). Hydraulic conductivity and diffusivity: Laboratory methods. In Klute, A. (Eds). Methods of soil analysis part 1: Physical and mineralogical methods. 2nd edition. Agronomy 9, America Society of Agronomy, Madison, WI. 199-224

Kumar, R. S., Kumar, Y. S., & Srinivas, P. (2013). Characterization, classification and evaluation of Chilli growing soils of Khammam District, Andhra Pradesh. *Int. J. Innovative Res. Dev*. 2 (9),26-33

Law-Ogbomo, K. E., & Nwachokor, M. A. (2010). Variability in selected soil physic-chemical properties of five soils formed on different parent materials in southeastern Nigeria. *Res. J. Agric. Biol. Sci*, *6*(1), 14-19

Malgwi, W.B., Ojanuga, A.G., Chude, V.O., Kparmwang, T. and Raji, B.A. (2000) Morphological and Physical Properties of Some Soil at Samaru, Zaria, Nigeria. Nigeria Journal of Soil Research 1: 58 - 64

McLean, E.O. (1965). Aluminum. Pp 978-998. In: C.A. Black (Eds.). Methods of soil analysis. Agronomy. No 9. Part II. American society of Agronomy, Maidson, Wisconsin. USA

McLean, E.O. (1965). Aluminum. Pp 978-998. In: C.A. Black (Eds.). Methods of soil analysis. Agronomy. No 9. Part II. American society of Agronomy, Maidson, Wisconsin. USA

Munsell Soil Colour Chart. (2009). Munsell soil colour charts (revised ed.) Baltimore.

Njoku, J.D (2012). Application of geographical information system technology in soil fertility variation analysis in Southeastern Nigeria. *International Journal of Science and Technology* 1: 47 - 59

Nsor, M.E. (2017). Pedogenesis, classification and management implications of soils derived from nanka sands of false bedded sandstones lithology in Orumba North L.G.A, Southeastern, Nigeria. Proceeding of the 41st Annual Conference of Soil Science Society of Nigeriaheld between 13-17thMarch, 2017 at ATBU, Bauchi, Nigeria. 195-204

Nsor, M.E., Otu, E J., okeafor, M.O. and Lifu, M.I. (2014). Physico-chemical evaluation and site suitability assessment of selected flood plain soils along river cross for arable cropping. *Journal of the Science in Agriculture, Food Technology and Environment* 13: 19 -31

Obianefo, C. A., Ezeano, I. C., Isibor, C. A., & Ahaneku, C. E. (2023). Technology Gap Efficiency of Small-Scale Rice Processors in Anambra State, Nigeria. *Sustainability*, *15*(6), 4840

Obianefo, C. A., Okoroji, N. O., Obiekwe, N. J., Osuafor, O. O., & Shah, Z. A. (2022). Economics of good agronomic practices adoption by rice farmers in value chain development programme, Anambra State, Nigeria. *African Journal of Food, Agriculture, Nutrition and Development*, *22*(8), 21308-21330

Ogunkunle, A.O., (2016). Management of Nigerian soil resources: An imperative for sustainable development. University Lecture, University of Ibadan. University Press, Ibadan. 88p

Okonkwor, E I. and Nsor, M.E. (2015). Land suitability evaluation of wetland soils of Adani, Enugu State, Nigeria for swamp rice cultivation. *Journal of Sustainable Agriculture and the Environment* 16 (1): 121-138

Olsen, S.R. and Sommers, L.E. (1982). Phosphorous In: Method of soil analysis. Page, A.L., Miller, R.H. and Keeney, D.R. (Eds). Madison, WI. American Society of Agronomy: 1572p

Orji Uzor, E.N. and Obasi, S.N. (2012). Properties and classification of erosion prone soils of Ukpo, Nnewi South L.G.A, Anambra State, Nigeria. *International Journal of Agricultural Sciences and Rural Development* 15(2): 1079 - 1084

Rhoades J.D. (1982). Cation exchange capacity. In Page A L. (Eds.). Methods of soil analysis part II. 2nd edition Agronomy Monogor.9.ASA, Madison, WI. 149-157

Soil Survey Staff (2014). Keys to soil taxonomy: 14th Edition, United States Department of Agriculture/Natural Resources Conservation Service, USA. 161-195

Sys, C, Van Ranst, E, Debaveye, I J, and Beernaert F. (1993). Land evaluation. part III: crop requirements. General Administration for Development Cooperation, Agricultural

Publication No. 7, Brussels-Belgium

Uzoho, B.U, Ekpe I.I., Ahukaemere, C.M., Ndukwu, B.N., Okoli N.H., Osis F.A and Chris-Emenyeonu, C.M. (2014). Nitrogen status of soils of selected land uses of cropping systems in the humid tropical rainforest, Southeastern Nigeria. *Advances in life Sciences and Technology* 25: 24-33

Van Reeuwijk, L.P. (1992). Procedures for soil analysis. 3rd edition. International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands. 34p

PHYSICAL PARAMETERS FERTILITY INDICATORS OF SELECTED CROP AND GRAZING LAND SOILS IN NORTH WEST PROVINCE OF SOUTH AFRICA

[1]Ogboin, P. T., [2]Kutu, F. R. and [3]Dickson, A. A.
Faculty of Natural and Agricultural Sciences, Food Security and Safety Niche Area Research Group, North-West University, Mafikeng Campus, Private Bag x2046, Mmabatho 2735, South Africa
University of Mpumalanga, Private Bag 11283, Mbombela, 1200 C/o D725 and R40, Riverside, Mbombela, South Africa, 1200
Faculty of Agriculture, Department of Crop and Soil Science, Niger Delta University, Wilberforce Island, Amassoma, Bayelsa State, Nigeria
Corresponding author email:ogboinpayou@gmail.com

ABSTRACT
Soil physical properties as fertility indicators represent the foundation for expressing chemical fertility of soils fundamental to plant growth. This study assessed the soil physical properties as fertility indicators of twelve different farmlands with distinct land use types and soil characteristics. One hundred and eighty surface and sub-surface soil samples were collected from four districts, distributed randomly across smallholder crop farm, commercial crop farm and communal grazing land, and analysed for selected physical properties (indicators) including water holding capacity, bulk density, **,** *total porosity, particle size distribution and silt/clay ratio. Computed mean values of these parameters were compared with established critical limits. The findings identified two soil textural classes. Results of physical indicators significantly ($p\leq 0.05$) varied across location, land use and soil depth. Water holding capacity of 63.7% was identified for smallholder crop farm (SCF), bulk density ($1.33 g/cm^3$) for commercial crop farm (CCF), TP (52.10%) and silt/clay ratio (1.40) were for communal grazing land (CGL). The soil physical propertied identified as fertility indicators of the various farmlands established that sustainable agricultural production could be practiced based on the critical limits of these parameters.*
Keywords: *land use types, critical limits, bulk density, soil porosity, water holding capacity, soil texture.*

1. Introduction

Physical parameters as fertility indicators of soil refer to the ability of these indicators to provide air, water and spaces to roots of the plants (Glinski, 2018). It could also be described in terms of its texture (particle size distribution), bulk density, particle density, porosity, water holding capacity, moisture content, temperature, friability and other parameters (Brady & Weil, 2013). Agricultural production depends much on the physical characteristics of soil and soil fertility enhancement is associated mainly those specific indicators or properties relating to water holding capacity and transmission capacities (Indoria *et al.*, 2017). Most physical properties considered as fertility indicators of soil possess prominent effects on the chemical and biological soil conditions, and these in turn influence plant growth (Delgado & Gómez, 2016). The combination of physical fertility indicators (parameters) of soil can impede or foster root development, shoot emergence and has effects on nutrient supply and pH (Rogers, 2015). They also plays functional roles in plant support capability for crops, movement, retention, availability of water, nutrients supply to plants, the penetration of roots, flow of heat and air (Phogat *et al.*, 2015).

Soil physical properties closely relate to agricultural land uses, cropping systems and their management practices (Agbede, 2010; Wang, 2010). There is serious concern that agricultural production could change the soil physical properties, as successful agricultural production entails sustainable use of soil physical parameters as fertility indicators (Indoria *et al.*, 2017). However, soil physical fertility indicators, including resilience characteristics, can decline rapidly within a short time (Brady & Weil, 2002). Arable farmlands in the North West Province (NWP) currently face the problem of soil physical fertility decline due to poor soil management (Moussa, 2007). In combating the on-going soil physical fertility problems with concerted efforts towards enhancing land productivity through sustainable use of soil resources, there is need to understand the soil physical fertility indicators (parameters) of the different land uses. The knowledge of soil physical fertility indicators is essential in defining and improving soil management practices to achieve optimum agricultural production (Dexter, 2004; Indoria *et al.*, 2017). However, little information is available on the physical properties that can be considered as fertility indicators of the study area. Therefore, this study assesses the soil physical properties considered as fertility indicators across selected smallholder and commercial crop farms as well as communal grazing lands in the research area, to proffer useful guide on effective management of lands for increased productivity.

2. Materials and Methods

2.1 Description of the Research Area

The research was carried out on farmlands located in four districts of NWP where crop cultivation and animal grazing are practiced. The districts are Dr Ruth Segomotsi Mompati (Taung) in the west, Ngaka Modiri Molema (Itsoseng) in the central part, Bojanala (Mathopestad) in the eastern part and Dr Kenneth Kaunda (Ventersdorp) in the south of the province (Figure 1). Geographical co-ordinates of the study area span between 24 38’ 10” S and 26 27’ 7” S latitude, 22 37’ 44” E and 28 57’ 20” E Longitude. North West Province is situated in the extreme national border part of South Africa (SA) and has precincts with Northern Cape to the west, Free State to the south, Gauteng and Limpopo to the east and an international border with Botswana to the north. The province also border with the Kalahari Desert in the west (READ, 2014). It covers a total land area of 116 320 km^2 (Walmsley & Walmsley, 2002), representing 9.7% of the total area of South Africa (Masigo & Matshego, 2005). The area is relatively uniform in terrain with flat topography in the west and central parts and undulating topography in the eastern part while the altitude ranges between 800 to 1100 m (Mangold *et al.*, 2002).

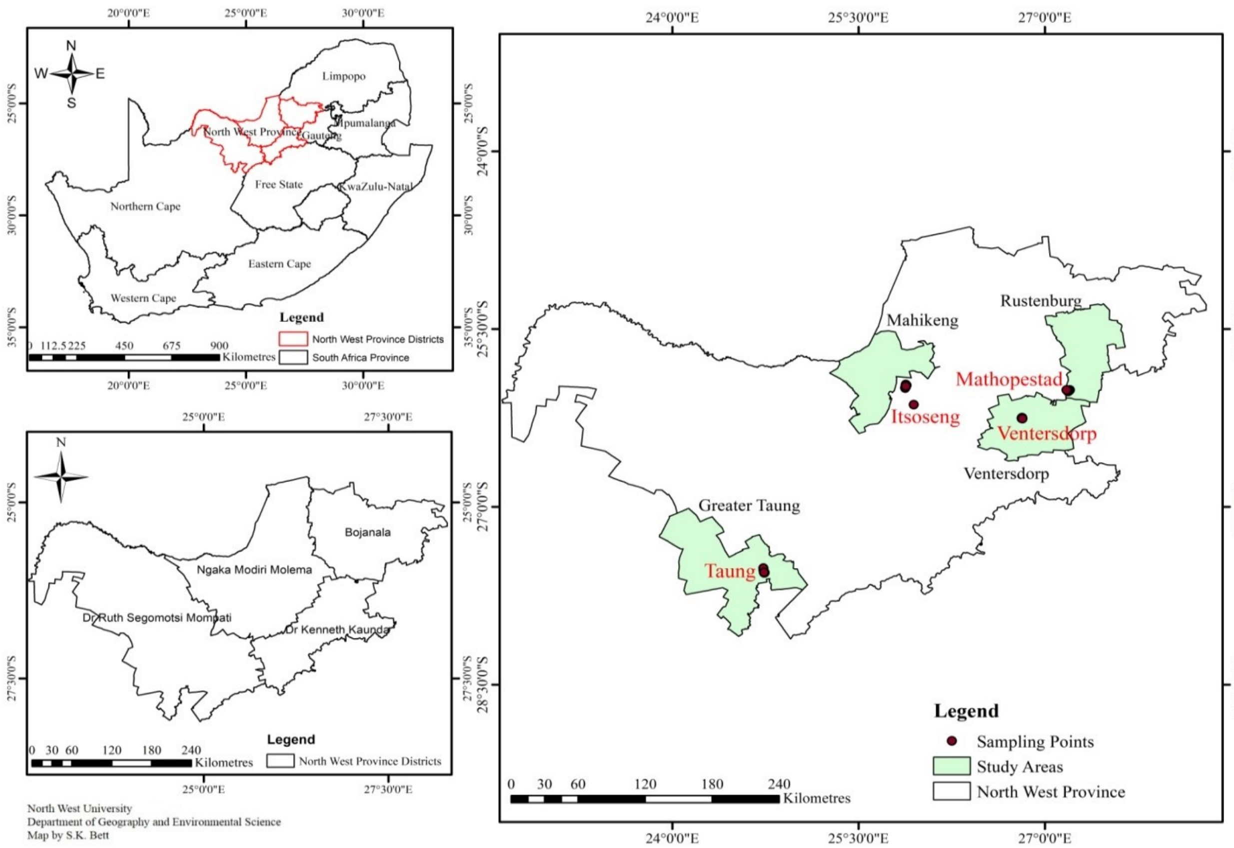


Figure 1: Map of the research area in NWP of South Africa

2.2 Climate of the Province

The NWP is semi-arid with rain pattern varying from east to west. Eastern portion of the region being wetter than the western part. Three different rainfall regimes are distinguished annually in the North West Province: 600 to 700 mm in the east, between 500 to 600 mm in the central, 400 to 500 mm in the west and less than 300 mm in the Kalahari area (Moussa, 2007; Sanchez, 2002).

The mean annual pan evaporation of North West Province is about 1800mm (Mangold *et al.*, 2002). Temperatures vary between extremes of -6.0° in the winter and 40°C in summer with an average of 19° C. The mean summer maximum temperatures vary from the high twenties to thirties (ºC) while the minimum in winter usually varies in the teens (13 to 19 o C) (Mangold *et al.*, 2002; Walmsley & Walmsley, 2002).

2.3 Vegetation

About 71.35% of the vegetation of NWP falls within savannah vegetation while the remainder falls within the grassland vegetation (Walsley &Walmsley, 2002). There are four major vegetation types in the province: Highveld in the south-east, Bushveld in the north-east, Middleveld as a thin region between the Highveld and the Bushveld and Kalahari Desert in the west (Mucina & Rutherford, 2006; Walmsley & Walmsley, 2002).

2.4 Geological and Agricultural Activities in NWP

Geology of the north east and north central regions of NWP are dominated by igneous rocks formation, whereas sedimentary rocks are found in the north western part (Moussa *et al.*, 2009; Venter *et al.*, 2012). These formations constitute the parent materials from which the soils are derived.

Agricultural activities in the province are pasture and forestry, cattle ranching and wildlife-related tourism (Masigo & Matshego, 2002). Irrigated agriculture is widely practiced in association with ostrich and chicken farming (Kasirivu *et al.*, 2011). The crops planted across the province are maize (*Zea mays L.*), sunflower (*Helianthis anuus*), groundnuts (*Arachis hypogaea*), sorghum (*Sorghum vulgare*) and vegetables such as spinach (*Spinnacia oleracea),* cabbage *(Brassica oleracea)*, beetroot *(Beta vulgaris),* and onions *(Allium cepa)* (Materechera, 2010).

2.5 Soils in the Study Area

Soils in the study area are largely sandy textured in the north-western region. Soil in the central region is dominated by red or brown sands with rock as well as weakly developed limestone soils associated with dolomite formations. The south-western part is characterised by undistinguishable rock and lithosol, soils containing coarse fragments and rock found at depths less than 30cm. The north-eastern region has lithosols, the southern and central regions are dominated by clay as well as sands and loams. The drier western region is characterised by red to yellow sands, while the southwest has sands high in calcium (De Villers and Mangold, 2002).

2.6 Soil Sample Collection

Soil sample collection was made from one smallholder crop farm, one commercial crop farm and one communal grazing land area in each of the four districts, Mathopestad (Bojanala), Itsoseng (Ngaka Modiri Molema), Ventersdorp (Dr Kenneth Kaunda) and Taung (Dr Ruth Segomotsi Mompati (Figure 1). Each of the twelve farms were sampled randomly and geo-referenced. Soil samples were collected from 5 points in each sampling site, using a soil auger and hand trowel at a depth of 0-15cm, 15-30cm and 30-45cm. The samples were bagged, labelled then taken to the laboratory for analysis. The samples were air-dried, crushed with a mortar and pestle, sieved through 2 mm sieve, and bagged with proper labelling. A total of 180 soil samples were collected for this study.

2.7 Laboratory determination of the soil physical indicators

2.8 Procedures for physical analysis

Soil samples collected were subjected to selected critical physical determinations that relate to soil fertility management with the following specific procedures.

2.9 Bulk Density (BD) and Total Porosity (TP) Analysis

Bulk density determination was based on the method described by Estefan et al. (2013) using a core method. The core sampler with a diameter of 5.2 cm and 10.2 cm height was pressed into the soil to reach the sampling depth and filled the inner cylinder with soil without compacting the sample. The soil sample was carefully removed, bagged and taken to the laboratory. The wet sample was weighed and recorded. It was oven dried at 105ºC to constant weight and the bulk density and total porosity were calculated.

2.10 Particle Size Analysis (PSA)

Soil texture determination was done using the hydrometer method as described by Okalebo *et al.*(2002). Fifty (50) gm of the soil sample was weighed into 400 ml polyethene bottle and 25 ml of 5% of sodium hexametaphosphate (calgon) dispersing solution, 200 ml of tap water was added and mixed thoroughly. Samples in well-labelled bottles with cork were transferred into a reciprocal shaker followed by 30 minutes of shaking for dispersion. Thereafter, the dispersed content of each sample bottle was completely transferred and washed into one litre cylinder, and made up to a litre mark with distilled water. The content of the cylinder mixed at least 10 times through end to end with the palms and the cylinder placed on the bench and the time immediately noted. After 15 seconds, a hydrometer was gently placed into the suspension and hydrometer reading taken after 40 seconds with the temperature reading simultaneously recorded; and this gives the weight of silt and clay in the 1 litre solution. After 2 hours, the hydrometer and temperature readings were recorded, temperature correction was made using the table as in Okalebo *et al.,* (2002) and calculations were made to obtain the different size fractions values for sand, silt, and clay under standard temperature.

2.11 Water Holding Capacity (WHC)

Soil water holding capacity (WHC) was determined using the method as described by Estefan *et al.* (2013). Thoroughly air-dried 2mm soil sample was mixed and 20 gm weighed into a filter paper in a funnel attached to a conical flask. The funnel filled with 20 ml of water using a graduated measuring cylinder until the sample was covered. The amount of water added was recorded and left to set until the sample was fully saturated. Water was drained into a conical flask for about 24 hours and the amount of water collected in the flask was measured with a graduated measuring cylinder and recorded. Water holding capacity was calculated using the formula: Water Holding Capacity (ml/l) =Water retained (ml)/100ml sample x10.

2.12 Data analysis

Statistical evaluation of the physical fertility indicators (properties) of soils in the study area was made on the physical parameters from the laboratory analyses. In other words, the results of the laboratory analyses were compared with critical levels for different classes of the respective parameters in evaluating the physical fertility indicators of soils. Data on laboratory analysis on soil samples were subjected to analysis of variance (ANOVA) and Pearson's correlation was applied to determine the association between the measured parameters. All statistical tests were conducted using Gen Stat Release Version 10.3 DE software package.

3. Results

3.1 Physical parameters as indicators of the soils from different land use types

The key selected physical parameters as indicators of soils that relate to fertility such as texture, silt/clay ratio, water holding capacity, bulk density, and total porosity results are presented in Table 1. The measured contents of these physical indicators were significantly different across the four locations ($p \leq 0.05$), land use types and soil depths. Soil samples from Taung had the highest mean sand content (73.16%) while soils from Ventersdorp had 57.90% sand content. The mean sand content in soils from Itsoseng and Mathopestad were not significantly different ($p \geq 0.05$). Soil samples obtained from Ventersdorp had the highest silt proportion (24.96%), which was significantly different. On the other hand, mean clay content in soils from Mathopestad was significantly higher than soils from all other locations while the silt/clay ratio was highest in Taung (1.81) and differed significantly from other locations. The highest (66.06%) recorded mean WHC of soils was from Mathopestad and differed significantly from the percent WHC of soils from other locations while the lowest (53.67%) was recorded from Taung.

Table 1: Effect of variation in location, land use types and soil depth on mean values of measured soil physical parameter indicators

Treatments	Sand %	Silt %	Clay %	Si/C Ratio	WHC %	BD g/cm³	TP %	STC
Locations								
Itsoseng	63.10b	19.14b	17.48b	1.19c	63.83b	1.29b	51.47b	SL
Mathopestad	64.72b	10.35d	24.92a	0.60d	66.06a	1.13c	57.49a	SCL
Taung	73.16a	15.94c	11.25c	1.81a	53.83d	1.41a	46.89c	SL
Ventersdorp	57.90c	24.96a	17.22b	1.54b	57.67c	1.39a	47.70c	SCL
LSD (0.05)	2.37	2.14	2.12	0.27	1.53	0.09	3.31	
Land use types								
CCF	64.75b	16.61b	18.38a	1.22	59.67b	1.33	49.85b	SL
CGL	67.35a	17.05b	15.89b	1.40	57.71c	1.31	50.72a	SL
SCF	62.06c	19.14a	18.89a	1.24	63.67a	1.27	52.10a	SL
LSD (0.05)	2.05	1.85	1.84	NS	1.33	NS	2.87	
Soil depth (cm)								
0 – 15	65.88a	18.54	15.64b	1.56a	59.88	1.31	50.89	SL
15 – 30	65.60a	17.08	17.40b	1.28b	60.33	NA	NA	SL
30 – 45	62.68b	17.17	20.12a	1.01c	60.83	NA	NA	SL
LSD (0.05)	2.05	NS	1.84	0.24	NS			

Main effect means within a column followed by the same letters are not significantly different from each other at $p \leq 0.05$; NS = not significant; STC = soil texture class; SL = sandy loam; SCL= sandy clay loam; TP = total porosity; CCF = commercial crop farm; CGL= communal grazing land; SCF= smallholder crop farm; NA = not applicable.

The recorded mean soil BD differed significantly across the different locations with the highest value (1.41 g/cm^3) in soil samples collected from Taung, which was not statistically different from soil samples collected from Ventersdorp. However, soils from Mathopestad had the least mean BD value of 1.13 g/cm^3. The recorded mean total porosity of 57.49% in soils from Mathopestad was highest and significantly different from the measured mean values from other locations with the least obtained mean porosity value of 46.89% recorded in the soil sample from Taung.

There was a significant variation in the three primary soil particles (sand, silt and clay) across the different land uses ($p \leq 0.05$). The highest recorded mean sand content 67.35% was on the communal grazing land (CGL) while the lowest mean value of 62.06% was on smallholder crop farm (SCF). The highest mean silt content of 19.14% was in SCF and the least recorded silt content value of 16.61% was in CCF. Although there was a significant variation in the mean clay content across land use types, the difference in mean clay content obtained in CCF and SCF was statistically the same but the highest value of 18.89% was in SCF. The highest recorded silt/clay ratio of 1.40 was from CGL while the least ratio of 1.22 was in CCF. Water holding capacity differed significantly across the variety of land use types with the highest recorded mean value of 63.67% obtained in SCF and the least value of 57.71% in CGL. There was no significant difference in the mean BD values measured across the land use types but CCF recorded the highest mean BD of 1.33 g/cm^3 while SCF recorded the lowest value of 1.27 g/cm^3. There was significant variation in total porosity ($p \leq 0.05$) across different land use types.

Significant variation in sand content was observed along soil depth with the recorded highest mean sand content of 65.88% obtained at the surface 0 - 15 cm depth while the least value of 62.68% was at 30 - 45 cm depth. There was no significant variation in silt content across soil depth but highest mean value of 18.54% was at 30 – 45 cm depth while the lowest value of 17.07% was by 15 - 30 cm depth.

Significant variation in clay content was found along soil depth. The highest recorded mean clay of 20.12% was at 30 - 45 cm while the least mean value of 15.64 % was at the surface 0 - 15 cm depth. Silt/clay ratio was significantly different across depth and the highest (1.56) obtained at 0 - 15 cm and lowest (1.01) at 30 - 45 cm depths. Water holding capacity was not statistically significant in the soil depths although, the recorded highest mean content of 60.83% was at 30 – 45 cm and the least (59.88%) was at 0 - 15 cm depth. Highest BD and total porosity values of 1.33 g/cm^3 in CCF and 52.10 %in CGL respectively were in the surface soils. Generally, the soil textures were sandy loam at both Itsoseng and Taung but sandy clay loam at both Mathopestad and Ventersdorp while the different land use types are dominated by sandy loam textural class at the surface 0– 30 cm depths but sandy clay loam texture at depths beyond 30 cm.

3.2 Interaction effect of location, land use types and soil depths on physical parameter indicators of soil

Interaction effect of location, land use types and soil depths on water holding capacity and sand fraction are presented on Table 2. Water holding capacity was significantly influenced by location, land use type and soil depth. The WHC highest value of 70.50% was in soil sample obtained from 0 – 15 cm soil depth at Itsoseng under SCF and the least (49.50 %) WHC was at Taung CGL from 0 – 15 cm depth. Sand particle distribution was highest (80.8%) at Taung from 0 - 15 cm depth. Conversely, the least sand (54.1%) was observed in Ventersdorp CGL from 30 – 45 cm depth.

Table 2: The interaction effect of location, land use types and soil depths on water holding capacity and sand particles in soils from North West Province

Land use	Location	Water holding capacity (%)			Sand (%)		
		0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
CCF	Itsoseng	60.5ghijk	62.0efgh	64.0cdefgh	62.5efghijkl	58.2hijkl	56.2l
CGL		61.0ghij	59.5ghijklm	60.0ghijlmk	68.8cdefg	71.7bcd	66.0defghi
SCF		70.5a	67.0abcde	70.0ab	62.4efghijkl	62.0efghijkl	60.8fghijkl
CCF	Mathopestad	61.5fghij	63.5defgh	66.5abcdef	65.1defghijk	70.0bcde	62.4efghijkl
CGL		65.0bcdefg	67.0abcde	64.5cdefg	65.2defghijk	66.3defgh	59.4hijkl
SCF		70.0ab	69.0abc	67.5abcd	69.3cdef	65.4defghij	59.4hijkl
CCF	Taung	50.5pq	53.5nopq	53.0opq	76.8abc	75.6abc	77.6ab
CGL		49.5q	49.0q	48.5q	80.8a	81.2a	80.4a
SCF		58.5hijklmn	60.5ghijk	61.5fghij	62.4efghijkl	62.8efghijkl	60.8fghijkl
CCF	Ventersdorp	59.5ghijklm	60.5jklmno	61.0ghij	59.2hijkl	57.2ijkl	56.8jkl
CGL		55.0kmnop	56.5ijklmno	57.0ijklmno	58.1hijkl	56.4kl	54.0l
SCF		57.0ijklmno	56.0kmnop	56.5ijklmno	60.5ghijkl	60.5ghijkl	58.5hijkl

Interaction effect within a column followed by the same letters is not significantly (p≥0.05) using Duncan's multiple range test at p≤ 0.05, CCF = commercial crop farm, CGF = communal grazing land, SCF = smallholder crop farm.

The interaction effect of location, land use type and soil depth on silt and clay samples are presented on Table 3. Smallholder crop farm in Ventersdorp obtained the highest (26.5%) silt at 30 – 45 cm depth, the least silt value (4.4%) was obtained in CCF at Mathopestad from 15 – 30 cm depth and there was significant variation across location, land use and soil depth. The highest (30.6%) clay was observed in Mathopestad CCF from 30 - 45 cm depth and the lowest value (5.8%) was recorded in Taung CGL from 0 – 15 cm depth. Clay significantly varied across location, land use and depth of soil.

Table 3: Interaction effect of location, land use and soil depths on silt and clay particles in North West Province

Location	Land use	Silt (%)			Clay (%		
		Depth (cm)			Depth (cm)		
		0-15	15-30	30-45	0-15	15-30	30-45
Itsoseng	CCF	19.9abcdefghi	21.6abcdefgh	19.5abcdefghij	18.16cdefgh	20.2bcdefgh	22.6bcdefg
	CGL	17.3cdefghijkl	14.5ghijklmn	18.6bcdefghijk	13.8hijkl	13.8hijkl	15.4ghij
	SCF	22.2abcdefg	21.00abcdefgh	18.2bcdefghujk	15.4ghij	17.0defghi	21.5bcdefgh
opestad	CCF	7.5mno	4.4o	7.8no	26.9ab	25.7abc	30.6a
	CGL	14.2hijklmn	11.0klmno	16.6defghijkl	20.7bcdefgh	22.6bcdefg	24.4abcde
	SCF	12.3ijklmn	9.9lmno	10.4lmno	18.4cdefgh	24.7abcd	30.3a
Taung	CCF	16.2efghijkl	16.6defghijkl	12.2ijklmn	7.5lm	7.8klm	10.2ijklm
	CGL	15.0ghijklm	13.0ijklmn	11.8jklmn	5.8m	7.0lm	8.2jklm
	SCF	24.2abcd	18.60bcdefghjik	15.8fghijkl	13.4hijkl	18.5cdefgh	23.4abcdef
Ventersdorp	CCF	23.8abcde	26.1ab	25.0abc	16.6fghi	16.6efghi	18.2cdefgh
	CGL	24.1abcd	23.4abcdef	25.0abc	17.8defghi	20.2bcdefgh	21.0bcdefgh
	SCF	25.7ab	24.9abc	26.5a	13.8hijkl	14.6hijk	16.2fghi

Interaction effect within a column followed by the same alphabets is not significantly (p≥0.05) different using DMRT at p≤ 0.05; CCF = commercial crop farm, CGF = communal grazing land, SCF = smallholder crop farm.

The consideration of data pertaining to silt: clay ratio and interaction effect clearly indicated that location, land use types and soil depth was significant (Table 4). The maximum silt: clay ratio (3.7) was recorded from 0 - 15 cm depth in Taung CGL and the least value (0.2) obtained in Mathopestad CCF from 15 – 30 cm.

Table 4: Interaction effect of location, land use and soil depths on silt/clay ratio in North West Province

Silt/Clay ratio				
Location	Land use	Depth (cm)		
		0-15	15-30	30-45
Itsoseng	CCF	1.1defghijkl	1.2defghij	0.8fghijkl
	CGL	1.4cdefgh	1.1defghijkl	1.2defghi
	SCF	1.6cdefg	1.4cdefgh	0.9efghijkl
Mathopestad	CCF	0.3ijkl	0.2jl	0.2ijkl
	CGL	1.0defghijkl	0.8fghijkl	1.0efghijkl
	SCF	0.9fghijkl	0.5hijkl	0.5hijkl
Taung	CCF	2.7ab	2.4abc	1.056defghijkl
	CGL	3.7a	2.0bcd	1.4cdefgh
	SCF	1.9bcde	1.2defghijk	0.7ghijkl
Ventersdorp	CCF	1.6cdefg	1.7cdefg	1.4cdefgh
	CGL	1.5cdefgh	1.2defgh	1.2defghi
	SCF	1.9bcde	1.8bcdef	1.6cdefg

Interaction effect within a column followed by the same letters is not significantly different from each other at p ≤ 0.05; CCF = commercial crop farm, CGF = communal grazing land, SCF = smallholder crop farm.

3.3 Relationship between Soil Physical Properties

Correlation analysis results of the physical parameters presented in Table 5 indicate that clay had highly significant positive relationship with WHC ($r = 0.628, p < 0.01$), and total porosity ($r = 0.523$, $p < 0.01$) while it had negative relationship with BD ($r = -0.523$, $p < 0.01$), sand ($r = -0.595$, $p < 0.01$), and silt ($r = -0.328$, $p < 0.01$). Relationship amid silt and BD was significant and positive ($r = 0.296$, $p < 0.05$) however, it had an inverse association with porosity ($r = -0.269$, $p < 0.05$), WHC ($r = -0.157$, $p < 0.05$), and sand ($r = -552$, $p < 0.01$). Sand had a positive relationship with BD ($r = 0.226$), negative relationship with porosity ($r = -0.226$) and both were not significant, but had highly significant negative relationship with WHC ($r = -0.552$, $p < 0.01$). The relationship between WHC and porosity was highly significant and positive ($r = 0.648$, $p < 0.01$) but this had a highly significant negative relationship with BD ($r = -0.648$, $p < 0.01$). Porosity also had highly significant negative relationship with BD ($r = -1.000$, $P < 0.01$). Silt/Clay had highly positive significant relationship with BD ($r = 0.408$, $p < 0.01$), sand ($r = 0.197$, $p < 0.01$), silt ($r = 0.566$, $p < 0.01$) and had highly negative significant relationship with porosity ($r = -0.408$, $p < 0.01$), WHC ($r = -0.501$, $p < 0.01$) and clay ($r = -0.761$, $p < 0.01$).

Table 5: Pearson's Correlation matrix between soil physical properties

	BD	Porosity	WHC	Sand	Silt	Clay	Silt/Clay
BD	1	-1.000**	-.648**	0.226	.296*	-.523**	.408**
Porosity		1	.648**	-0.226	-.296*	.523**	-.408**
WHC			1	-.425**	-.157*	.628**	-.501**
Sand				1	-.552**	-.595**	.197**
Silt					1	-.328**	.566**
Clay						1	-.761**
Silt/Clay							1

** Correlation is significant at the 0.01 level.
* Correlation is significant at the 0.05 level.

4. Discussion

4.1 Physical parameter indicators of soils

Physical parameter indicators of soils generally include texture, bulk density, porosity, aggregate stability and others. These affect processes of water retention and other attributes (Schoenholtz *et al.*, 2000).

Soil is basically seen as being physically poor when it shows low rates of water infiltration, as a result of surface runoff, poor consistency, low aeration, poor root density and difficulty for mechanization (Dexter, 2004). Soil texture is a vital factor that influences the balance between water and gases, but it is very constant over time, independent of soil management. However, bulk density and total porosity can reasonably affect water/air relationships, soil use and management (Beutler *et al.*, 2002).

Textural class indicators of soils in North West Province differ across different locations with respect to the physical indicators measured and these are presented in Table 2. The soils from Itsoseng and Taung appeared similar texturally but, the indicators differed statistically. This suggests that soils may have similar textural classes but different properties. This means that soil must be properly evaluated based on physical indicators rather than textural classification, which provides only a broad categorisation rather than specific and unique features of the soils. The distribution of sand, silt and clay fractions were influenced by all factors studied, viz: location, land use and soil depth. Soil separates rated as very low (< 10%), low (10 – 25%), moderate (25 – 40%), high (40 - 50%) and very high (>50) for sand, silt and clay contents respectively (Hazelton and Murphy, 2016). According to the Hazelton and Murphy ratings, sand was rated high in the study area. Taung communal grazing land recorded the highest amount of sand particles at 0 – 15 cm depth and significantly differed from all other locations and land use types but had no statistical difference on soil depth. The higher sand content of the soils could be attributed to the granite (igneous) parent material over which they are formed or may be possibly influenced by the physical pedogenic process in the location. Generally, soils from Taung area had more sand than all other locations. It could be inferred that these soils have developed in recently deposited sand materials such as alluvium or dunes (Bruandi *et al.*, 2005). The result is in line with Saley Moussa (2007) who reported that soils from western Bophirima area of NWP was dominated by sand particles and low in silt and clay fractions.

The eeffect of location, land use and soil depth on silt and clay are shown in Table 2. Silt was rated low, while clay was low - moderate in the study area. The highest silt content was observed in Ventersdorp smallholder crop farm. Silt content was rated low at all depths and locations and was significantly higher at 30 – 45 cm depth. The highest clay was observed in Mathopestad commercial crop farm at 30 – 45 cm depth and was influenced by soil depth, but rated moderate. The content of clay increased with depth. This could be due to clay migration or illuviation. Essoka and Esu (2003) presented increase in clay with soil depth showing that clay had moved down the profile by lessivage. In general, the distribution of sand, silt, and clay were irregular in the different locations and land use types, which could be attributed to the different tillage practices made in the area.

There was a clear indication that location, land use and soil depth had significant effect on silt/clay ratio (Tables 2 and 5). Silt/clay ratio highest was recorded in Taung CGL at 0 – 15 cm depth and significantly higher than other locations and depths. Egbuchua and Ojobor (2011), reported that silt/clay ratios of soils below 0.15 was attributed be old parent material, while those above 0.15 were regarded as young parent materials. The soils recorded silt/clay ratio of more than 0.15 confirming that the soils were of young parent materials and has good potential for weathering to release nutrients over time. It was also reported by Nwaka and Kwari (2000) that in sandy soils, high silt/clay ratio may be related to the coarse texture of the parent material and youthfulness of the soil.

4.2 Structural Indicators of the Soils

Structural indicators of soils are physical attributes affected by physical indicators such as water holding capacity, porosity and others are very pertinent in crop production (Dexter, 2004). Effect of location, land use and soil depth on water holding capacity (WHC) of the research area are presented in Table 3. The significant effects of location, land use and soil depth on WHC could be attributed to the differences in soil particle distribution and organic carbon content. The maximum value was recorded on SCF Itsoseng at 0 – 15 cm depth and this significantly differed across soil depth. The diverse land uses differed in their water holding capacities due to the variations in sand, silt and clay contents. Similar research results were reported by Wakene (2001) that WHC is influenced by particle size distribution. This result confirms Evanylo and McGuinn (2009) who reported that soils with great water retaining capacity provide more water to the plant, but soil texture also determines what portion of the soil water is available to plants. Same authors also reported that clay soils retain more water, sandy soils the least, and loamy soils intermediate. Still, loamy soils provide the most plant available water because considerable amount of the water in the small pores in clay soils are held too strongly and unavailable to plants.

The bulk density (BD) values obtained in the area are shown in Table 2 and were ideal for normal crop growth compared with the ideal bulk densities (g/cm^3) developed by Evanylo & McGuinn, 2009). Taung recorded the highest BD, but was not significantly higher than Ventersdorp. Soils with high bulk density cause restrictions to root growth, poor movement of air and water through the soil (Gleason *et al.*, 2008). Generally, soils with low bulk densities have favourable physical conditions for plant growth (Chaudhari *et al.*, 2013). Total porosity (TP) values are presented in Table 2. The Table depicts a significant effect of land use as well as location on the total porosity of the soils. The highest was recorded in Mathopestad and might be attributed to its high clay content. High clay content increases soil total porosity (Brady & Weil, 2013). The soil total porosity can be classified based on the size and connectivity of the pores. Typically, total porosity can be categorized into micro and macro pores. The macro pores are easily affected by land use and soil management (Dexter, 2004). However, least value of total porosity was obtained in Ventersdorp. Generally, the soils are within range for normal crop growth. Conversely, the least total porosity was higher than the critical value of 30% in compacted sub soils, while more than 60% in well-aggregated and high OM surface soils (Brady & Weil, 2013).

5. Conclusion

The results of this study showed a marked variation in soil physical properties as fertility indicators across the different locations, land use types and soil depths, which might have been influenced by the farming systems and environmental factors of climate and topography. Textural classes obtained in the study area ranged from sandy loam to sandy clay loam. Water holding capacity, BD and TP recorded in the study area were ideal for normal crop growth.

References

1.Beutler, A., Centurion, J., Souza, Z., Andrioli, I. & Roque, C. 2002. Water retention in two oxisols under different uses. *Revista Brasileira de Ciência do Solo*, 26(3):829-834.

2. Bouyoucos, G.J. 1951. A Recalibration of the Hydrometer Method for Making Mechanical Analysis of Soils 1. *Agronomy Journal*, 43(9):434-438.

3. Brady, N.C. & Weil, R. 2013. Nature and properties of soils. The Pearson new international edition: Pearson Higher Education.

4. Bruandi, A., Hartmann, C. & Lesturgez, G. 2005. Physical properties of tropical sandy soils: A large range of behaviour. In *Management of Tropical Sandy Soils for Sustainable Agriculture Proceedings*. pp 148-158. FAO Bangkok.

5. Chaudhari, P.R., Ahire, D.V., Ahire, V.D., Chkravarty, M. & Maity, S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications*, 3(2):1-8.

6. Delgado, A. & Gómez, J.A. 2016. *Principles of Agronomy for Sustainable Agriculture*. Springer. p. 15-26).

7. De Villers, B. & Mangold, S. 2002. The biophysical environment. In Mangold, S., Kalule, M., and Walmsley, J., 2002. State of the environment report 2002 North West Province, South Africa, North West Province Department of Agriculture, Conservation and Enviroment 2002. Full report http://www.nwpg.gov.za/soer/fullreport.

8. Dexter, A.R. 2004. Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma*, 120(3-4):201-214.

9. Egbuchua, C. & Ojobor, S. 2011. Characterization of some hydric soils in the Niger-Delta region of Nigeria for land evaluation purposes. *International Journal of Advanced Biological Research*, 1(1):77-82.

10. Essoka, A. & Esu, I. 2003. Profile distribution of sesquioxides in the inland valley soils of Central Cross River State, Nigeria. *Nigerian Journal of Soil and Environmental Research*, 4(1):41-49.

11. Estefan, G., Sommer, R. & Ryan, J. 2013. Methods of soil, plant, and water analysis. *A manual for the West Asia and North Africa region*:170-176.

12. Evanylo, G. & McGuinn, R. 2009. Management practices and soil quality: Measuring, assessing, and comparing laboratory and field test kit indicators of soil quality

attributes. *Virginia Cooperative Extension*:450-400.

13. Gleason, R.A., Laubhan, M.K., Euliss Jr, N.H., Tangen, B.A. & Kermes, K.E., 2008. Ecosystem services derived from wetland conservation practices in the United States Prairie Pothole Region with an emphasis on the US Department of Agriculture Conservation Reserve and Wetlands Reserve Programs. US Geological Survey, Reston, Virginia.
14. Glinski, J. 2018. Soil physical conditions and plant roots. CRC press.
15. Group, S.C.W. & Macvicar, C. 1991. Soil classification: A taxonomic system for South Africa. Pretoria: Department of Agricultural Development.
16. Hazelton, P. & Murphy, B. 2016. Interpreting soil test results: What do all the numbers mean? CSIRO publishing.
17. Indoria, A., Sharma, K., Reddy, K.S. & Rao, C.S. 2017. Role of soil physical properties in soil health management and crop productivity in rainfed systems: Soil physical constraints and scope. *Current science*, 112(12):2405.
18. Kasirivu, J., Materechera, S. & Dire, M. 2011. Composting ruminant animal manure reduces emergence and species diversity of weed seedlings in a semi-arid environment of South Africa. *South African Journal of Plant and Soil*, 28(4):228-235.
19. Mangold, S., Kalule-Sabiti, M. & Walmsley, J.J. 2002. State of the Environment: Report 2002, North West Province, South Africa: North West Province Department of Agriculture, Conservation and Environment.
20. Masigo, A. & Matshego, C. 2002. Provincial Report on Education and Training for Agriculture and Rural Development in North-West Province. *National Department of Agriculture: Mafikeng, South Africa*.
21. Masigo, A. & Matshego, C. 2005. Provincial Report on Education and Training for Agriculture and Rural Development in North-West Province. *National Department of Agriculture: Mafikeng, South Africa*.
22. Materechera, S.A. 2016. Soil properties and subsoil constraints of urban and peri-urban agriculture within Mahikeng City in the North West Province, South Africa. *South African J Soil Sediments*, 18: 494-505 DOI 10,1007/s 11 36 8-016-1569-0
23. Materechera, S.A. 2010. Utilization and management practices of animal manure for replenishing soil fertility among smallscale crop farmers in semi-arid farming districts of the North West Province, South Africa. *Nutrient cycling in agroecosystems*, 87(3):415-428.
24. Moussa, A.S., Van Rensburg, L., Kellner, K. & Bationo, A. 2009. Exploring differences of soil quality as related to management in semiarid rangelands in the western Bophirima District, North West province, South Africa. *African Journal of Range and Forage Science*, 26(1):27-36.
25. Mucina, L. & Rutherford, M.C. 2006. The vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute.
26. Nwaka, G. & Kwari, J. 2000. The nature and properties of the soils of Jere Bowl near Maiduguri in Borno State. *Samaru J Agric Res*, 16:25-40.
27. Okalebo, J.R., Gathua, K.W. & Woomer, P.L. 2002. Laboratory methods of soil and plant analysis:

A working manual. Second edition. Sacred Africa, Nairobi.

28. Phogat, V., Tomar, V. & Dahiya, R. 2015. Soil Science: An Introduction. *Indian Society of Soil Science IIndia,* p. 135-171).

29. Read, N. 2014. North West Environment Outlook Report 2013. *North West Provincial Government, Mahikeng, South Africa.- Anecdotal-- None*.

30. Rogers, D.H. 2015. Important agricultural soil properties. (Kansas State University. *Agricultural Experiment Station and Cooperative Extension Service); 935*.

31. Saley Moussa, A., 2007. Evaluation of selected soil properties in semi-arid communal rangelands in the Western Bophirima district, South Africa (Doctoral dissertation, North-West University).

30. Sanchez, P.A. 2002. Soil fertility and hunger in Africa. *Science*, 295(5562):2019-2020.

40. Schoenholtz, S.H., Van Miegroet, H. & Burger, J. 2000. A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. *Forest ecology and management*, 138(1-3):335-356.

41. Venter, A.D., Vakkari, V., Beukes, J.P., Van Zyl, P.G., Laakso, H., Mabaso, D., Tiitta, P., Josipovic, M., Kulmala, M. & Pienaar, J.J. 2012. An air quality assessment in the industrialised western Bushveld Igneous Complex, South Africa. *South African Journal of Science*, 108(9-10):1-10.

42. Wakene, N. 2001. Assessment of important physicochemical properties of Dystric Udalf (Dystric Nitosols) under different management systems in Bako area, Western Ethiopia. *A*lemaya University, Alemaya, Ethiopia.

43. Walmsley, D., Walmsley, J., Mangold, S. & Kalule-Sabiti, M., 2002. North West province state of the environment report: Overview. Mmabatho, South Africa: North West Department of Agriculture, Conservation and Environment.

44. World Reference Base for Soil Resources (WRB)2006. A Framework for International Classification, Correlation and Communication. World Soil Resources Rep.103. IUSS/ISRIC/FAO.

MINERALOGY OF SOME SELECTED SOILS OF THE RIMA VALLEY TERRACES AT GORONYO AREA, SOKOTO STATE, NIGERIA.

Haruna F.D. [1*], S.S. Noma[2], N.G. Hayatu[2], A. Aliyu[1], S. Sani[1], M.Y. Abdullahi[1], A. Nabayi[3], S. Dahiru[1], T. Mohammed[4] and A. Muhammad[5]

[1]*Department of Soil Science, Faculty of Agriculture, Federal University Dutsin-Ma, PMB 5001 Katsina State, Nigeria .*

[2] *Department of Soil Science and Land Resources Management, Usmanu Danfodiyo University, Sokoto, Nigeria.*

[3]*Department of Soil Science, Federal University Dutse, Jigawa State.*

[4] *Department of Soil Science and Land Management, Federal University of Technology Minna, Niger State, Nigeria.*

[5]*Department of Crop Protection, Faculty of Agriculture, Federal University Dutsin-Ma, PMB 5001 Katsina State, Nigeria .*

Corresponding author email:fharuna@fudutsinma.edu.ng

ABSTRACT

Mineralogical studies are conducted in order to take inventory of soil resources for effective and efficient utilization of the soils. Information regarding the mineralogy of the soils of the study area have not been documented. To address this, the mineralogical study was carried out to identify the minerals in the study area. A detailed soil survey was conducted at Rima Valley terraces Goronyo area at a scale of 1:5,000 for 50 hectares of land. Four profile pits were excavated and coordinates of each profile was recorded using GPS device. The soil profiles were described according to FAO guidelines. Nine soil samples were selected for mineralogical analyses. X-ray Diffraction Analysis (XRD) technique has been employed to study the mineralogy of the fine earth separates (<2mm). Quartz being the dominant mineral at both surface and subsurface horizons of the four profiles studied, 100% in seven out of nine horizons, except in C-horizon of pedon 3 (Birjingo series) where quartz was 28% and thorium carbide was 72% and in B2-horizon of pedon 4 (Majjiyar Maidagwaba series) maladrite was 90% while 10% was bismuth iodide. The dominance of quartz in most horizons indicates the presence of high resistance of the mineral to weathering and its dominance in the initial parent material.

Keywords: *Mineralogy, Cultivated Soils, Rima Valley Terraces, Goronyo Area.*

INTRODUCTION

Soil information is essential for taking appropriate land use decisions to achieve optimal productivity, ensure environmental sustainability and safeguard our civilization (Khordebin and Landi, 2011). The potentialities of soils can readily be tapped when information on physical, chemical, biological, morphological and mineralogical properties are available (Lawal *et al*., 2013). Soil mineralogy is determined because of its strong influence on soil behavior, its use in soil classification and relevance in soil genetic processes. An understanding of soil mineralogy is central to understanding virtually all facets of humanity's use and misuse of soils and is often the key to solving specific environmental problems (Schulze, 2002).

Minerals in soils form about 45% of the components of an ideal soil, while the remaining 55% are shared by soil organic matter (5%), soil water (25%) and soil air (25%) (CTAHR, 2007). Therefore, the major component of soil is the mineral matter which depends largely on the nature and composition of the parent rocks.

However, since about three fourths of the earth's crust is made up of silicon and oxygen, the silicate minerals occupy a central position in the mineral constituents of the soil (Mirsal, 2008). Soils commonly contain primary minerals, which are formed from magma and provide insight into characteristics such as parent material provenance, uniformity, and weathering rates (Warren and Thomas, 2008). Soils also contain secondary minerals, which are formed from weathering processes of primary minerals (Brady and Weil, 2002). The nutrient supply capacity of a soil through weathering of primary minerals diminishes as the extent of soil weathering increases (Brady and Weil, 2008). Quartz being the most abundant mineral after feldspars and widely distributed l found on Earth's surface. It is ubiquitous, durable and plentiful in all parts of the world. It forms at all temperature and abundant in igneous, sedimentary, and metamorphic rocks. The chemical composition of quartz is nearly 100% Silicon and Oxygen (SiO_2) (Geology, 2005). Although generally colourless due to its predominantly silicon and oxygen composition, quartz can exist in a wide array of colors because of impurities. Quartz is important for the Critical Zone because of its composition and distribution. Because quartz is resistant to weathering, it is often one of the last minerals to dissolve. Sand and gravel sized pieces of quartz act as a 'skeleton' for soil, providing porosity for water to infiltrate into soils. (Foster *et al.,* 2015). A downside of having soils dominant in quartz is that its silicon and oxygen structure does not provide other essential elements for plants thus, making it a poor substrate for plants to grow on only very tough and hardy plants capable of scrounging for nutrients directly from other minerals or relying heavily on atmospheric deposition of nutrients are able to live in the nutrient poor soils derived from predominantly quartz (Foster *et al*., 2015). Thorium carbide, maladrite and Bismuth iodide have no nutritional value to soils and plants but are used for numerous industrial uses. The bulk of the soil solid fraction is constituted by soil minerals, which exert significant direct and indirect influences on the supply and availability of most nutrient elements (Sparks, 2003). Soil minerals play vital roles in soil fertility since mineral surfaces serve as potential sites for nutrients' storage, in dictating the suitability and behavior of the soil for various land use, they contribute to soil structural formation, are sources of many plant nutrients, and can act as sorbents for several environmental pollutants (CTAHR, 2007). Therefore, it is important to know the types of minerals that make up a soil so that one can predict the degree to which the soil can retain and supply nutrients to plants (Silva and Uchida, 2000).

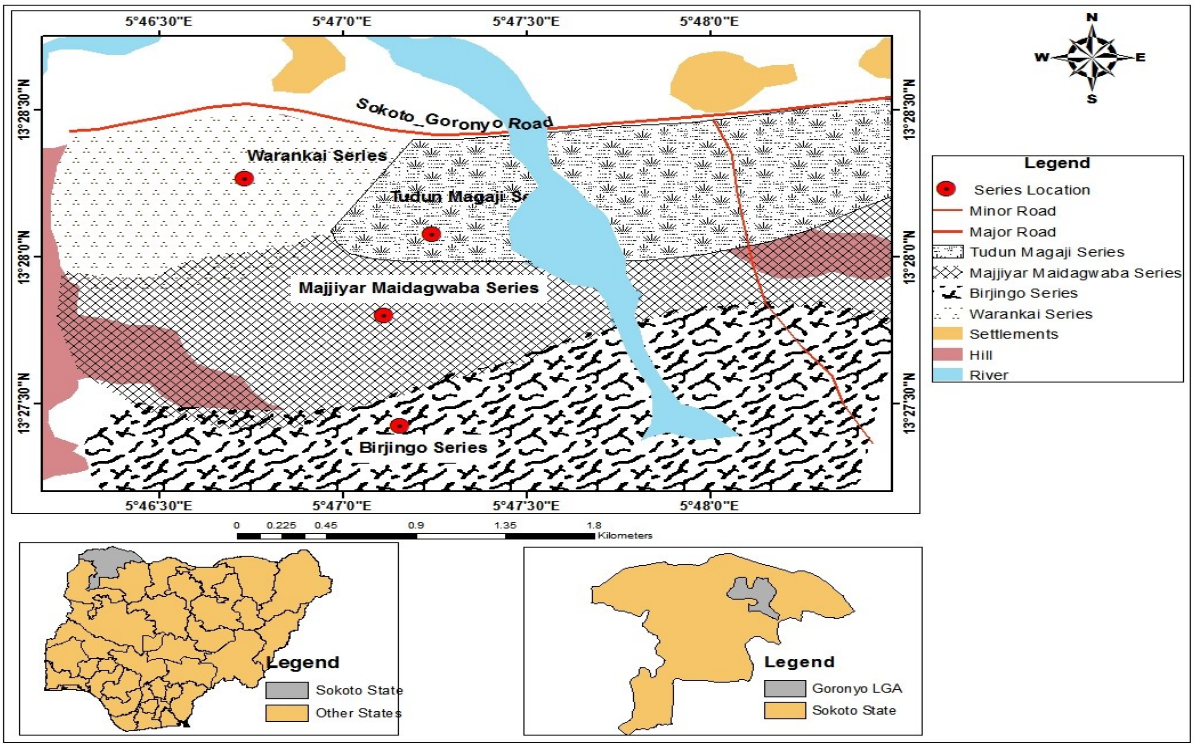
Although, some studies relating to the soils of Sokoto state have been conducted (Noma and Gabasawa. 2005; Noma *et al*. 2004; Yakubu 2006, Noma *et al*. 2011; Sharu et *al*. 2013; Lukman *et al.* 2016 Hayatu *et al*. 2020; Dahiru *et al*. 2023), none of such studies focused on the mineralogical studies of the soils of Goronyo terraces Sokoto State. It is against this background that the present study was conducted and aimed at studying the morphology and |mineralogy of the soils of the study area in order to open new opportunities in the utilization of the abundant soil minerals in the area.

MATERIALS AND METHODS

1) Description of the study area

The study was carried out at Goronyo terrace area, Sokoto State, Nigeria, as shown in Figure 1. Goronyo is located 62 km East of Sokoto metropolis and between latitude 13^0 27' N to $13^0$45' N and longitude $5^0$40' E to $5^0$67' E (Okeke *et al*., 2007). The area has a total land mass of 2,013 km^2 with population projection of 314,300 as at 21-03-2022, population density 156.2/km^2, 3.5% Annual population change from 2006 census -2022 (NPC, 2025) The length of growing period is 90-150 days (Ojanuga, 2006). The agro-ecological zone is dry sub-humid zone (Illela-Sokoto-Yelwa plain). The vegetation zone is Sudan-Sahel Savannah type which is characterized by two seasons the rainy season which starts between mid-May to early-June and reaches its peak in August and the dry season which starts in mid-October and ends in late-April. The coldest months are November to January which are characterized by dusty weather called harmattan (Ojanuga, 2006). The annual rainfall is between 626 mm to 818 mm temperatures are generally extreme, with average daily minimum of 16 ^{0}C during cool months of December and January and in the hottest month of April to June an average maximum of 38 ^{0}C and minimum of 24 ^{0}C (NiMet, 2018). The soils of Goronyo overlies the marine sediments of Rima and Sokoto group which are called the Taloka, Dukamaje and Wurno formation consisting of fine-grained sandstone, mudstone and siltstone (Ifabiyi, 2013).

Figure 1: A Map showing different soil series.



Source: Spot 5 Satellite image, Drawn by GIS Lab. Department of Geography UDUS.

2) Field Study

A reconnaissance visit was paid to obtain first-hand information, followed by detailed soil survey at a scale of 1:5,000 for 50 hectares of land. The general site description such as climate, vegetation, crops grown, erosion hazard, presence of salts and Alkali, land use, depth to water table, drainage type and condition were recorded. Four Profile pits were excavated (2 x 1.5 x 2 m) and described morphologically following FAO (2006) guidelines. For each profile, depth, structure, texture, consistence, roots, pores, colour, date of description, authors, date of description as well as horizon boundary were recorded. The coordinates of each profile was recorded using global positioning system (GPS) device. Disturbed soil samples were collected from each genetic horizon after description and stored in well-labelled nylon bags accordingly and transported to the laboratory for mineralogical analyses.

3) Soil samples collection and preparation for mineralogical analysis

Soil samples were air-dried for 48 hours and ground to pass through 2 mm sieve using mechanical shaker in Geology Department Laboratory at Usmanu Danfodiyo University Sokoto (UDUS) to obtained the fine earth separates (<2 mm) for X-ray diffraction analysis.

4) Mineralogical Analysis

X-Ray Diffraction analysis

X-ray diffraction analysis (XRD) of the selected nine soil samples of fine earth separates (<2 mm) was done at Central Research Laboratory, Umaru Musa Yar'adua University, Katsina State. Minerals were identified based on d-spacing and peaks (Ulery and Drees, 2008).

Data Analysis

The data obtained were subjected to descriptive statistics such as mean, range and percentages using Microsoft Excel package (2016).

RESULTS AND DISCUSSION

Morphological Properties of the Soils.

The morphological properties of the soils are presented in Table 1. The horizon sequences in all pedons are the same as A-horizon overlying B horizon and C horizon. The nature of these horizon sequences is indicative of old soils in all pedons which is not in support with Yakubu and Ojanuga (2012) results in their study of characteristics and classification of soils on quaternary cover sand in Sokoto-Rima basin, Nigeria, where they found out horizons sequences in all pedons are the same as A horizon overlies C horizon the nature of these horizon sequences is indicative of young soil in all the pedons.

The soil colour in Warankai series

pedon 1) is strong brown (7.5YR 5/6) grading to reddish yellow (7.5YR 6/8) at the surface, strong brown (7.5YR 5/8) subsurface and brownish yello(10YR 6/8), to very pale brown (10YR 7/4) in the substratum (C-horizon). In Tudun Magaji series (pedon 2) the soils are brown (7.5YR5/4) to strong brown (7.5YR4/6) at the surface, strong brown (7.5YR5/6) to yellowish brown (10YR5/8) subsurface. In Birjingo series (pedon 3) the soil is brownish yellow (10 YR6/6) to yellowish brown (10YR 5/4) at the surface, brownish yellow (10YR 6/6) to strong brown (7.5YR 5/6) at subsurface and reddish yellow (7.5YR 6/8) in the C-horizon. In Majjiyar Maidagwaba series (pedon 4) the soil colour is very pale brown (10YR7/4) in the surface, reddish yellow (7.5YR7/6) in the subsoil and very pale brown (10YR 7/4) and (10YR 7/3) in the substratum, discernible variations in the colour depicting the influence of topography, location, weathering and parent material. Difference in organic matter content and parent material may have been responsible for the difference in soil colour. Yakubu and Ojanuga (2012) obtained similar results in their study of characteristics and classification of soils on quaternary cover sand n Sokoto-Rima Basin, Nigeria.

The structure of the soils was subangular blocky in the surface horizons of all the pedons. In the subsoil of pedon 1 and 3 the structure is platy and that of pedon 2 and 4 is subangular blocky, the structure in substratum is subangular blocky in pedon 1and 2 and pedon 3 and 4 is platy structure.

The Consistency in surface soils is loose in all pedons. Horizon BC1 in pedon 1 is loose, and subsurface of pedon 2 and 3 are firm, the C-horizon in pedon 1 is loose and firm in pedon 2 and 4, in pedon 3 is friable. Other features included many roots present in the surface and subsurface horizons, no roots in substratum of pedon 1 and 2. Many medium pores present in all surface horizons, common to few pores in subsurface and Substratum few pores in pedon 1 and 4, there was mottles in Cg2 pedon 1 (7.5YR7/6), pedon 2 C-horizon (10YR6/6) and pedon 4 C2 horizon

(10YR7/2). Many medium to fine coarse fragment

Table1: Morphological Properties of the Soils of Rima Valley Terraces, Goronyo area

Pedon	Horizon	Depth (cm)	Color	Mottles	Texture	Structure	Consistence	Roots	Pores	Coarse Fragment	Boundary
1. Warankai series											
	Ap	0 - 23	7.5YR5/6	_	SL	Sab	Lo	3fr	3mp	_	DW
	AB	23 – 68	7.5YR6/8	_	SL	Sab	Lo	1fr	2fp	3mco	DS
	B	68 – 92	7.5YR5/8	_	SL	Pl	Lo	1fr	1fp	1fco	DS
	Cg1	92–124	10YR6/8	_	S	Sab	Fi	_	2fp	2fco	DS
	Cg2	124-155	10YR6/6	7.5YR7/8	S	Sab	Lo	_	_	3mco	DS
	C	155-200	10YR7/4	_	S	Sab	Lo	_	1fp	_	DS
2. Tudun Magaji series											
	Ap	0-18	7.5YR5/4	_	SL	Sab	Lo	2fr	3mp	_	DS
	AB	18-36	7.5YR4/6	_	SL	Ab	Fi	3mr	3mp	1fco	DW
	Bw1	36-82	7.5YR5/6	_	LS	Sab	Fi	1fr	2fp	2mco	DS
	Bw2	82-129	10YR5/8	_	LS	Sab	Fi	1fr	2fp	_	DW
	C	129-200	10YR5/4	10YR6/6	LS	Sab	Fi	_	2mp	1fco	DS
3. Birjingo series											
	Ap	0-34	10YR6/6	_	SL	Sab	Lo	3mr	3mp	_	DS
	AB	34-63	10YR5/4	_	SL	Sab	Lo	3mr	1fp	_	DS
	Bt1	63-88	10YR6/6	_	SL	Pl	Fi	1fr	1fp	1fco	DS
	Bt2	88-122	7.5YR5/6	_	SL	Pl	Fi	3fr	3mp	_	DS
	C	122-200	7.5YR6/8	_	SL	Pl	Fr	3fr	3mp	_	DS
4. Majjiyar Maidagwaba series											
	Ap	0-22	10YR7/4	_	SL	Sab	Lo	3mr	3mp	_	DS
	B1	22-53	7.5YR7/6	_	SL	Sab	Lo	3fr	1fp	3mco	DS
	B2	53-84	10YR7/4	_	SL	Sab	Fr	1fr	_	_	DS
	B3	84-141	7.5YR7/6	_	SL	Sab	Fr	1fr	1fp	1fco	DW
	C1	141-170	10YR7/4	_	SCL	Pl	Fi	1fr	1 fp	_	DW
	C2	170-200	10YR7/3	10YR7/2	SCL	Pl	Fi	1fr	1fp	_	DS

Texture:S(sandy), L(Loamy), C(clay), Structure: ab (angular blocky), pl (platy), sab (sub angular blocky), Consistency: Fi (firm), Fr (friable), Lo (loose). Boundary:

DS (diffuse smooth), DW (diffuse wavy). r (root), p (pores), co (coarse) - f (fine), m (medium) ,1(few), 2(common), 3(many).

X-Ray diffraction analysis (XRD) of fine-earth separates

The results of the mineralogy of the fine earth (<2 mm) separates of pedons 1 and 2 are presented in Tables 2 as well as Figures 2 and 3. The results revealed that quartz is the predominant mineral in the selected horizons of the two profiles studied being 100% mineral content. The dormancy of quartz 100% in the horizons indicates the high resistance of the mineral to weathering and also its dominance in the initial parent material, similar results were reported by Yakubu and Ojanuga (2012) where they reported quartz as the predominant mineral ranging from 94-95% in their studies of soils on quaternary cover sand in Sokoto-Rima basin and of Raji *et al.* (1997) reported similar results in a study conducted on sand dunes around Sokoto.

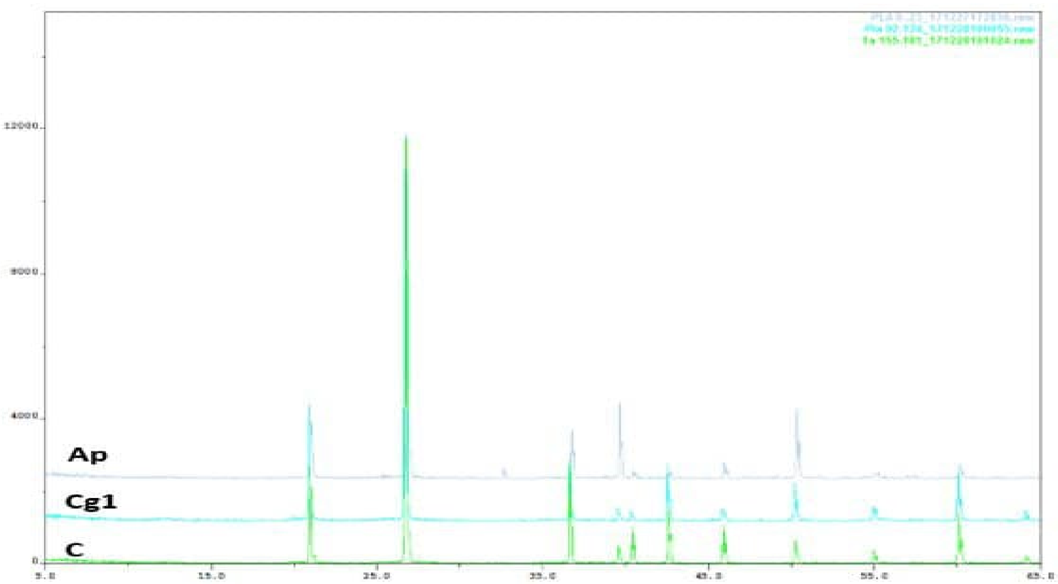
Table 2: Fine earth mineralogy of some selected horizons of Warankai series and Tudun magaji series

Pedons	Horizon	Depth(cm)	2Θ-value	d-spacing(Å)	Minerals (%)			
					Qz	ThC	Ma	Bi.I
1.Warankai								
	Ap	0-23	20.8632	4.256	100	-	-	-
	Cg1	92-124	20.8632	4.256	100	-	-	-
	C	155-181	20.9036	4.246	100	-	-	-
2.Tudun Magaji								
	Bw1	36-82	20.9958	4.228	100	-	-	-
	C	129-173	21.0850	4.210	100	-	-	-

Qz=Quartz, ThC= Thorium Carbide, Ma= malladrite, Bi.I= Bismuth Iodide.

PEDON 1

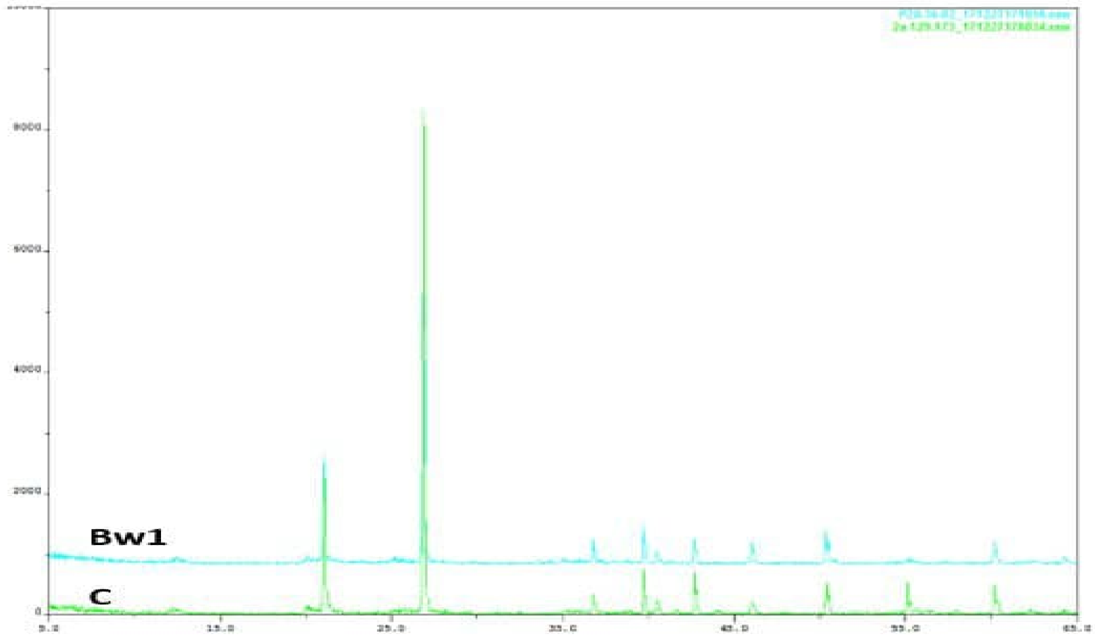
Intensity



2Θ

Figure 2: X-ray Diffractograms of fine earth separates of Warankai series.

PEDON 2



2Θ

Figure 3: X-ray diffractograms of fine earth separates of Tudun Magaji Series.

The results of the mineralogy of the fine earth separates of pedon 3, as presented in Table 3 and Figure 4, demonstrate that quartz is the predominant mineral in the Ap-horizon (100%) with a d-spacing of 4.246 Å. This finding suggests a significant resistance of quartz to weathering processes, which implies that it has been a major component of the initial parent material. This observation is consistent with the findings of Yakubu and Ojanuga (2012), who reported that quartz comprised 94-95% of the mineral content in their study of soils on quaternary cover sand in the Sokoto-Rima Basin. Similarly, Raji *et al.* (1997) observed a high predominance of quartz in their research on sand dunes around Sokoto. In contrast, the C-horizon of pedon 3 shows a different mineral composition, with quartz making up 28% and thorium carbide 72%, and a d-spacing of 3.320 Å. This shift in mineral composition across horizons highlights the variability in the mineralogical characteristics of soils, which can be attributed to differences in the parent material and the degree of weathering. Sedimentary rocks of Cretaceous and Tertiary ages are the major geological formation of the present Sokoto State. The rocks of the sedimentary deposits laid down in three main phases, continental Pre-Maastrichtian and Tertiary along with intervening marine Mastrichtian to Paleocene phase and recent drift materials overlying surfaces.

(Sombroek and Zonneveld, 1971). The significant presence of thorium carbide in the C-horizon indicates a different source of material or secondary mineral formation processes compared to the Ap-horizon. Yakubu and Ojanuga's (2012) study underscores the prevalence of quartz in the region's soils, emphasizing its resilience and dominance in the parent material. Their findings are echoed in the research conducted by Raji *et al.* (1997), which earlier reported the predominance of quartz in the mineralogy of soils in Sokoto. These consistent findings across different studies reinforce the understanding of quartz as a major component in the soils of this region, reflecting both the geological history and the ongoing pedogenic processes.

Further studies by Adebiyi et al. (2011) on the mineralogy of soils in southwestern Nigeria also highlight the predominance of quartz, underscoring its stability and resistance to weathering. Also, Adepetu and Nabhan (2000) reported similar mineralogical compositions in their studies on the soils of the Nigerian savanna, where quartz was a dominant mineral, reflecting the influence of the parent material and pedogenic processes.

Table 3: Fine earth mineralogy of some selected horizons of Birjingo series

Pedons	Horizon	Depth(cm)	2Θ-value	d-spacing(Å)	Minerals (%)			
					Qz	ThC	Ma	Bi.I
3.Birjingo								
	Ap	0-34	20.9036	4.246	100	-	-	-
	C	122-200	26.8311	3.320	28	72	-	-

Qz= Quartz, ThC = Thorium Carbide, Ma= malladrite, Bi. I = Bismuth Iodide

PEDON 3

Intensity

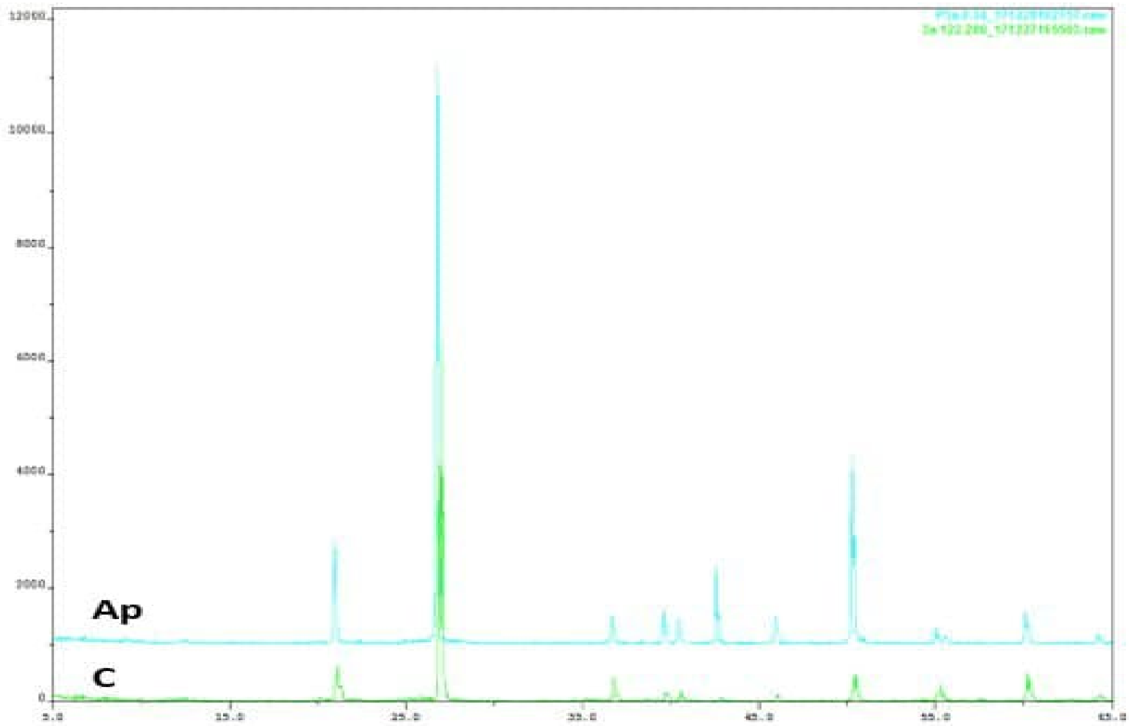


Figure 4: X-ray diffractograms of fine earth separates of Birjingo Series.

In the Majjiyar Maidagwaba series, the mineralogical analysis presented in Table 4 and Figure 5 reveals that the B2-horizon is predominantly composed of malladrite (90%) and bismuth iodide (10%), with a d-spacing of 4.420 Å. The C1-horizon, on the other hand, is composed entirely of quartz (100%), with a d-spacing of 4.256 Å. These findings align with the work of Yakubu and Ojanuga (2012), who identified quartz as the predominant mineral (ranging from 94-95%) in their studies of soils on quaternary cover sand in the Sokoto-Rima Basin. Similarly, Raji *et al*. (1997) reported quartz as the major mineral in their research on sand dunes around Sokoto.

The high percentage of malladrite in the B2-horizon suggests specific geochemical conditions that favor the formation or preservation of this mineral. Malladrite's presence might indicate unique environmental or depositional conditions during soil formation. The minor presence of bismuth iodide also points to particular geochemical influences, potentially linked to anthropogenic activities or natural biogeochemical cycles in the area.

Quartz in the C1-horizon (100%) being the sole constituent reinforces its stability and resistance to weathering processes, consistent with Yakubu and Ojanuga (2012) and Raji *et al*. (1997). This mineral's persistence through various soil horizons indicates its significant role in the soil's parent material and its resilience against chemical and physical weathering.

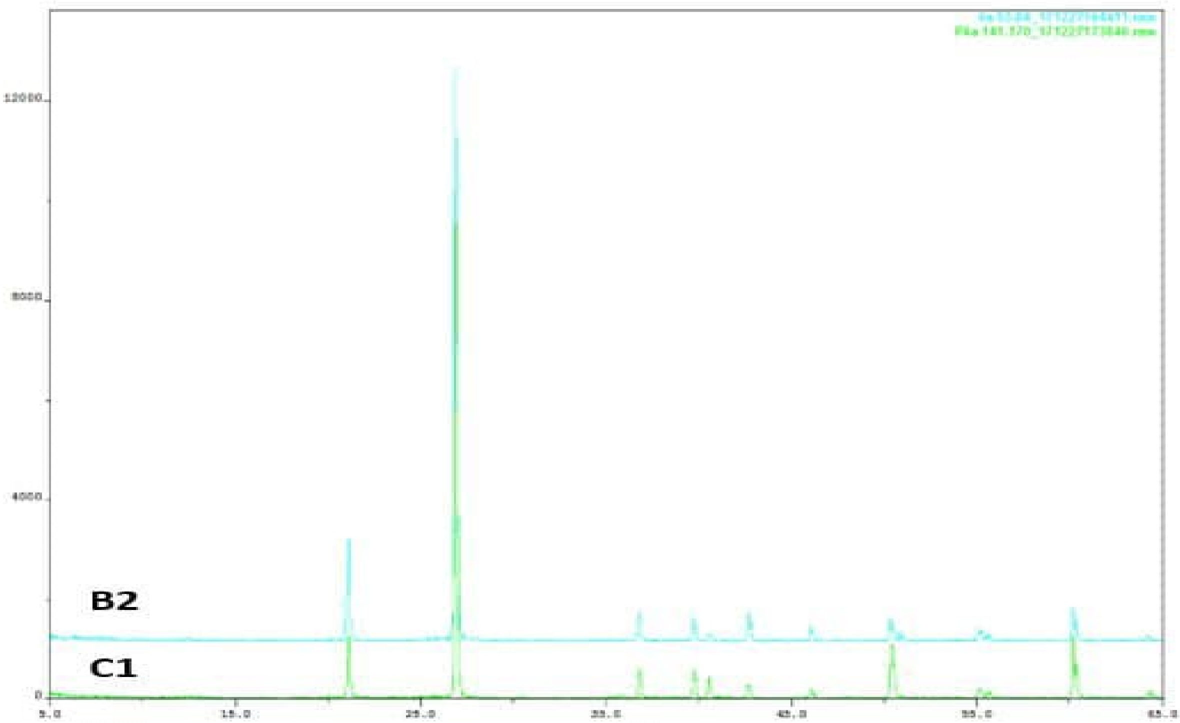
Further studies, such as those by Esu and Akamigbo (1995), who examined the mineralogy of Nigerian soils, and Fashina *et al*. (2006), who investigated soil mineralogy in the savanna regions, also highlighted the prevalence of quartz. These studies corroborate the findings that quartz is a major mineral component in various soil types across Nigeria, indicating its widespread presence and stability.

Table 4: Fine earth mineralogy of some selected horizons of Majjiyar Maidagwaba series

Pedons	Horizon	Depth(cm)	2Θ-value	d-spacing(Å)	Minerals (%)			
					Qz	ThC	Ma	Bi.I
4.Majjiyar	B2	53-84	20.0725	4.420	-	-	90	10
Maidagwaba	C1	141-170	20.8632	4.256	100	-	-	-

Qz= Quartz, ThC = Thorium Carbide, Ma= malladrite, Bi. I = Bismuth Iodide

PEDON 4
Intensity



2Θ

Figure 5: X-ray diffractograms of fine earth separates of Majjiyar Maidagwaba series

Conclusion

The result of the study showed that quartz is the predominant mineral constituent of the soil this indicates that the soils are highly weathered and poor in fertility which need to be addressed as they contribute to poor crop production in the area While thorium carbide, malladrite, bismuth iodide were also found in fine-earth separates (<2mm). The study soils requires high nutrient inputs and cultural management practices that could improve the fertility status for rainfed agriculture.

REFERENCES

Adebiyi, F. M., Amusan, A. A. and Lawal, A. A. (2011). Mineralogical and geochemical characterization of soils in southwestern Nigeria. *International Journal of Soil Science, 6(2), 89-98.*

Adepetu, J. A. and Nabhan, H. (2000). Soil fertility management in the Nigerian savanna: Soil mineralogy and its implications. *Tropical Soil Science*, 3(1), 25-37.

Brady, N.C. and R.R. Weil (2002). *The Nature and Properties of Soils.* Thirteenth edition. Prentice Hall, Upper Saddle River, New Jersey 960 pp.

Brady, N.C. and R.R. Weil (2008). *The Nature and Properties of Soils.* Fourteenth edition. Prentice-Hall, Upper Saddle River, New Jersey.

CTAHR (2007). Soil profile: Soil Nutrient Management for Maui County; College of Tropical Agriculture and Human Resources: University of Hawaii at Manoa. http://soils.usda.gov/education/resources/k-12/lessons/profile/

Dahiru S., Noma, S.S, Buji, I.B., Hayatu, N.G., and F.D. Haruna (2023). Pro perties and Classification of Soils of Magajin Gari District, Gummi Local Government Area Zamfara State, North-West Nigeria. *Journal of Arid Zone Economy* 2(2):103-115 ISSN;2992-4952.

Esu, I. E. and Akamigbo, F. O. R. (1995). Characteristics and classification of selected soils in the savanna region of Nigeria. *Soil Science Society of Nigeria Journal*, 7(1), 19-28.

Excel (2016). Microsoft office excel spreadsheet, version 2016.

FAO (2006). *Guidelines for Soil Description.* Fourth Edition. Food and Agriculture Organization of the United Nations Rome, Italy, 109 pp.

Fashina, A. S., Olowolafe, E. A. and Jayeoba, O. J. (2006). Soil mineralogy and its implications for soil management in the Nigerian savanna. *Journal of Agricultural and Environmental Sciences*, 5(2), 123-134.

Foster, M.A., Anderson, R.S., Wyshnytzky, C.E., Ouimet, W.B. and Dethier, D.P., (2015). Hillslope lowering rates and mobile-regolith residence times from in situ and meteoric 10Be analysis, Boulder Creek Critical Zone Observatory, Colorado. Bulletin, 127(5-6), pp.862-878.

Geology (2005): Geoscience News and information http://geology.com>minerals>quartz Accessed on 12th/2/2018.

Google (2025). Population Goronyo Local Government Area in Nigeria. https://citypopulation.de/en/Nigeria/admin/sokoto/nga034006_goronyo. Access 18th March,,2025.

Hayatu N.G., Noma S.S.,Nabayi A., Abdelsatter M.M., Haruna F.D., Amadou A. Sani I., Sharu M.B., Anka A.B. and S.D. Abubakar (2020). Characterization and Classification of Soils on grazing lands in kwallatawa village, Sokoto State, Nigeria. SVU-*International Journal of Agricultural Science.* 2 (2): 326-

338.Doi:10.21608/svuijas.2020.46715.1046.

Ifabiyi, I.P. (2013). Climate change adaptation in Goronyo local government area, Sokoto state, Nigeria. The case of rural water supply in semi-arid Region. *Journal of sustainable development in Africa V.15*(8):42-56.

Khordebin, S. and Landi, A. (2011). Comparison of the Land Qualitative Suitability with the Use of FAO method and ales model for Major Crops in Sardasht of Behbahan Khuzestan Province, Iran. Middle-East *Journal of Scientific Research*, *10* (4): 477-481.

Lawal , B. A., A.G. Ojanuga, P. A. Tsado, and A. Mohammad (2013). Characterization, Classification and Agricultural Potentials of Soils on A Toposequence In Southern Guinea Savanna of Nigeria. *International Journal of Biological, Veterinary, Agricultural and Food Engineering, 7* (5):146-150.

Lukman S. A., S.S. Noma, M. Yakubu, M. Audu, G.A. Abubakar and M.M. Sauwa (2016). Characterization and Classification of Soils of Adarawa Village, Tangaza Local Government, Sokoto State. ASUU Journal of Science, 3(2):17-28. ISSN: 2276-9595.

Mirsal, I. (2008). Soil Pollution: Origin Monitoring and Remediation. Springer Verlag, XV, Pp.316.

NiMet, (2018). Nigerian Meteorological Agency, Seasonal Rainfall prediction (SRP) ISSN 23467150-46PP.

Noma, S.S., A.G.Ojanuga, S.A. Ibrahim an d M. A. Iliya (2004). Detailed Soil Survey of the Sokoto-Rima Floodplains at Sokoto, Nigeria. In: F.K. Salako M.T. Adetunji, A.G. Ojanuga, T.O. Arowolo and S.O. Ojeniyi (eds). Managing Soil resources for Food Security and Sustainable Environment. Proceedings of the 29th Annual Conference of the Soil Science Society of Nigeria University of Agriculture Abeokuta, 6-10 December. Pp.83-92.

Noma, S.S and A.I. Gabasawa (2005). Assessment of the Quality of Water and Irrigated Soils of Sokoto-Rima Floodplains. Bulletin of SAN, VOL. 26(2005):63-69.

Noma, S.S.,I.I. Tanko, M.Yakubu,, A.U. Dikko, A.A. Abdullahi and M. Audu (2011). Variability in the physicochemical properties of Soils of Dundaye District, Sokoto State, Nigeria. In Hassan,W.A., Kyiogom, U.B., Tukur, H.M.,Ipinjolu, J.K., Maigandi, S.A., Singh, A., Ibrahim N.D., Dikko A. U., Bashir, Y.A., And Muhammad, N. (Eds). *Mobilizing agricultural research towards attaining food security and industrial growth in Nigeria.* Proceedings of the 45th Annual Conference of the Agricultural Society of Nigeria held at the Faculty of Agriculture, Usmanu Danfodiyo University Sokoto Nigeria.24th to 28th Oct.

Ojanuga, A.G. (2006). Agro ecological zones of Nigeria National Special Programme for Food Security and FAO. Pp124.

Okeke, K. I., Owa, O. and Omoayena, B.O. (2007). Socio economic impact of irrigation on crop production. The case of Middle Rima Valley irrigation project in Goronyo, SokotoState Nigeria. Proceeding of the 21st Annual Conference of Farm Management Association of Nigeria. Pp149- 151, OlabisiOnbanjo University, Ogun state.

Raji, B. A., Esu, I.E. and V.O. Chude (1997). The Mineralogy of Haplustults and quartzipsamments derived from sand dunes, NW Nigeria. In; B.R. Singh (Ed.), *Management of Marginal Lands in Nigeria,* Proceedings 23rd Annual Conference of the Soil Science Society of Nigeria (SSSN), hold at UDUS Sokoto, 2-5th 1997.

Schulze D. G. (2002). Soil Mineralogy with Environmental Application Volume 7. https://doi.org/10.2136/sssabookser7.c2 citation: 17 Book Series: SSSA.

Sharu M.B., Yakubu M., Noma S.S., and Tsafe A.I.(2013). Characterization and Classification of Soils on an Agricultural landscape in Dingyadi District, Sokoto State Nigeria. *Nigerian Journal of Basic and Applied Science* (June, 2013),21(2): 137-147.

Silva, J. and Uchida, R.S. (2000). *Plant nutrient management in Hawaiis soils*: Approaches for Tropical and Subtropical Agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honololu.

Sombroek, W.G. and I.S. Zonneveld (1971). Ancient dune fields and fluviatile deposits in the Rima-Sokoto River Basin (NW Nigeria). Soil Survey Paper no5, Netherlands Soil Survey Institute Wageningen 109pp

Sparks, D.L. (2003). *Environmental Soil Chemistry* 2nd ed.San Diego, CA: Academic press.

Ulery A.L. and C.R. Drees (2008). Petrographic Microscope Techniques for Identifying Soil Minerals in Grain Mounts. *Methods of soil analysis.* Part 5. Mineralogical methods. SSSA Book Ser. 5. SSSA. Madison, pp962.

Warren L. and Thomas, J.E. (2008). Petrographic Microscope Techniques for Identifying Soil in Grain Mounts, *Method of soil Analysis Part 5. Mineralogical Methods Soil Sci. Soc. of Amer. Book series no.5.*

Yakubu, M. (2006). Genesis and Classification of Soils Over Different Geological Formations and Surfaces in the Sokoto Plains Nigeria. PhD Thesis. Soil Science and Agricultural Engineering Department, Usmanu Danfodiyo University Sokoto (Unpublished).

Yakubu, M. and Ojanuga A.G. (2012). Characteristics and Classification of Soils on Quaternary Cover sand in Sokoto-Rima Basin, Nigeria. *Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension:* V. 11(1):21-32.

INFLUENCE OF RICE HUSK BIOCHAR AND WHITE ACACIA LEAF POWDER ON SOIL ORGANIC CARBON, NITROGEN AND YIELD OF AMARANTHS IN SUDAN SAVANNA

[1]G. A. Abubakar, & [2]H. M. Barde
[1&2]Department of Soil Science and Land Resources Management, Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto, Nigeria
e-mail: garba.aliyu@udusok.edu.ng

ABSTRACT
A trial was conducted to investigate the influence of rice husk biochar and Faidherbia albida leaf powder on soil organic carbon, total nitrogen and yield of amaranths in the field. Biochar was incorporated at the rate of 2.5 tons ha^{-1} and Faidherbia albida leaf powder was also applied at rate 2.5 tons ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) replicated 3 times. The data on soil organic carbon, total nitrogen and amaranths growth and yeld, were collected and subjected to analysis of variance (ANOVA). The study revealed that combination of rice husk biochar (RHB) and Faidherbia albida leaf powder (FAL) significantly ($P < 0.05$) increases soil organic carbon 1.57 gkg^{-1} as compared 1.07 gkg^{-1} for control, total nitrogen 0.11 gkg^{-1} as compared to 0.06 gkg^{-1} for the control. The average yield of amaranths was also higher in the treatment with combination of rice husk biochar (RHB) and Faidherbia albida leaf powder (FAL) compared to the control or application of RHB or FAL alone.
Keywords: Amaranths, Biochar, *Faidherbia albida* Organic carbon, Total nitrogen,

Introduction

Worldwide, it is estimated that feeding the world population will need 60% more yield by 2050 (Rosenstock, 2016; Fróna *et al.,* 2019). Such a massive increase in agricultural production needs to be accomplished without jeopardising soil and environment. Biochar is comparatively new, but it becomes familiar day by day all around the world. The word "biochar" comes from a combination of "bio-" means "biomass" and "char" means "charcoal" (Schulz and Glaser 2012). Biochar is a carbon-rich material produced through the pyrolysis or slow combustion of biomass, such as agricultural residues, wood chips, or manure and stable form of charcoal that can be used as a soil amendment to enhance soil fertility, retain moisture, and sequester carbon (Lehmann and Joseph, 2009). Biochar has a high surface area, which provides a habitat for microorganisms and enhances nutrient retention and availability in the soil (Jeffery *et al*., 2011). Biochar is highly porous fine-grained charcoal, which has been produced under limited oxygen condition using organic biomass that optimises certain special characteristics like large surface area and porosity and ability to preserve in soils for a long time with very little biological deterioration (Robertson and Wiggering, 2014). As a result, it can be differentiated from other charcoals because it can be used as a soil amendment (Warnock *et al.* 2007).

Gum Arabic tree commonly known as the white *acacia* or *Faidherbia albida*, is a deciduous tree native to Sub-Saharan Africa and the Middle East (Le Houérou, 1994). It is well-adapted to arid and semi-arid environments and plays a crucial role in soil improvement, erosion control, and moisture regulation (Le Houérou, 1994).

The leaves of *Faidherbia albida* contain high levels of nitrogen and other nutrients, making them a valuable organic resource for improving soil fertility and moisture retention (Mokgolodi *et al.,* 2011).

Amaranthus viridis, commonly known as slender *amaranth* or green *amaranth*, is an annual herbaceous plant belonging to the *Amaranthaceae* family, widely distributed in tropical and subtropical regions and is known for its edible leaves and seeds (Das, 2016). *Amaranthus viridis* is considered a nutritious leafy vegetable rich in vitamins, minerals, and antioxidants (Umar *et al.,* 2011). The plant has cultural and economic significance in many regions, as it is used as a food source and in traditional medicine (Ogwu, 2020). Its fast growth rate, adaptability to diverse climates, and high nutritional value make it a promising crop for food security and sustainable agriculture (Munir *et al*., 2019). Understanding the influence of biochar and *Faidherbia albida* leaf on moisture retention and the subsequent impact on the growth and yield of *Amaranthus viridis* can provide valuable insights for optimising cultivation practices and enhancing the productivity of this important leafy vegetable.

Water scarcity low nitrogen level pose significant challenges to agricultural productivity in sudan savannah agroecological zone (Danso *et al.,* 2018). Enhancing moisture retention and soil nitrogen in soils is crucial for sustainable crop production, especially in arid and semi-arid regions. Biochar, a carbon-rich material produced by the pyrolysis of organic matter, has gained attention as a soil amendment due to its ability to improve soil water-holding capacity and nutrient availability (Lehmann and Joseph, 2009), Faidherbia leaf powder, has also been recognised for its positive impact on soil moisture conservation and nutrient cycling (Bayala *et al.,* 2015).

Rice husk biochar (RHB) can be used as a soil amendment as a sustainable approach in crop production. Due to its adsorptive capability, nutrient retention capacity and high silica content, RHB can improve soil fertility and improving the effectiveness of fertilizer when mixed due to its nutrient retention capacity and high silica content (Karam *et al.,* 2022). High silica content in rice husk biochar provides better nutrient retention, turgidity, microbial biomass and structure for plant (Singh *et al.,* 2018; Asadi *et al.,* 2021; Karam *et al.,* 2022). Smith *et al.* (2013) reported that biochar application improved soil water retention and enhanced the growth performance of various crops.

Njoloma *et al.* (2018) found that Faidherbia leaves mulch significantly increased soil moisture content and improved the growth of crops. However, limited research has been conducted specifically on the combined influence of rice husk biochar and Faidherbia leaf powder on soil nitrogen, growth and yield of *Amaranthus viridis*. In investigating the synergistic effects of biochar and *Faidherbia albida* leaves, this study aim to contribute to the current understanding of sustainable soil management practices for enhancing moisture retention and improving the growth yield of *Amaranthus viridis*. Findings of this study will allow farmers and researchers to understand the impact of organic amendments on soil moisture retention and crop productivity. This knowledge will equip them with valuable information to make informed decisions regarding soil management strategies, leading to sustainable agricultural practices. The main objective of this study is to assess the influence of rice husk biochar and Faidherbia leaf powder amendment on soil nitrogen, soil organic carbon and yield of *Amaranthus viridis* in sudan savanna agroecological zone.

Material and Methods

The study was conducted during March-April 2024 Dry season at University

Fadama Teaching and Research Farm of Usmanu Danfodiyo University, Sokoto. Sokoto State. The field study area lies on latitude 13° 030`N and longitude 5° 23" E and at an altitude of about 350m above sea level with minimum and maximum temperature of 15°C and 40°C respectively (Singh *et al*. 2011) and 645 mm of rainfall (SERC, 2022). The treatment consist of rice husk biochar at a rate of (2.5 tha-[1]), *Faidherbia albida* leaves (2.5 tha-[1]), combination of rice husk biochar and *Faidherbia albida* leaves and control. The treatment applied 2m x 2m plot size in a randomized complete block design (RCBD) replicated three times. A total of twenty (20) soil samples were collected systematically to form a composite sample using auger at depth of 0 to 30cm to make a composite sample before and after the experiment. Soil organic carbon (SOC) was determined using Walkey and Black wet oxidation method as described by (Nelson and Sommers, 1975). Total nitrogen was determine using micro Kjehdahl digestion and distillation methods described by (Bremner and Mulvaney, 1982). Amaranth was planted using dibbling method and monitored by measuring stand establishment count, plant height, number of leaves per plant and fresh biomass at 30 days after sowing manually by cutting at soil level, and total fresh above ground biomass was determined. Data collected were subjected to analysis of variance (ANOVA) using SPSS and means separated using Least Significant Difference (LSD) at ($P < 0.05$).

Results and Discussion

Soil Organic Carbon

The result of organic carbon and total nitrogen before the experiment are presented in Table 1. The result showed that soil organic carbon (1.07 g/kg) and total nitrogen (0.06 g/kg) were low based on the rating (Chude, 2011). Combination of Rice husk biochar with *Faidherbia albida* leaf powder (RHB+FAL) had the highest mean value of 1.57 g/kg, followed by *Faidherbia albida* leaf Powder (FAL) with mean of 1.33 g/kg, Rice husk biochar (RHB) with a mean of 1.13 g/kg and Control (CTR) has the lowest mean of 1.07 g/kg which were statistically different from one another ($p < 0.05$). The result of this study is in agreement with the finding of Nguyen *et al.,* (2018) who reported that the use of RHB+FAL significantly increased soil organic carbon (SOC) levels compared to the control. This may be due to increase in mineralization due to nitrogen content in RHB+FAL which may have led to increase in carbon content and microbial activity. Likewise, Kumar *et al.* (2019) reported the organic carbon content in the soil increases when treated with combination of rice husk biochar and *Faidherbia albida* leaf powder compared to those treated with rice husk biochar and *Faidherbia albida* leaf powder alone.

Soil Total Nitrogen

The total nitrogen of the soil presented in Table 1. The results showed that there was a significant difference ($P < 0.05$) among the treatments. RHB+FAL has the highest mean value of 0.11 g/kg followed by FAL with mean value of 0.08g/kg, while RHB and CTR has the lowest mean values of 0.06g/kg which were statistically different from one another ($p < 0.05$). These values were low based on the rating ((Chude, 2011). This finding of the research was in line with study conducted by Olatunji *et al.* (2012) who reported that application of organic material tend to increase soil Nitrogen. This could be due to enhanced mineralization from added organic material (Adeniyan and Ojeniyi, 2005).

Table 1: Influence of Rice Husk Biochar and *Faidherbia albida* Leaf Powder on Soil Organic Carbon and Total Nitrogen.

Treatment	Organic carbon (gkg^{-1})	Total Nitrogen (gkg^{-1})
Before Soil	1.07	0.06
Faidherbia albida leaves powder	7.8	0.7
After		
RHB	1.13^{b}	0.06^{b}
FAL	1.33^{ab}	0.08^{b}
RHB+FAL	1.57^{a}	0.11^{a}
CTR	1.07^{b}	0.06^{b}
SE±	0.07	0.01
P. Value	0.03	0.01
Significance	*	*

Mean in a column followed by similar letter (s) are not significantly different at 5% level of significance using least significant difference (LSD). * = significant, RHB= Rice husk biochar, FAL= *Faidherbia albida* leaves powder, RHB+ FAL= Rice husk biochar + *Faidherbia albida*, CTR= Control.

Growth and Biomass Yield

The result for stand establishment count is presented (Table 2). The result showed that there were significant differences ($P \leq 0.05$) among the treatments. Combination of RHB+FAL had the highest mean value of 88.0, followed by RHB with mean of 76.0, FAL had a mean value of 69.0, and CTR has the lowest mean of 49.0. Another study conducted by (Mugwira *et al.,* 2021) investigated the effects of biochar and *Faidherbia albida* leaf amendment on stand establishment in relation to *Amaranthus,* showed that there was a significant difference in stand establishment between the two treatments, and combination of biochar and *Faidherbia albida* leaf amendment resulted in higher seedling density and biomass production of *Amaranthus spp*. This was attributed to the higher nutrient availability in the soil due to the combined effects of biochar and *Faidherbia albida* leaf amendment.

The results for plant height are presented in Table 2. The results showed significant differences ($P < 0.05$) among the treatments. Combination of RHB+FAL has the highest mean height of 20.6 cm, followed by RHB with mean value of 17.5 cm, FAL has mean of 17.0 cm while the CTR has the lowest mean value of 14.9 cm. This result was in agreement with the finding of (Zhang *et al.,* 2019) that organic matter addition can significantly impact plant height, nutrients uptake, and yield in *Amaranths* cultivation due to nutrients released during decomposition. Singh *et al.,* (2018) found that organic matter addition significantly increased plant height and biomass production in *Amaranths*. This is likely due to the fact that organic matter can increase soil pH, making these micronutrients more available to plants, the addition of organic matter can significantly impact plant height and nutrient uptake in *Amaranthus* by providing a readily available source of carbon and nitrogen, increasing root biomass, and improving micronutrient availability (Chen, 1996).

The number of leaves presented in Table 2. The result showed an increased among the treatments which ranged from 11.0 -15.0 However, this increase was not significant (P > 0.05) among the treatments. This result was in agreement with the finding of Nguyen *et al.,* (2021), and (Mugwira) *et al.,* (2021), who found no significant difference in term of stem diameter, number of branches between the treatments. Combination of RHB + FAL was significant (P < 0.05) compared to FAL, RHB and control treatments.

Table 2: Influence of Rice husk biochar and *Faidherbia albida* Leaf Powder Amendment on Stand Establishment Count, Plant height, Number of Leaves and Fresh Biomass

Treatment	Stand Establishment Count (%)	Plant Height (cm)	Number of Leaves	Fresh Biomass (kgha^{-1})
RHB	76^{ab}	17^{b}	11	1650b
FAL	69^{b}	17^{b}	14	1700b
RHB+FAL	88^{a}	21^{a}	15	2280a
CTR	49^{c}	14.9^{b}	12	690c
SE±	4.88	0.70	0.74	114
P. Value	0.01	0.01	0.14	0.02
Significance	*	*	NS	*

Mean in a column followed by similar letter (s) are not significantly different at 5% level of significance using least significant difference (LSD). * = significant, NS = not significant. RHB= Rice husk biochar, FAL= *Faidherbia albida* leaves powder and CTR=Control

Conclusion

The results obtained in this study showed that combined application of rice husk biochar and *Faidherbia albida* leaf powder can significantly improve soil organic carbon, total nitrogen and amaranth agronomic yield parameters.. However, combined application of RHB+FAL showed better performance in respect to several growth parameters compared to sole application of biochar or *Faidherbia albida* leaf powder. Farmers should consider incorporating Rice husk biochar and *Faidherbia albida* leaf powder as soil amendments in *amaranth* cultivation to improve soil fertility and promote plant growth.

References

Adeniyan, O.N and Ojeniyi, S.O. (2005). Effect of poultry manure, NPK 15-15-15 and combination of their reduced levels on maize growth and soil chemical properties. *Nigerian Journal of Soil Science,* 15:34-41.

Asadi, H., Ghorbani, M., Rezaei-Rashti, M., Abrishamkesh, S., Amirahmadi, E., Chengrong, C. H. E. N., & Gorji, M. (2021). Application of rice husk biochar for achieving sustainable agriculture and environment. *Rice Science*, 28(4), 325-343.

Bayala, U., Kizilkaya, R., and Asik, B. B. (2015). Assessment of soil fertility: A review of selected methods. *International Journal of Soil Science*, 5(1), 1-15.

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen-total. In: A.L. page, R.H. Miller, and D.R. Keeney (eds.) Methods of Soil Analysis, Part 2; Chemical and Microbiological Properties. American Society of Agronomy, Inc., Madison, WI, pp. 595-624.

Chen, Y. (1996). Organic matter reactions involving micronutrients in soils and their effect on plants. *Humic Substances in Terrestrial Ecosystems,* 507-529.

Chude, V.O (2011). Soil fertility management in Nigeria. Soil fertility initiative; National programme for food security (NPPS).

Danso, I., Webber, H., Bourgault, M., Ewert, F., Naab, J. B., & Gaiser, T. (2018). Crop management adaptations to improve and stabilize crop yields under low-yielding conditions in the Sudan Savanna of West Africa. *European Journal of Agronomy*, 101, 1-9.

Das, S. (2016). Amaranthus: a promising crop of future. Singapore:: Springer, pp. 13-48.

Fróna, D., Szenderák, J., & Harangi-Rákos, M. (2019). The challenge of feeding the world. *Sustainability*, 11(20), 5816.

Jeffery, P., Sohi, S., & Kim, J.-H. (2011). The role of biochar on microorganisms in relation to *Amaranthus spp*.: A review. *Journal of* Environmental *Management*, 120(1-2), 165-177. Doi: 10.1016/j.jenvman.2011.06.007

Karam, D. S., Nagabovanalli, P., Rajoo, K. S., Ishak, C. F., Abdu, A., Rosli, Z., Muharam, F.M. & Zulperi, D. (2022). An overview on the preparation of rice husk biochar, factors affecting its properties, and its agriculture application. *Journal of the Saudi Society of Agricultural Sciences*, 21(3), 149-159.

Kumar, A., Kumar, S., & Singh, P. (2019). Combination of rice husk brand and *Acacia albida* as treatment for managing *Amaranthus* population dynamics: *A sustainability perspective. Journal of Sustainability,* 13(1), 1-10.

Le Houérou, B. (1994). Assessment of water retention of gum Arabic tree in Semi arid regions: A review of selected methods. *International Journal of Soil Science,* 5(1), 1-15.

Lehmann, J., & Joseph, S. (2009). Biochar: A novel carbon-based mitigation agent for climate change mitigation and crop management. *Carbon Managemen*t, 1(1), 75-86.

Mokgolodi, N. C., Setshogo, M. P., Shi, L. L., Liu, Y. J., & Ma, C. (2011). Achieving food and nutritional security through agroforestry: a case of *Faidherbia albida* in sub-Saharan Africa. *Forestry Studies in China*, 13, 123-131.

Mugwira, T., Mugwira, T., Mugwira, T., & Mugwira, T. (2021). Effects of biochar and *Acacia albida* leaf amendment on soil physicochemical properties in Pinus patula plantations in Zimbabwe. *Journal of Cleaner Production,* 325, 129221.

Munir, M., Khan, M., Ahmad, M., & Ahmad, S. (2019). Effect of biochar and *Acacia* albida leaf on moisture retention and yield of *amaranths* (*Amaranthus* hypochondriacus L.) in arid region. *Journal of Applied Sciences and Environmental Management, 23(3), 161-168.*

Nelson D. W. Sommers, L. E. (1975). Total organic carbon and organic matter. In: L. A. Page, R. H. Miller, D R. Keeney, Eds., Methods of Soil Analysis, Part 2. Chemical and Microbiological Methods. *American Society of Agronomy, Madison, 19*82, pp 539-579.

Nguyen, T. T., Nguyen, T. T., & Nguyen, T. H. (2018). Enhancing *amaranths* yield and soil properties by using rice husk biochar (RHB) and *acacia albida* (*Acacia mangium*) bark (AB) in the Mekong Delta region. *Journal of Soils and Sediments*, 19(6)

Nguyen, T. T., Nguyen, T. T., & Nguyen, T. H. (2021). Enhancing *amaranths* yield and soil properties by using rice husk biochar (RHB) and *Acacia albida* (*Acacia mangium*) bark (AB) in the Mekong Delta region. *Journal of Soils and Sediments*, 19(6), 1845-1857.

Njoloma, E., Mbwita, S., & Mbwita-Likwaloa, M. (2018). *Acacia albida* leaf as a source of organic matter for improving soil moisture retention in relation to *Amaranthus hypochondriacus* L. In Proceedings of the 1st International Conference on Agriculture and Biology (pp. 137-141). *University* of *Zambia*, Lusaka..

Ogwu, M. C. (2020). Value of Amaranthus [L.] species in Nigeria. London: IntechOpen. pp. 1-21.

Olatunji, O., Ayuba, S. A., Anjembe, B.C and Ojeniyi, S.O. (2012). Effect of NPK and organic manure on cowpea and soil composition. *Nigeria Journal of Soil Science,* 22(1): 108-114.

Robertson F, and Wiggering, H. (2014). Assessing soil erosion risk and its effect on crop productivity in EU-27 using the LUCAS topsoil database. *Land Degradation & Development, 25(6), 524-539.*

Rosenstock, L.R. (2016). Soil erosion and the global carbon budget. *Environment, Development and Sustainability, 17(3), 443-464*

S.E.R.C. (2022) Sokoto Energy Research Center, Usmanu Danfodiyo University, Sokoto Meteorological Data.

Schulz R. & Glaser D. (2012). Soil Fertility and agricultural sustainability. *Proceedings of the National Academy of Sciences, 104(33), 13268-13272.*

Singh, C., Tiwari, S., Gupta, V. K., & Singh, J. S. (2018). The effect of rice husk biochar on soil nutrient status, microbial biomass and paddy productivity of nutrient poor agriculture soils. *Catena*, 171, 485-493.

Singh, J., Sahoo, R., and Cheema, J.S. (2011). Abiotic stress-responsive genes: Their functional role and application for improving abiotic stress tolerance in plants, *Critical Reviews in Biotechnology, 31:4, 305-322.*

Singh, K., Singh, P., & Singh, A. (2018). Days to 50% maturity and its relationship with *Amaranthus* population dynamics under rainfed and irrigated conditions. *Journal of Applied Ecology, 35(4), 1253-1258.*

Smith, A., Gee, G. W., and Bauder, J. W. (2013). Effects of Biochar on Soil Moisture Retention and Plant Growth. In; Klute A. (Ed.), Methods of Soil Analysis: Part 1 - Physical and Mineralogical Methods (2nd ed., pp. 383-411). *Agronomy Monograph* No. 9. ASA and SSSA.

Umar, K. J., Hassan, L. G., Dangoggo, S. M., Maigandi, S. A., & Sani, N. A. (2011). Nutritional and anti-nutritional profile of spiny amaranth (Amaranthus viridis Linn). *Studia Universitatis Vasile Goldis Seria Stiintele Vietii* (Life Sciences Series), 21(4).

Warnock, A. Lehmann G., Lane, L. J., & Bouyoucos, G. J. (2007). Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal*, 54(5), 464-465.

Zhang, X., Wang, X., & Zhang, Y. (2019). Plant height and its relationship with *Amaranthus* population dynamics. *Journal of Applied Ecolog*y, 56(1), 128-134.

INTEGRATED SOIL FERTILITY MANAGEMENT: PANACEA FOR SUSTAINABLE CROP PRODUCTION AND IMPROVED LIVELIHOOD OF SMALLHOLDER FARMERS: A SURVEY

Ande O.T[1]., Huising J.E.[2], Are K.S.[1], Fademi I.O.[1], Lawal B.O.; Nurudeen O.O[4]., Oyerinde G.T.[3], Mesele S.A.[2], Oluwatosin G. A[1]. and Adedian J. A.[1]

[1]Institute of Agricultural Research and Training, O.A.U., Moor Plantation, Ibadan.

[2]. International Institute of Tropical Agriculture, Ibadan

[3].Indorama Eleme Fertilizer and Chemicals Ltd, Abuja,

[4] Ekiti State University, Ado Ekiti.

Corresponding author email:funmiande67@gmail.com

ABSTRACT

A survey was conducted to convey the significance of Integrated Soil Fertility Management (ISFM) to relevant stakeholders to boost agricultural productivity and enhance the livelihood of smallholder farmers in Southern Nigeria. The Nigeria Soil Health Consortium (South) coordinated by AGRA/IITA and hosted by Institute of Agricultural Research and Training was saddled with the responsibility to promote wider uptake of ISFM protocols among small holder farmers in southern ecologies of Nigeria. The survey was conducted in eight States of Nigeria comprising: Ogun, Oyo, Osun, Ondo, Lagos, Akwa- Ibom, Edo and Delta States in collaboration with extension agents. Interview schedule was used to elicit information from farmers while questionnaires were produced for extension agents in all the selected States. Results showed that the age long problems of fertilizer availability, accessibility and affordability still persist. Moreover, lack of adequate knowledge in soil management in spate of climatic change has aggravated soil fertility decline among smallholder farmers. Hence, integrated soil fertility management approach where resources within the farms are pulled together with little external inputs based on farmers' knowledge of their soils will suffice the problem of low productivity. Strategic use of ISFM protocols is recommended for the region which include, improved high yielding seed varieties, combined use of organic and inorganic fertilizers, local adaptations strategies such as proper tillage, supplementary water supply, inclusion of cereal-legume cropping systems, live mulching, cover cropping as appropriate and continuous training of farmers on implementation of the strategies.

Keywords: *Agricultural productivity, Extension workers, Farmers, Integrated soil fertility management strategies*

Introduction

Land degradation and decline in soil fertility have become serious threats to agricultural productivity in Sub-Saharan Africa, Nigeria inclusive. The declining fertility of soils as a result of soil nutrient mining is a major cause of decreased crop yields and per capital food production in Nigeria. Decreasing soil fertility accompanied with increasing population pressure is one of the major causes of the gap between demand for and supply of food.

Provision of adequate food supply to satisfy the needs of the whole population has always been one of the pressing needs of the Nigerian government. One of the reasons for the failure of agricultural plans in satisfying this need is underestimation of the importance of soil status and, therefore, mismanagement of the nation's soil. For soil to continue to meet the demand of crops for nutrient availability, there is need to protect and conserve the soil. In Nigeria, various attempts have been made to restore the fertility of degraded arable lands. Greater emphasis was given to the promotion and use of modern inputs such as improved seeds and mineral fertilizer. Facilitating the provision of fertilizer and promoting soil fertility replenishing technologies received continuous attention in all past extension programmes. Hence these efforts proved abortive as low soil fertility still persist. A major reason given for the decline in per capita food production in Nigeria over the last two to three decades is the gradual decline in land productivity.

Available information shows consistent decrease in yield per hectare of major food crops in Southern Nigeria. Evidence from the literature suggests that the main reason for this persistent decline in soil productivity is the perpetuation of unsustainable soil management practices by small food crop farmers that dominate the food production landscape in the country (Ande 2014, Agbonlahor, 2003). Long-term experiments have shown that combined organic and inorganic soil treatments such as Integrated organic and inorganic fertilizers, intercropping systems, improved fallows and integration of cereals-legumes lead to net soil bio-physical and economic gains than solitary applications (Mugwe *et al.*, 2009; Ande et al, 2010; Ande and Senjobi, 2014a; Ande et al, 2018; Odunjo et al, 2022; Aruna et al, 2024). With much emphasis recently being placed on Integrated Soil Management Technologies in Nigeria, there is need to find out the gap and methods for eliminating and closing the gap. This is necessary to achieve optimum production through adoption of Integrated Soil Management Techniques.

Integrated soil fertility management (ISFM) is a knowledge intensive approach to soil management practice (Bationo *et al.*, 2004). In order to create awareness on ISFM practices, dissemination of knowledge and information should be done through regular trainings. Training provides an understanding of what a technology entails and facilitates its efficient adoption and utilization.

Identifying training needs of stakeholders (farmers and extension agents) and addressing the needs will ensure optimum production. Extension agents are able to disseminate required information, tailor extension services on ISFM to effectively benefit farmers. Farmers on the other hand will be able to take up new technologies or innovations in ISFM to improve soil fertility, increase productivity, food security, protect environment and increase income.

This study therefore assesses the training needs of stakeholders (farmers and extension agents) in ISFM technologies and the preferred methods of achieving these trainings. Understanding of this will assist in developing effective training package to close the gap identified. It will also lead to prioritization of areas of training, increase awareness on ISFM technologies and accelerate adoption and utilization.

Survey Objective

The major objective of the study was to assess stakeholders' awareness, knowledge level and training needs for sustainable uptake and utilization of ISFM technologies in Nigeria.

In order to achieve the major objectives, the following specific objectives were set:

1. To determine the soil fertility problems experienced by farmers and the level of severity of such problems;
2. To assess extension agents and farmers' competency (knowledge) in ISFM technologies;
3. To identify the training needs of stakeholders (farmers and extension agents) and most preferred training methods for ISFM by farmers.

Methodology

Location Survey Instrument & Data Collection

The survey was conducted in 8 states of Nigeria comprising: Ogun, Oyo, Osun, Ondo, Lagos, Akwa- Ibom, Edo and Delta states in collaboration with extension agents. The study population comprised farmers and extension agents from the selected states. Interview schedule was used to elicit information from farmers while questionnaires were produced for extension agents in all the selected states. Three farming communities were selected from each state with the help of the Agricultural Development Programmes. A list of all farmers was obtained from the village extension agent in each community. Random sampling technique was used to select farmers and a total of two hundred and forty-five farmers were selected and interviewed from the eight states, however, 214 interview schedules were used for the analysis. Also, a total of sixty-six extension agents were interviewed from all the selected states.

Data were collected using interview schedule all respondents were small- scale farmers who derive their income mainly from agricultural activities. A brief explanation of the study's objective was given to farmers after which they gave oral consent to participate in the survey. The interviews were however voluntary and farmers were assured of the confidentiality of their responses. The interview elicited information of socio-economic and farm related characteristics of farmers, which include: sex, age, years of schooling, marital status, household size, years of farming experience, membership of farmers/ cooperative association, farm size, ownership etc.

Farmers were also asked about awareness of ISFM technologies, sources of information and frequency of such information, severity of soil fertility problems on their farm, knowledge of farmers in the use of ISFM areas, importance of such areas, preferred extension delivery method(s) for each of the ISFM skill/ knowledge areas and best times to receive training/ extension services. Also, information was obtained from Extension agents on their background, awareness of ISFM technologies, involvement in training activities on ISFM, competency in training farmers on ISFM technologies, and their training needs in ISFM.

Training needs assessments were assessed by requesting farmers and extension agents to assess their current knowledge (competence) in different ISFM areas and also to rate the importance of the training need. The level of the current knowledge was measure on a five point Likert-type scale ranging from none (1) to very high (5). Farmers were also requested to assess the importance of the training on ISFM technologies on a three point Likert- type scale with response options ranging from not important (1) to very important (3).

The major ISFM areas of the training needs include conduct of soil fertility test, erosion control and soil conservation, use of improved varieties, minimal conservation tillage, use of inorganic fertilizers, management and use of animal & farmyard manure, composting and incorporating farm residues into the soil. Others include, use of cover crops/mulching, growing of Nitrogen fixing legumes, intercropping cereals and legumes, crop rotation, liming/reduction of acidity, agroforestry and combine usage of organic and inorganic fertilizers.

Data Analysis

Data for the survey were analyzed using IBM SPSS version 20. Descriptive statistics (frequencies, means, and standard deviations) were used to analyse data. Training needs were assessed using Borich Model which is one of the most widely used models for assessing training needs in agricultural extension. Following this model, a weighted discrepancy score was calculated for evaluation and ranking of farmer's training needs. A Mean Weighted Discrepancy Score was calculated to describe the overall rankings for each of the training areas. The competencies with the highest scores were those with the highest need and priority for training.

Results and Discussion

Personal and Socio-economic attributes of farmers

The data in Table 1 shows the socio-economic attributes of farmers. The majority of the farmers were male (69.9%) while 30.4% were female. The minimum number of years of farmers was 24 while the maximum was 79. The highest period of schooling was 25 while the least was 0. A sizable percentage of the farmers had no formal education which may hinder their ability to access different types of information and training. However, the mean year of schooling was 8.45. Majority (87.9%) of the farmers were married and had mean household size of 7.22. Years of farming experience was between 1 and 55 years. Majority (71.5%) of the farmers were members of farmers' association and cultivated between 0.2 and 50 hectares of land.

Table 1: Socio- economic of characteristics of farmers

S/N	Attributes	Definition	Distribution
1.	Sex	Sex of respondents as male and female	149 (69.9%) Male 65 (30.4%) Female
2.	Age	Actual age	Min 24 years: max 79 years
3.	Education/ years of Schooling	Highest education attained	Max=25 years; min=0
4.	Marital Status	Marital status of respondents	Married (87.9%)
5.	Household Size	Number of persons in the household	7.22
6.	Years of farming experience	Number of years spent in farming	Min 1: max 55 Mean 18.70
7.	Membership of farmers' association	Membership of farmers' association	Association member 153 (71.5%)
8.	Farm size	Areas of land cultivated or used for farming	Min=0.2ha; Max= 50ha mean=3.8

Sources of Information

The most common source of information for farmers was from the Agricultural Development Projects (ADPs) operating in each state of Nigeria (Table 2). ADPs are the extension arm of the States' Ministry of Agriculture saddled with the responsibility of disseminating information and new technologies to farmers. Fifty percent of farmers frequently obtain information from the ADPs. Other frequent sources of information include other farmers (38.8), Private Extension Agencies (12 %), NGOs (9 %) and National Agricultural Research Institutes (9 %). The findings show that farmers also source information from other farmers which is an indication that farmers learn from other farmers' experimentation and experience.

The study clearly showed that more than half of the farmers had received trainings /advice on most of the ISFM technologies at one time or the other in time past (Table 3). These include use of improved varieties/germplasm (improved maize seeds and cassava cultivars etc.) (62 %), use of inorganic fertilizers (51 %), composting (56 %), and use of cover crops/mulching (55 %), intercropping cereals with legumes

(52 %), crop rotation (52 %) and use of organic and inorganic fertilizers (59 %). Also, half of the farmers indicated they have received information/advice on erosion control and soil conservation (50 %), growing of nitrogen fixing legumes (50 %) and management and use of animal and farm yard manure (51 %A lesser percentage indicated they have received training/advice on conduct of soil fertility (48 %), minimum and conservation tillage (49.1%), incorporation of farm residue into the soil (47 %), liming (32 %), agroforestry (45 %). Other ISFM areas in which farmers have received training/advice include pest and diseases management (42 %) and use of irrigation (36 %).

The ease of use and the high yields associated with inorganic fertilizers could have made farmers to learn more about the inorganic fertilizers. It was observed during the survey that although farmers indicated the use of organic and inorganic fertilizers, majority of the farmers in the study area used the organic and inorganic fertilizers separately. They lack the knowledge of combining the two types of fertilizers in adequate proportions for improved productivity.

Table 2: Frequency of Information Source

S/N	Information source	Frequently	Occasionally	Never
1.	ADP	107 (50%)	31 (14.5%)	76 (35.5%)
2.	NARIs	19 (8.9%)	23 (15.4%)	162 (75.6%)
3.	Private Extension Agencies	25 (11.6%)	32 (14.9%)	157 (73.7%)
4.	NGOs	20 (9.3%)	37 (17.2%)	157 (73.7%)
5.	Other farmers	83 (38.8%)	107 (60.8%)	24 (17.2%)

Table 3. ISFM areas farmers have received training or advice

ISFM thematic areas	**Frequency**	**Percentage**
Conduct of soil fertility test	103	48.1
Erosion control and soil conservation	107	50.0
Use of Improved Varieties	133	62.1
Minimum/conservation Tillage	105	49.1
Use of Inorganic fertilizers	111	51.8
Management and use of animal and farmyard manure	109	50.9
Composting	120	56.1
Incorporating farm residues into the soil	100	46.7
Use of cover crops/mulching	118	55.1
Growing of nitrogen fixing legumes	107	50.0
Intercropping cereals and legumes	112	52.3
Crop rotation	112	52.3
Liming (soil acidity)	84	32.3
Agroforestry	96	44.9
Use of organic and inorganic fertilizers	127	59.3
Others-Pest/disease Management	89	41.6
Irrigation	78	36.4

*Multiple responses provided

Severity of Soil Fertility Problems

The severity of soil fertility problems on farm is presented in Table 4. The table show that declining crop yields, poor soil fertility, flood and erosion were the most severe soil fertility problems experience by farmers with mean of 2.66, 2.36, 2.35 and 2.35 respectively. Declining soil fertility, poor soil fertility, flood and erosion have been reported as major challenges facing smallholder farmers (Mugwe *et al* 2004). It is however necessary to give adequate consideration to the soil fertility problems technical skill gap of the farmers for effective delivery. The implication of these results is that there is need to improve on the farmers' knowledge through trainings in order to achieve the perceived maximum economic returns, feasibility and acceptability of the soil fertility management technologies in the study area.

Table 4: Severity of Soil Fertility Problems on Farm

S/N	Soil fertility problems	Highly severe	Severe	Moderately	Less severe	Not severe	Mean	SD
1.	Erosion	36 (16.6%)	19 (8.8)	25 (11.5%)	38 (17.5%)	96 (44.2%)	2.35	1.52
2.	Flood	27 (12.4%)	30 (13.8%)	24 (11.1%)	42 (19.4%)	91 (41.9%)	2.35	1.45
3.	Declining crop yields	55 (25.3%)	56 (25.8%)	38 (17.5%)	37 (17.1%)	28 (19.9%)	2.66	1.37
4.	Poor water retention by the soil	22 (10.1%)	17 (7.8%)	31 (14.4%)	43 (19.8%)	101 (46.5%)	2.14	1.36
5.	Gravel pan	25 (11.5%)	18 (8.3%)	14 (6.5%)	50 (23.0%)	107 (49.3%)	2.08	1.39
6.	Soil salinity	10 (4.6%)	32 (14.7%)	24 (11.1%)	59 (27.2%)	89 (41.1%)	2.13	1.24
7.	Poor soil fertility	84 (38.7%)	45 (20.7%)	31 (14.3%)	32 (14.7%)	22 (10.7%)	2.36	1.39

N=214 ?

Farmers' Knowledge and Importance of ISFM Technologies

The knowledge/competency of farmers of ISFM technologies did not vary much across the two zones. Across the two zones, farmers were competent on the use of improved varieties (mean=3.14- SW; mean= 3.53-SS) and crop rotation (mean=3.18 -SW; mean=3.18 SS). Farmers in Southwest however were more competent in the use of organic and inorganic fertilizers (mean=3.15) and use of inorganic fertilizer (mean=2.97). Farmers in the area were however not competent in the use of composting (mean=2.03-SW; mean=1.89 SS), agroforestry (mean=2.26-SW; mean=2.44-SW), liming (mean=2.35 SW; mean= 2.02-SS) (Table 5). Also, farmers exhibit high importance to composting (mean=2.64-SW; mean=2.60-SS), use of organic and inorganic fertilizers (mean=2.55-SW; mean=2.56 SS), improved varieties (mean=2.46SW; mean=2.56 SS; and soil fertility test (mean=2.37-SW; mean=2.51-SS). However, they showed less importance to the liming and conservation tillage among others (Table 6). The findings call for the need to increase farmers' competency levels in the weak identified ISFM areas.

Table 5. Mean Scores of Farmers' Knowledge (Competency) of ISFM Technologies

ISFM technologies	(South West) Knowledge		(South South)			
	Mean	**Standard Deviation (SD)**	**Rank**	**Mean**	**Standard Deviation (SD)**	
Conduct of soil fertility test	2.48	1.42	11	1.89	1.16	12
Erosion Control and Soil Conservation	2.58	1.30	10	2.44	1.12	10
Use of Improved Varieties	3.24	1.41	1	3.53	1.19	1
Minimum/ Conservation Tillage	2.46	1.23	12	2.53	1.00	9
Use of Inorganic fertilizers	2.97	1.40	4	2.88	1.10	3
Management and use of animal farmyard manure	2.82	1.35	7	2.65	1.00	7
Composting	2.03	0.83	15	1.86	0.93	13
Incorporating farm residues into the soil	2.74	1.31	9	2.70	1.10	6
Intercropping cereals with legumes	2.92	1.31	5	2.88	1.16	3
Use of crop residue	2.79	1.22	8	2.35	0.97	11
Growing of Nitrogen fixing legumes	2.87	1.23	6	2.58	1.01	8
Crop rotation	3.18	1.29	2	3.18	1.15	2
Liming	2.35	1.17	13	2.02	1.28	12
Agroforestry	2.26	1.27	14	2.44	1.26	11
Use of organic and inorganic fertilizers	3.15	1.48	3	2.88	1.12	3

N=214 (1=None; low=2; medium=3; high=4; very high=5)

Table 6. Mean Scores of Farmers' Importance of ISFM Technologies

ISFM technology	South West Importance Mean	Standard Deviation (SD)	Rank	South South Mean	Standard Deviation (SD)	Rank
Conduct of soil fertility test	2.37	0.59	5	2.51	0.60	4
Erosion Control and Soil Conservation	2.31	0.60	7	2.39	0.62	7
Use of Improved Varieties	2.46	0.54	3	2.56	0.59	2
Minimum/ Conservation Tillage	2.19	0.69	15	2.25	0.71	13
Use of Inorganic fertilizers	2.40	0.63	4	2.39	0.62	6
Management and use of animal farmyard manure	2.24	0.67	8	2.25	0.80	14
Composting	2.64	0.48	1	2.60	0.49	1
Incorporating farm residues into the soil	2.22	0.68	9	2.33	0.60	12
Intercropping cereals with legumes	2.17	0.66	13	2.37	0.69	8
Use of crop residue	2.22	0.71	10	2.33	0.63	11
Growing of Nitrogen fixing legumes	2.21	0.62	11	2.35	0.64	10
Crop rotation	2.36	0.63	6	2.40	0.67	5
Liming	2.16	0.65	14	2.11	0.67	15
Agro forestry	2.20	0.73	12	2. 37	0.74	9
Use of organic and inorganic fertilizers	2.55	0.62	2	2.56	0.70	3

N=214 ; SW=157; SS=57 (1=Not Important; 2=Important; 3=Very Important)

Training needs of Farmers.

The training needs assessment revealed a number of ISFM technologies which farmers expressed need for training. Table 7 show the training needs of the respondents in the form of weighted scores, which were also ranked within each ISFM areas. The highest-ranking training needs are considered the most important training needs of the farmers. The highest-ranking training needs as expressed by farmers is in composting, followed by soil fertility test, agroforestry and liming. Crop rotation, use of improved germplasm, use of organic and inorganic fertilizers and incorporation of crop residue into the soil were the lowest ranked training needs as expressed by farmers. This shows ISFM areas where emphasis can be placed to increase farmers' productivity and income.

Table 7. Training needs of farmers in the ISFM Technologies

S/N	ISFM technologies	Mean Weighted Discrepancy Score (MWDS)	Rank
1	Conduct of Soil Fertility Test	0.19	2
2	Erosion Control and Soil Conservation	-0.50	5
3	Use of Improved Varieties	-1.92	14
4	Minimum/ Conservation Tillage	-0.62	6
5	Use of Inorganic fertilizers	-1.26	11
6	Management and use of animal farmyard manure	-1.19	9
7	Composting	1.69	1
8	Incorporating farm residues into the soil	-1.56	13
9	Intercropping cereals with legumes	-1.24	10
10	Use of crop residue	-0.91	7
11	Growing of Nitrogen fixing legumes	-0.92	8
12	Crop rotation	-1.94	15
13	Liming	-0.12	4
14	Agroforestry	0.23	3
15	Use of organic and inorganic fertilizers	-1.30	12

Personal Information of Extension Agents.

The personal information of the field staff (extension agents) is shown in Table 8. The survey revealed that 47.0% of the extension agents were within the age range of 41 and 50 years while 37.9% were within the age range of 51-60years. Only 15.1% were in the age range of 31-40 years while none of the extension staff were under thirty years of age. The extension staff are generally older and are not being replaced which gives great concern to the extension advisory system in the country. Male dominance (78.8%) was also evident among the extension staff with female constituting only 21.2%. Twenty-six percent of the staff were holders of either National Certificate in Education or Ordinary National Diploma certificate while 34.8% were holders of Higher National Diploma certificate. Thirty percent were holders of Bachelor of Science degree in agricultural related fields while 9.1% had Masters of Science degree. Almost 41% of the extension agents had crop production as their field of study, 39% were experts in Agricultural Extension and Economics. Only 7.7% and 6.1% of the Extension agents were experts in soil and Agricultural Technology respectively. Major responsibility of Extension agents was to train, disseminate and provide technical and advisory services for farmers. Number of years of work experience varies from 1 to more than 20years with 36.4% having more than 20years of experience and 25.7% having between 16 and 20 years of experience. Only 4.5% had <5years of work experience.

The data in the table also revealed that 66.6% of the Extension Agents indicated their awareness of ISFM. This implies the need to increase efforts at creating more awareness of the ISFM technologies.

Table 8 : Background Information of Extension Agents

Background Information	Frequency	Percentage
Age		
1-10	11	16.6
11-20	30	45.5
21-30	21	32.3
31-40	04	6.1
Sex		
Male	52	78.8
Female	14	21.2
Educational Qualification		fm
BSC	20	30.3
HND	23	34.8
NCE/OND	17	25.8
M.Sc	6	9.1
Field of Study		
Animal Production	3	4.5
Crop production	27	40.9
Agricultural Extension &Economics	26	39.4
Soil Science	5	7.6
Agricultural Technology	4	6.1
Agricultural education	1	1.5
Years of Experience		
<5	3	4.5
5-10	9	13.6
11-15	13	19.7
16-20	17	25.7
>20	24	36.4
Awareness		
Aware	44	66.6
Not Aware	22	33.3

Training needs of extension agents

The training needs assessment revealed a number of ISFM technologies which Extension agents (EAs) expressed need for training. Table 9 show the training needs of the EAs in the form of mean weighted discrepancy scores (MWDS), which were also ranked within each ISFM areas. Differences between EAs perceived relevance (importance) and ability for each competency produced identifiable needs. The highest-ranking training needs are considered the most important training needs of the Extension agents and include soil fertility testing, erosion control and soil conservation, incorporation of residues into the soil, agroforestry, composting, liming and conservation tillage. Use of inorganic fertilizers and the use of organic and inorganic fertilizers and incorporation of crop residue into the soil, intercropping cereals with legumes and management and use of animal and farmyard manure were the lowest ranked training needs as expressed by EAs.

Table 9. Training needs of Extension Agents on ISFM Technologies

S/N	ISFM technologies	Mean Weighted Discrepancy Score (MWDS)	Rank
1	Conduct of Soil Fertility Test	1.55	1
2	Erosion Control and Soil Conservation	0.75	2
3	Use of Improved Varieties	0.04	8
4	Minimum/ Conservation Tillage	0.08	7
5	Use of Inorganic fertilizers	-1.67	15
6	Management and use of animal farmyard manure	-1.63	14
7	Composting	0.15	5
8	Incorporating farm residues into the soil	0.51	3
9	Intercropping cereals with legumes	-1.44	12
10	Use of crop residue	-1.11	9
11	Growing of Nitrogen fixing legumes	-1.17	10
12	Crop rotation	-1.33	11
13	Liming	0.08	6
14	Agroforestry	0.27	4
15	Use of organic and inorganic fertilizers	-1.60	13

Preferred Training Methods by farmers

The results on preferred methods of training show that most farmers preferred on farm demonstration as most suitable training methods in teaching skills in almost all the ISFM technologies. This is as a result of the practical training it entails and the fact that it also enhances learning experience. However, research findings have shown that combination of two or more training methods should be promoted since these produce positive effects on farmers' acceptance of information than using only one method. On farm demonstrations, training and field days raises farmers' awareness where both literate and illiterate people learn best by seeing (Isiaka, 2001). Radio programme and Television were less preferred since most of these programmes are broadcasted when farmers do not watch or listen to them.

Table 10. Preferred Training methods by farmers

S/N	ISFM	FD	FFS	OFD	TW	IFV	FFE	WM	RP	TV
1.	Conduct of soil fertility test	19 (8.8)	63 (29.4)	75 (35.0)	36 (16.8)	14(6.5)	3 (1.4)	2(0.93)	2 (0.93)	-
2.	Erosion control and soil conservation	2 (0.93)	28(13.5)	91(42.5)	45 (21.0)	16 (7.5)	4 (1.86)	1 (0.5)	17 (7.9)	10 (4.6)
3.	Use of improved varieties	10 (4.6)	26 (12.1)	72 (33.6)	40 (18.7)	39 (18.2)	17 (7.9)	5 (2.3)	4 (1.8)	1 (0.5)
4.	Minimum Tillage	22 (10.2)	24 (11.2)	79 (36.9)	44 (20.5)	16 (7.5)	12 (5.6)	6 (2.8)	-	-
5.	Use of inorganic fertilizers	16 (7.5)	19 (8.4)	86 (40.1)	39 (18.2)	25 (11.7)	21 (9.8)	-	-	8 (3.7)
6.	Management and use of animal and farmyard manure	27 (12.6)	19 (8.8)	99 (42.3)	37 (18.3)	7 (3.3)	23(10.7)	2(0.9)	-	-
7.	Composting	6 (2.8)	23 (10.7)	92 (42.9)	41 (19.1)	28 (13.1)	5 (2.3)	3 (5.0)	3 (1.4)	13 (6.1)
8.	Incorporating farm residues into the soil	11 (5.1)	23 (10.7)	101 (47.2)	44 (20.5)	18 (13.0)	9 (4.2)	5 (2.3)	3 (1.4)	2 (0.9)
9.	Use of crop residue	11 (5.1)	38 (17.7)	96 (44.8)	37 (17.2)	16 (7.4)	12 (5.6)	6 (2.8)	3 (1.4)	-

10.	Growing of nitrogen fixing legumes	10 (4.6)	35 (16.3)	91 (42.5)	42 (19.6)	11 (5.1)	3 (1.4)	3 1.4)	2 (0.9)	-
11	Crop rotation (cereal-legume)	8 (3.7)	27 (12.6)	133 (62.1)	29 (13.5)	7 (3.3)	10 (4.6)	4 (1.8)	2 (0.9)	5 (2.3)
12.	Liming (soil acidity)	13 (6.1)	27 (12.6)	102(47.6)	6 (2.8)	39 (18.2)	13 (6.0)	4 (1.8)	5 (2.3)	5 (2.3)
13.	Agroforestry	29 (13.5)	6 (2.8)	126 (58.9)	11 (5.1)	11 (5.1)	2 (0.9)	4 (1.8)	12 (5.6)	13 (6.07)
14.	Use of organic and inorganic fertilizers	24 (11.2)	19 (8.8)	124 (57.9)	11 (5.1)	10 (4.6)	11 (5.1)	4 (1.8)	5 (2.3)	6 (2.8)

FD=field days; FFS=Farmers' field schools; OFD=On-farm demonstration; TW=training workshops; IFV=individual farm visits; FFE=farmer to farmer extension; 7WM= Written materials; RD=Radio programme; TV=Television programme

Conclusions and Recommendations

The findings from the survey has shown the severity of soil fertility problems in the study area. It further revealed that both farmers and extension agents showed different competence and needs for training. However, there is need to prioritize training based on the identified gaps.

The highest-ranking training needs as expressed by farmers is in composting, followed by soil fertility test, agroforestry and liming. Crop rotation, use of improved germplasm, use of organic and inorganic fertilizers and incorporation of crop residue into the soil were the lowest ranked training needs as expressed by farmers. The highest-ranking training needs that are considered the most important training needs of extension agents include soil fertility test, erosion control and soil conservation, incorporation of residues into the soil, agroforestry, composting, liming and conservation tillage.

Based on the findings of the study, the following recommendations are made:

There is need for awareness creation and training of both farmers and extension agents in the use of ISFM technologies. The highest ranked gaps should therefore receive more training and the training must be matched with best delivery methods. Priority should be given to composting, soil fertility test, agroforestry and liming for farmers while soil fertility test, erosion control and soil conservation, use of crop residue, agroforestry, composting liming and conservation tillage must be concentrated on for extension workers. Continuous in-service training on ISFM technologies should be facilitated for extension agents so as to be deeply educated in the identified areas.

Training of farmers and extension agents should emphasize practical training and observation rather than theoretical training. This will help to ensure that new learning is absorbed by farmers and extension agents.

Regular field surveys to assess and monitor changes in the training needs of farmers and Extension agents on ISFM technologies is also recommended.

Soil information at large scale useful for advisory services for small-scale farmers should be made available and popularised for sustainable land use and food security.
Development of policy brief from the comprehensive report.

References

Adesoji, S.A., Farinde, A. J., Ajayi, O.A. (2006). Assessment of the training needs of Fadama
farmers for future agricultural extension work development in Osun State, Nigeria. *J. Appl. Sci*., 6(15): 3089-3095.

Agbonlahor, M.U., Aromolaran, A.B and Aiboni, V.I (2003). Sustainable soil management
practices in small farms of southern Nigeria: A poultry -food crop Integrated Farming Approach. *Journal of Sustainable Agriculture* 22 (4): 1-8

Ande, O.T., Adeyolanu, O.D., Are, K.S. and Oke, A.O. (2014) Soil quality and variability assessment of Ultisols derived from sand stone in south western Nigeria. *Moor Journal of Agricultural Research* 15: 112-123. (Nigeria)

Ande O.T., Adeyolanu, O.D., Are, S.K., Adelana, A., Oke, A., Ojo, O.A., Oluwatosin G.A. Adelabu, L.A. and Taiwo, O. (2014). Digital soil mapping and morphogenetic characterization of soils of Ebonyi formation in South Eastern Nigeria. *Earth Science Research* 5 (1): 1-9. (Canada)

Ande, O.T., Senjobi B.A., Adediran, J.A. and Oluwatoyinbo, F.I. (2010). Effects of land use on nutrient distribution on a gently undulating landscape in the derived savanna of Southwestern Nigeria. *Moor Journal of Agriculture* 11: 1 – 7. (Nigeria)

Ande, O.T**.** and Senjobi, B.A. (2014). Land degradation assessment of agrarian soils in Ebonyi state for sustainable production. *Journal of Ecology and Natural Environment* 6 (6): 200-204. (Nigeria)

Ande, O.T**.,** Huising, J., Ojo, O.A., Azeez, J.O., Ojeniyi, S.O. Olakojo, S.A. and Fademi, I.O. (2017). Status of integrated soil fertility management (ISFM) in Southwestern Nigeria. *International Journal of Sustainable Agricultural Research* 4 (2): 28-44. (UK)

Aruna O A., **O. T.** Ande**,** S. O.Dahunsi, J. O. Ogunwole and A. L. Ibaba (2024). Impact of bio-digestate and fertilization on the soil chemical properties, growth and yield of maize (Zea mays (L.) Research on crops, 28(1) 33-42 DOI:10.51830/2348-7542.2024.ROC-1039

Bationo, A., Kimetu , J., Ikeera, S., Kimani, S., Mugendi, D., Odendo, M., Silver, M., Swift, J., Sanginga, N. (2004). The African network for soil biology and fertility: new challenges and opportunities. In: Bationo A (ed) Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science Publishers and Tropical soil Biology and Fertility Institute of CIAT, Nairobi, pp 1–23

Isiaka, B.T. (2001). “Information Technology”.11th National Congress of the Nigerian, Rural Sociological Association (NRSA). University of Uyo, Nigeria, September 17th - 20th, 2001.

Mugwe, J., Mugendi, D., Mucheru-Muna, M., Merchx, R., Chianu, J., Vanlauwe. B. (2009), Determinants of the Decision to Adopt Integrated Soil Fertility Management Practices by Small Holder Farmers in the Central Highlands of Kenya. *Expl Agricu*. Volume 45, pp 61-75 Cambridge University Press

Odunjo, T.E., Oguweide, T.A., Fademi, I.O., Anoke, E.O., Uthman, A.C.O. and Ande, O.T**.** (2023). Soil quality improvement with verti-compost for sustainable maize cultivation on degraded soils. *Moor Journal of Agricultural Research* 22: 1-12. (Nigeria).

EFFECT OF LAND USE TYPES ON SOIL PHYSICAL AND CHEMICAL PROPERTIES IN ALEX EKWUEME FEDERAL UNIVERSITY NDUFU ALIKE, EBONYI STATE.

***Orji, J. F., C. S. Iroegbu and J. Nnamdi**

[1&2]*Department of Soil Science, Alex Ekwueme Federal University Ndufu Alike, Ebonyi State,*

**Corresponding author email:revjeph@gmail.com*

ABSTRACT

The study investigated the effect of land use types on soil physicochemical properties of different land use types at the Alex Ekwueme Federal University Ndufu Alike, Ebonyi State. Four land use types were selected namely fallow land, grass land, continuously cultivated land and forest land. Soil samples were collected at 0-10 cm, 10 – 20 cm and 20 – 30 cm soil depth and replicated three times, the experimental design was a 4 x 3 x 3 factorial laid out in a completely randomized design (CRD). Disturbed and undisturbed samples were collected for physical and chemical analysis. The results obtained showed that the soil in the study area was predominantly sandy loam and sandy clay loam in texture. The soil of the study area was slightly acidic. Bulk density values obtained were lowest in forest land (1.24 g/cm^3) and the highest at the continuously cultivated land (1.75 g/cm^3). The highest (53%) and lowest (34%) values for total porosity were obtained in the forest land and continuously cultivated land respectively. The total nitrogen (0.75 – 1.58 g/kg), available phosphorus (13.7 – 31.6 mg/kg), Soil organic carbon (4.4 – 11.7 g/kg), Na^+ (0.103 – 0.244 cmol/kg), CEC (5.176 – 12.837 cmol/kg) and % base saturation (59 – 96%) varies from low to high across the land use types with 0 – 10 cm recording the highest and 20 – 30 cm recording the lowest. The results suggest that forest land, fallow land and grass land should be encouraged while continuously cultivated land should be properly managed for sustainable agricultural production.

Key words: *Land Use Types, Soil, Chemical Properties*

Introduction

Obviously, land is used for several and different purposes which may be either agricultural or non-agricultural. Land use type can be said to be the arrangements, activities and inputs undertaken by people in given land cover type with a view of producing, changing and managing it (FAO/UNEP,1999). In rural areas of our country Nigeria for instance, agriculture and simple residential buildings are the common uses of land whereas in the urban areas, ultra-modern residential buildings, commercial centres, recreational centres, road networks and agricultural activities are the major uses of land (Popoola and Mgbonu, 2018). Soil quality is influenced by the management practices the land is subjected to such as settlements, arable land, football field, pasture, roads and managed woodlands. The change in land use types leads to global warming and climate change. Many researchers (Kekong *et al.*, 2018; Mohammed, 2017) observed that land use affects both the chemical, physical and biological properties of the soil that tend to affect the quality attributes and fertility status of the soil. According to (Yihenew and Geheyaw, 2013, Gebayaw, 2007 and Mohammed, 2017), land use affects both the chemical, physical and biological properties of the soil that tend to affect the quality attributes and fertility status of the soil. Land use types affect surface runoff and change in resilience of soil to environmental impacts

(Hacisalihoglu, 2007). The extent of these changes varies with land use type, management practice and vegetation cover (Celik, 2005).

Soil properties deteriorate with changes in land use especially from forest to arable land (Oguike and Mbagwu, 2009). Fawole *et al.* (2016) observed that the extent of these changes varies with land use type, management practice and vegetation cover. Soil properties deteriorate with changes in land use especially from forest to arable land (Oguike and Mbagwu, 2009). The land use types have the tendency to cause soil compaction and erosion as a result of alteration of the soil physical and chemical properties (Wang *et al*., 2006); Misir *et al.,* 2007); Chokor and Egborah, 2018).

Naturally, with continuous cultivation, physical and chemical properties of soils are adversely impoverished leading to loss of organic matter, erosion, leaching of soil nutrients and later decreased productivity (Ezeaku *et al.,* 2015). On the other hand, intercropping of trees or mixed planting according to Fedaku *et al.* (2018) produces better soil. Uchenna *et al.* (2017) in their studies reported that soil properties vary overtime with land use types and the knowledge of such changes could be vital for sustainable food production and land usage. Information on the effect of land use types on soil physicochemical properties of Ndufu – Alike soil is scanty hence the need for the research. The objective of this work, therefore, is to study the effect of land use types on soil physical and chemical properties of different land use types in Alex Ekwueme Federal University Ndufu Alike, Ebonyi State.

Materials and Methods

Site location

The study was carried out at the Teaching and Research Farm of Faculty Agriculture of Alex Ekwueme Federal University Ndufu Alike, Ebonyi state, southeastern Nigeria. The area lies between latitude 06° 8.29N and Longitude 08°8.63E and altitude 55m in the derived savanna zone of southeastern Nigeria. The rainfall ranges from 1700 to 2000mm with mean annual rainfall of 1800mm (Anyadike 2002). The mean annual temperature ranges from 27°C to 31°C throughout the year. The relative humidity is 80% during rainy season but declines to 65% in the dry season (FDALR, 1990). The field work was carried out in four selected land use types within the university namely; Forest Land, Grass Land, Fallow land and Continuously Cultivated Land and and their description are as follows;

Forest Land (FL): The Forest land is located at the back of the old female hostel at the University (Alex Ekwueme Federal Univeristy Ndufu Alike, Ebonyi State). The land was said to have existed for over 100years as the villagers also mentioned that the heart of the forest is also a dangerous place for anyone to enter therefore it is prohibited for hunting and farming activities in it. The land possess trees, grasses, herbs and shrubs such as wire grass (*Sporobulus pyramidalis*), tridax (*Tridax procumbens*), giant star grass (*imperata cylindrical*), guinea grass (*Panicum maximum*), oil palm (*Elaeis guincensis*), mango (*Magnifera indica*), etc.

Grass Land (GL): The Grass land is located close to the Male Hostel regarded as the University (Alex Ekwueme Federal University Ndufu Alike, Ebonyi State) football field. The grass land is periodically under-cut especially the area that serves as field for games. Some parts of the land is use to graze animals. The grass land has existed over 13years. The land is grown with herbs but dominated by grasses such as Tridax (*Tridax procumbens),* giant star grass (*Imperata cylindrical*), Guinea grass (*Panicum maximum*). The land area for the purpose of the study is measured 50 m x 50 m (0.5 ha).

Fallow Land (FL): The Fallow land is located close to the Engineering Faculty. The fallow has lasted for more than 13 years. There are different types of vegetation covering the land but among major ones are scattered trees, herbs, shrubs and grasses like guinea grass (*Panicum maximum),* wire grass *(Sporobulus pyramidalis*), goat weed (*Ageratum conyzoides*)*,*stubborn weed *(Sida acuta)*. The land area of 50 m x 50 m (0.5ha).

Continuously Cultivated Land (CCL): Otherwise known as arable land located close to the Faculty of Agriculture Alex Ekwueme Federal University Ndufu Alike, Ebonyi State. The arable land is the research/experimental farm of the Faculty of Agriculture. The area has been under yearly cultivation for more than six years by students and staff of the Department. It has been subjected to conventional tillage operations, use of chemicals (like fertilizers, herbicides and pesticides), organic amendments and other cultural practices. Common crops grown in rotation include yam (*Dioscorea spp),* cassava (*Manihot spp),*maize (*Zea mays* L*)*, vegetables, cucumber and leguminous crops. The land area measured out for the purpose of the research will be 50 m x 50 m (0.5ha). The selection of the four land use types above is to have better representation of the various land use practice in AE-FUNAI, South Eastern Nigeria.

Soil Sampling

Soil samples were collected from the selected four land use types at three depths (0 – 10 cm, 10 – 20 cm and 20 – 30 cm) using core samplers and soil auger for soil physical and chemical determinations. Within each land use type, three (3) core and auger samples each were collected from the three soil depths and replicated three times. The undisturbed samples collected with core samplers of 6 cm height and 5 cm of diameter were used for bulk density determination. The auger soil samples were air – dried, gently crushed and passed through 2mm-sieve to obtain fine earth separates for soil particle size distribution and chemical analysis.

Laboratory methods

Particle size distribution of the less than 2mm fine earth fractions was determined using Bouyoucous hydrometer method as described by Gee and Bauder (1986). Bulk Density was determined using core sampling method after oven drying the soil samples to a constant weight at temperature of 105°C for 24hours (Blake and Hartage, 1986; Grossman and Reinsch, 2002). The Total Porosity was calculated from soil bulk density using us assumed particle density of 2.70gcm^3 . TP= (1-Bd/Pd) X 100/1

Soil pH was determined using glass-electrode pH meter. The pH was determined on a 1:2.5 soil: solution ratio in both water and 0.01M $CaCl_2$ solution (Mc Lean, 1982). Available phosphorus was obtained by the Bray-2 method (Bray and Kurtz, 1945). Organic carbon was determined by Walkley – Black dichromate wet oxidation method (Nelson and Sommer, 1982), Total Nitrogen was extracted using the mico-kjeldahl technique (Bremner and Mulvaney, 1982). Exchangeable $H^+$and Al^{3+} were determined by tritrimetric method using KCl (Mcleean, 1965). Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted with 1N neutral ammonium acetate (NH_4OAC) solution, Ca^{2+} and Mg^{2+} were determined by titration, while K^+ and Na^+ were measured by flame photometry (Grant, 1982). Cation exchange capacity was obtained by ammonium acetate displacement method. Base saturation was obtained using the appropriate formula.

Data Analysis

Data were analysed using analysis of variance (ANOVA) Obi (2002). Separation of treatment means for significant effect was done using Fisher's –Least significance difference (F-LSD).

Results and Discussion

The results of the physical parameters of the various land use types studied are presented in Table 1. The study area had the sand fraction across the soil depths ranging from 393 to 693 g/kg, silt fraction ranging from 145 to 345 g/kg and clay fraction ranging from 152 to 322 g/kg. Thus, the soils in the study area were predominantly sandy loam and sandy clay loam and was significantly ($p < 0.05$) affected by land use (Table 1). The textural variation across the land use types might be attributed to the selective removal of soil particles from one location to another by agents of soil erosion and variation in weathering intensity (Kolo, 2019). The sand fraction decreased generally with depth in all land use types. The general decrease in sand fraction with depth could be attributed to the sorting through eluviation- illuviation process as was reported by Thomas and Oke (2018). The distribution of silt fraction was irregular with depth across the land use types. The clay fraction increased generally with depth in all land use types. From the results, it can be observed that the values of sand are greater than clay and silt. The same is clay value over silt. This is in tandem with the general trend in particle size distribution which is sand > clay > silt, this was also observed by Asadu and Akamigbo (1983) in most soils of southeastern, Nigeria.

Across the soil depths (0 – 30 cm), the value of bulk density was significantly different ($P < 0.05$) among the land use types and ranged from 1.24 to 1.75 gcm^{-3}. The highest (1.73 gcm^{-3}) and lowest (1.24gcm^{-3}) bulk density values at 0 – 10 cm soil depth were recorded at continuously cultivated land and forest land respectively (Table 1). The low bulk density observed in soils of forest land has advantage of increased porosity (Vogelmann *et al*., 2010) with accompanied adequate aeration."The increase in bulk density with depth may be attributed to compaction caused by the weight of the overlying horizons and decrease in organic matter with depth. This agrees with the reports of Chaudhari *et al.* (2013) and Fedaku *et al.* (2018) as they reported increasing bulk density with depth due to changes in organic matter content, porosity and compaction. "

Total porosity values of the soils were significantly different ($P < 0.05$) among the land use types. Total porosity varied from 34 to 53% across the soil depths of the various land use types. Forest land consistently recorded the highest values (53%, 51% and 49%) while continuously cultivated recorded the lowest values (35%, 34% and 34.2%) across the soil depths and among the land use types (Table 1). The decrease in total porosities with depth might be attributed to the decrease in organic matter content with depth (Hassan and Shuaibu, 2006)."

The results of the chemical properties of the land use types are presented in Tables 2. The soils of the studied area were significantly different ($p < 0.05$). The results showed that soil from Forest land had the highest values for total nitrogen (TN), organic carbon, available phosphorus, exchangeable calcium (Ca), exchangeable sodium (Na) and exchangeable potassium (K) while the lowest values were recorded by the soil from continuously cultivated land. In all the land use types, the soils were slightly acidic and increased with soil depths. The soil pH was lowest in the top soils of continuously cultivated land (5.4) and the highest at the forest land (6.0).

The total nitrogen (TN) content decreased significantly with soil depths in all the land use types. The values of total nitrogen were observed to decrease significantly with soil depths in all land use types and were rated very low to low in all the land use types based on the scale by Enwezor *et al.* (1989) and Kayode *et al*. (2018). The low values of TN might be linked to low organic matter content of the soils as OM accounts for 93 to 97% of total nitrogen (Meysner *et al*., 2006)." According to Nsor and Adesemuyi (2018) low TN could be attributed to the volatilization of gaseous forms of nitrogen during burning and agreed with Uzoho *et al*. (2014) who observed low nitrogen values in areas degraded by bush burning. The lower TN observed at the lower depth might be linked to the higher water table which contributes immensely to leaching of nitrogen usually the nitrate form (Adegbite *et al*., 2019).

The highest value of organic carbon content was obtained at the Forest land (11.7 g/kg) while the lowest value was obtained at the continuously cultivated land (6.5g/kg) at 0 – 10 cm and across the soil depths. Organic carbon was observed to be in the following order: Forest land > Fallow land > Grass land > Continuously cultivated land. Therefore, high nutrient recycling occurs in the forest land due to the high litter falls (Chokor and Egborah, 2018).

Similarly, available phosphorus (P) decreased with soil depths. Available P was not deficient across the three depths in all the land use types when compared to the critical value of 10 – 16 mg/kg as reported by Chokor and Egborah (2018). (Table 2). Calcium (Ca) content was significantly different ($p > 0.05$) among land use types and the highest and lowest values (5.8 Cmolkg^{-1}) and (2.8 Cmolkg^{-1}) across the land use types were obtained at the Forest land and Continuously cultivated land respectively. The value was high for all the soils of the different land use types across the soil depths according to Enwezor *et al* (1989). This observation is in agreement with Nsor (2017) who reported high calcium content of soils in southeastern Nigeria. .Magnesium (Mg) content was significantly different ($p<0.05$) among the land use types studied. The highest value was obtained in Forest land (1.88 cmolkg^{-1}) while the lowest was at the continuously cultivated land (1.00 cmolkg^{-1}). The results showed that the top soil had the highest values in all the land use types and decreased down the depths. The values of Mg were rated high across the depths for all the soils under different land use types when compared with the critical value of 0.2 – 0.4 cmolkg^{-1} according to Akirinde and Obigbesan (2000); Shehu *et al*. (2015); Nsor *et al*. (2018)."Mg content was not deficient in any of the four land use types (Table 2). Potassium (K) , Sodium (Na), Exchangeable Acidity (EA), cation exchange capacity (CEC) and percentage base saturation (%BS) contents were all significantly different ($p<0.05$) among the land use types studied (Table 2).

Conclusion

The results of the study showed that the total N, organic carbon, organic matter, available P, potassium (K), calcium (Ca) and sodium (Na), cation exchange capacity (CEC) and percentage base saturation (%BS) were all significantly different ($p > 0.05$) among land use and decreased with soil depths while the soil was slightly acidic. The forest land recorded the lowest values for bulk density and total porosity. Forest land recorded highest values while continuously cultivated land recorded the lowest values for all the soil nutrients. The significance difference between the forest land and other land use types shows the need to encourage the conservation of our soil.

	SAND (g/kg)	SILT (g/kg)	CLAY (g/kg)	TC	BD (gcm^3)	TP (%)
			0-10 cm			
Fallow Land	583	245	172	SL	1.40	47
Grass Land	693	145	162	SL	1.49	44
Con. Cul. Land	633	155	212	SCL	1.73	35
Forest Land	573	275	152	SL	1.24	53
Mean Value	620.5	205	174.5		1.47	44.75
FLSD	10.94	24.55	9.30		0.05	1.63
			10–20 cm			
Fallow Land	533	215	252	SCL	1.43	44
Grass Land	593	195	212	SCL	1.60	39.3
Con. Cul. Land	573	155	272	SCL	1.70	34
Forest Land	453	335	212	L	1.30	51
Mean Value	538	225	237		1.51	42.08
FLSD	4.12	3.00	6.80		0.18	2.83
			20 – 30 cm			
Fallow Land	493	185	322	SCL	1.44	45.9
Grass Land	593	145	262	SCL	1.63	38.7
Con. Cul. Land	563	145	292	SCL	1.75	34.2
Forest Land	393	345	262	L	1.32	49
Mean Value	510.5	205	284.5		1.54	41.95
FLSD	9.92	5.99	10.24		0.03	0.74

Table 1: physical properties of soil across the various land use type.

TC: Textural Class; BD: Bulk Density; TP: Total Porosity; CV: Coefficience of Variance; SL: Sandy Loam;
SCL: Sandy Clay Loam; SL: Samdy Loam; L: Loam; Con. Cul. Land: Continuously Cultivated Land.

Table 2: Chemical Properties of Soil of the various Land Use Types studied

Ca: Calcium; Mg: Magnesium; K: Potassium; Na: Sodium; EA: Exchangeable Acidity; CEC: Effective Cation Echange Capacity; BS: Base Saturation. Con. Cul – Continuously cultivated land

Land use Types	pH (H_20)	P (mg/kg)	TN(g/kg)	OC(g/kg)	OM(g/kg)	Ca (cmol/kg)	Mg(cmol/kg)	K(cmol/kg)	Na (cmol/kg)	EA(Cmol/kg)	CEC (Cmol/kg)	BS (%)
								0-10cm				
Fallow Land	5.8	28.3	1.54	8.4	14.2	5.2	1.66	0.177	0.135	1.48	8.99	91
Grass Land	5.9	26.8	1.12	7.8	13.6	5.1	1.20	0.133	0.129	2.32	5.18	96
Con. Cul. Land	5.4	17.9	0.91	6.5	11.1	2.8	1.00	0.123	0.113	2.31	12.77	74
Forest Land	6.0	31.6	1.58	11.7	20.2	5.8	1.88	0.201	0.156	2.73	6.64	89
Mean Value	5.8	27.95	1.29	8.6	14.8	4.73	1.44	0.16	0.13	1.21	8.39	87.5
FLSD (0.05)	0.55	0.54	0.02	0.019	0.01	0.52	0.96	0.58	0.58	0.03	5.12	2.83
								10-20cm				
Fallow Land	5.4	23.7	1.18	6.7	11.8	4.3	1.40	0.112	0.139	2.44	6.56	77
Grass Land	5.3	20.2	1.06	5.7	9.8	3.2	1.20	0.119	0.121	2.32	6.53	90
Con. Cul. Land	5.2	17.0	0.82	5.3	9.1	2.4	1.00	0.130	0.104	2.26	12.12	73
Forest Land	5.7	24.4	1.33	9.7	16.7	4.4	1.80	0.147	0.191	1.86	8.36	65
Mean Value	5.4	21.33	1.09	6.9	11.9	3.60	2.23	0.13	0.14	2.30	8.39	76.3
FLSD (0.05)	0.76	1.80	0.02	0.52	0.001	0.35	0.35	0.018	0.003	0.22	0.006	1.15
								20–30 cm				
Fallow Land	5.2	18.5	0.96	4.8	8.4	3.2	1.20	0.110	0.122	2.42	7.64	74
Grass Land	5.1	18.4	0.86	4.4	7.7	2.3	1.20	0.109	0.120	1.73	9.50	92
Con. Cul. Land	5.0	13.5	0.75	5.3	9.1	1.8	0.98	0.115	0.104	2.20	12.83	67
Forest Land	5.6	19.9	0.98	5.2	10.4	4.3	1.78	0.146	0.165	2.60	8.74	59
Mean Value	5.2	17.58	0.89	0.52	8.9	4.08	2.68	0.15	0.16	2.63	9.68	73.0
FLSD (0.05)	0.44	2.88	0.006	0.03	0.05	0.26	0.87	0.01	0.005	0.099	0.022	2.58

References

Adegbite, K.A., Okafor, M.E., Adekiya A.O., Alori, E.T. and Adebiyi O.T.V. (2019) Characterization and classification of soils of a toposequence in a derived savannah agroecological zone of Nigeria. *The Open Agriculture Journal* 13: 44 - 50.

Anyadike, R.N.C. (2002). Climate and vegetation in Ofomata, G.E.K. (ed), A Survey of the Igbo Nation. Africana First Publishers. Pp 73-82.

Asadu, C.L.A., Nnaji, G.U. and Ezeaku, P.I. (2012). *Conceptual issues in pedology*. University of Nigerian Press Limited, University of Nigeria, Nsukka, Nigeria. 34 – 57.

Blake, G.R and Hartage KH (1986). Bulk density. In Klute A (Ed) Methods of Soil Analysis Part 1 American Society of Agronomy 409 Madison Wisconsin, 364-375.

Bray, R.H and Kurtz L.T. (1945) Determination of total organic and available forms of phosphorus in soils. Soil Science (59) 39-45.

Bremner and Mulvanney (1982) Total nitrogen. In: Page A et al (Eds) Methods of soil analysis part 2 ASA, Madison, Wisconsin, pp 595-624.

Celik, I. (2005). Land use effects on organic matter and physical properties of soil in the southern Mediterranean highland of turkey. Soil and Tillage Research 83: 270 – 277.

Chaudhari, P.R., Ahire, D.V., Ahire, V.D., Chkravarty, M., and Maity, S. (2013). Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coinboire soils. *International Journal of Science and Research Publications* 3 (2): 1 - 8

Chokor, J.U and Egborah, J.O (2018). Effect of Land use types on selected soil physical and chemical properties in the Univeristy of Benin Nigeria Journal of Soil Scince 28 (1) 276 -286.

Ezeaku, P.I., Eze, F.U. and Oku, E.J. (2015). Profile distribution and degradation of soil properties of an Ultisol in Nsukka Semi-Humid Area of Nigeria. African Journal of Agriculture Research,10 (11): 1306 – 1311.

Enwezor, W.O., Udo, E.J., Usoro N.J., Ayotade K.A., Adepetu, J.A., Chude, V.O and Udegbu, C.I. (1989). *Fertilizer use and management practices for crops in Nigeria*. Series 2. Federal Procurement and Distribution Division, Federal Ministry of Agriculture, Water Resources and Rural Development, Lagos. 119 – 121.

Fedaku, A., Kibebew, K.A, Bobe, B.A. and. Asmare, M.B. (2018). Characterization and classification of soils of Yikalo subwatershed in lay Gayint District, Northwestern Highlands of Ethiopia Endalkachew. Eurasian Journal of soil.

Federal Department of Agricultural Land Resources (FDALR) (1999). Status of agricultural landuse in Nigeria. In: evolving an effective agricultural landuse policy for Nigeria. Abuja, Federal Ministry of Agriculture and Natural Resources, P. 165.

Fawole, O.A., Ojetade, J.O., Muda, S.A. and Amusan, A.A. (2016). Genesis and classification of soils on a toposequence underlain by mica schist in Ife Area, Southwestern Nigeria. *Global Journal of Science Frontier Research: Agriculture and Veterinary* 16 (7): 31 - 42

Food and Agricultural Organization (FAO) (1999). Guidelines for land use planning. FAO Development series. FAO Rome, p. 96.

Grossman, R.B and Reinsch, T.G, (2002) Bulk density and linear

Extensibility core method. In Dare, J. H. and Topp. G.C Eds., Methods of soil Analysis. Part 4. Physical methods. SSSA incorporated.
Gee, G.W and Bander J.W (1986). Particle size Analysis. In: Klute, A. (eds). Methods of soil Analysis. Part 2: Chemical and Microbiological properties. 2nd ed. Agron . Monograph 9, ASA and SSSA, Madison, WI, USA . pp 320-376.
Gebeyaw, T. (2007). Soil fertility status influenced by different land uses in Maybar areas of south wello zone, North Ethopia. An MSc thesis submitted to the faculty and department of plant sciences, school of graduate studies, Haramaya University.
Hacisalihoglu, S. (2007). Determination of soil erosion in a steep hill slope with different land use types, A case study in Metesdorf (Rumertal/ Germany). *Journal of Environmental Biology*, 28, 433 – 438.
Kekong, M.A; Attoe, E. E and Adiaha, M. S. (2018). Effect of nitrogen fortified rice mill waste on soil chemical properties and yield of maize in Nigeria. Pp 331 – 337.
Kolo, J. (2019). Investigation of topographic influence on soils supporting *Cannibis sativa* and their alternative use for rice production in Southwestern Nigeria. Unpublished PHD Thesis at Soil Science Department, University of Nigeria, Nsukka. 87p
Misir, N. M.; Misir, U.; Karahalil and Yavuz, H. (2007). Characterization of Soil Erosion and Its Implication to forest management. *Journal of Environmental Biology*, 28, 185 – 191.
McLean, E.O. (1965). Aluminum. Pp 978-998. In: C.A. Black (Eds.). Methods of soil analysis. Agronomy. No 9. Part II. American society of Agronomy, Maidson, Wisconsin. USA.
Meysner, T., Szajdak, L. and Kus, J. (2006). Impact of the farming systems on the content of biologically active substances and the forms of nitrogen in the soils. *Agronomy Research,*4: 531 – 542.
Mohammed, Y. M. (2017). Impact of landuse and management practice on soil physical and chemical quality indicators of vertisols at Pawe North Western Ethiopia. *African. Journal. Agric. Res.* 12(15): 1306 – 1313.
Nelson, D.W and Sommers, L.E (1998). Total organic carbon and organic matter. In: Methods of soil analysis, 3rd Ed. Spaus D.L; page A.L..Helmke, P.A Leoppert, R.H; Soltanpour, P.N., Tahatabai M.A and Johnson, C.I (Eds) Amenrican society of Agronomy; Madison, WI, USA pp, 961-1010.
Nsor, M.E. (2017). Pedogenesis, classification and management implications of soils derived from Nanka sands of false bedded sandstones lithology in Orumba North L.G.A, Southeastern, Nigeria. Proceeding of the 41st Annual Conference of Soil Science Society of Nigeria held between 13 - 17th March, 2017 at ATBU, Bauchi, Nigeria. 195 – 204.
Nsor, M.E and Adesemuyi, E.A (2018) Nature, properties and management of soils derived from an acid and basic igneous rock parent material in southern Nigeria. *Nigeria Journal of Soil Science*, 28 (1): 161 – 172.
Oguike, P. C and Mbagwu, J. S. C. (2009). Variations in some physical properties and organic matter content of soils of coastal plain sand under different landuse types. World Journal of Agricultural Science 5(1): 63 – 69.

Popoola, E.O and Mgbonu, K (2018). Variability in soil properties of the different land use types in federal college of Education Kontagora, Niger state, Nigeria. In: Oluwatosin G.A, Ande O.T, Adediran J A and Anikwe M.A.N (eds). Sustainable management of soil and water resources for food security, climate change adaptation and mitigation. Proceedings of the 42nd Annual Conference of the Soil Science Society of Nigeria, 22-30 pp.

Thomas, E.Y and Oke O.S (2018) Assessment of some trace elements from selected soil along the top sequence in Ibadan, South western Nigeria. Proceedings of the 42nd Annual Conf. of the Soil Science Society of Nigeria p 434-447.

.Uchenna, S.O., Agbani, L., Ihem, E. and Onyegbule, U (2017). Influence of land use types on soil properties and micronutrients concentrations on soils of similar lithology in Owerri, Southeast Nigeria. Journal of Agricultural Science .4:1- 9

.Uzoho, B.U, Ekpe I.I., Ahukaemere, C.M., Ndukwu, B.N., Okoli N.H., Osis F.A and Chris-Emenyeonu, C.M. (2014). Nitrogen status of soils of selected land uses of cropping systems in the humid tropical rainforest, Southeastern Nigeria. *Advances in Life Sciences and Technology* 25: 24 – 33.

Vogelmann, E.S., Reichert, J.M., remert, D.J. Mentges, M.I., Vieira, D.A, Peixotode Baros, C.A, and Fasimmirin, J.T (2010). Water repellency in Soils of humid subtropical Climate of Rio Grande do sul, Brazil. Soil Till. Res. 110, 126-133.

Wang, J., Projietu, V.Q. and Liding, C. (2001). Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China. *Journal of Arid Environment* 48: 537 - 550 63.

Yihenew, G.S. and Getachew A. (2013). Effect of different land use systems on selected physicochemical properties of soils in North-western Ethopia. *Journal Agricultural. Science.* 5(4):112 – 120

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COMPARATIVE EFFECT OF SELECTED FERTILIZERS ON SOIL CHEMICAL PROPERTIES OF THE PROPOSED SITE FOR CASSAVA CULTIVATION IN ONDO SOUTHWESTERN NIGERIA – INCUBATION STUDY

Ayeni, L. S.
Department of Agricultural Science,
Adeyemi College of Education, Ondo, Nigeria
Corresponding author email:leyesam@yahoo.com

ABSTRACT
The major aim of soil and plant analysis before planting is to detect the nutrients that are deficient before planting and possibly proffering necessary solution. An incubation study was conducted to determine the amount of OM, N, P, K, Ca, Mg as well as Fe, Cu, Zn and Mn released to the soil by NPK 15:15:15, urea, single super phosphate (SSP), muriate of potash (MOP), Wood ash (WA) and Poultry manure (PM). Soil samples were collected from the field proposed for planting cassava in Ondo southwestern Nigeria. Three hundred grammes of soil samples were used for the experiment. Poultry manure and wood ash were each applied at 0.5 g and mineral fertilizer types were each applied at 0.2 g /300g soil. The treatments were incubated in the laboratory for 30, 60 and 90 days. The pretreatment analysis showed that the soil was slightly acidic, low in N, P, Ca, K and fairly adequate in micronutrients. All the treatments decreased soil pH at 30 days. All the nutrients were increased at 30 days of incubation and thereafter decreased at 60 days and 90 days. Among the fertilizers, application of NPK 15:15:15 fertilizer had better balanced N, P and K release to the soil for a short period while poultry manure added extra Ca and Mg to the soil in addition to N, P and K in balanced proportion and the nutrients were gradually released to the soil. Poultry manure will be the proper choice of fertilizer for crops like cassava that spend more than six months before harvesting.
Key words: *cassava, fertilizer types, incubation, soil analysis*

Introduction

Molindo (2008) opines that there is inadequate scientific basis for advising farmers on the appropriate quantity of organic residues or fertilizers to be recommended to farmers after incubation of organic residues in the soil that, planting should be done. Sustainable optimum **crop production requires** appropriate fertilizer use. Over-application of mineral fertilizers leads to waste and low profit. Inadequate nutrients supply usually leads to soil nutrients depletion (Howeler, 2002). Adequate plant nutrition leads to good photosynthesis, good growth and increase in quantity and quality of harvests. Pre-planting planning of fertilizer application focuses on knowing the nutrients deficient in the soil and applying actual dosage of the plant requirement in order to ensure balanced nutrition (Janssen, 2011). It has been established that excess or deficient of a particular nutrients may affect the availability of other nutrients (Ayeni and Adeleye, 2011). For example, there is positive interaction between N and P (Ayeni and Adeleye, 2011). adequate uptake of N and P usually leads to increase in crop yield while high rate of K fertilization may lead to reduction in Mg or Ca uptake. This is because cations such as K, Ca and Mg usually compete for plant uptake. There is also synergistic relationship between S and N. Excess P concentrations may lead to reduction in Zn uptake by plants. Plants require all the fourteen essential nutrients (N, P, K, Ca, Mg S, Fe, Cu, Zn, Mn, Mo, Co, Na and Be) for optimum growth and yield in adequate quantity and in balanced proportion (Ayeni, and Adetunji, 2010). This is the essence of soil and plant analysis before planting is done. Incubation and analysis of the nutrients present in the fertilizers before direct application to the main field will show the synergistic and antagonistic effects on the plants and the soil.

Cassava tolerates any type of soil provided it has minimum nutrients. It can be grown in any soil where other crops fail to perform. Despite the fact that cassava can grow in any type of soil but it may not be able to reach its optimum performance if the fertility of the soil is too low. Cassava needs balanced nutrients for better growth and yield. Due to continuous cultivation of the available lands, most of the nutrients required for the optimum production of cassava have been used up. Sittibusaya & Kurmarohita (1978) in an experiment conducted in south east Thailand, report that after 15 years of continuous cassava production without fertilizer application the yield of cassava tubers dropped from 30 t/ha to 17 t/ ha. Literature has revealed that cassava required considerable amount of N, P, Ca, Mg and some minor nutrients. Vanlauwe *et al.*, (2008) opined that cassava required considerable amount of N, P and K but preferable K. For example, Vanlauwe *et al.*, (2008) maintained that cassava tubers require large amount of K with the ratio of 5:1:10 of N: P: K respectively in comparison with other crops with ratio 7:7:7 N: P: K. Cassava required N for vegetative growth at the early stage of its development.

IFA (1992) affirmed that cassava requires low amount of P but when the soil is used to grow crops continuously, the soil may be depleted in P to the extent that the available P in the soil may not be sufficient for cassava utilization for optimum yield.

Cassava requires K for carbohydrate formation and tuberization (IFA, 1992, Ezui *et al.*, 2016). Potassium also helps in water uptake from the soil, regulates the balance between assimilation and respiration in plants. It also improves net assimilation of nutrients in cassava roots which results in vigorous growth and reserve assimilates called tubers. (Jansson, 1980). Howeler (1981) affirmed that there is synergistic relationship between N and K in optimum production of cassava. Nitrogen helps in vegetative growth while K helps in tuber formation; thus the absence of one leads to poor growth and yield.

Susan John *et al.* (2010) maintained that a farm grown with one hectare of cassava will produce 30 metric tonne of fresh tuber and will remove as much as 180-200 kg N, 15-22 kg P_2O_5 and 140-160 kg K_2O from the soil. Howeler, (1981) states that, on an average, cassava extracts about 4.91, 1.08, and 5.83 kg of N, P, and K respectively per ton of harvested tuber. Howeler, (1981) and Kanapathy (1974) state that, cassava requires 4.91, 1.08, and 5.83 kg for N, P and K respectively in tropical soils for cassava to attain the tuber yield of one ton/ha. This is the main reasons. Hence, the objective of this study was to evaluate the potentiality of fertilizer types in increasing soil nutrients for cassava production.

Materials and Method

Routine soil Analysis

Fifty core soil samples were randomly taken from the entire experimental field at 0-20 cm depth for nutrients analysis to determine the nutrients status of the soil. Parts of the soil samples were used for incubation study. The collected soil samples were bulked, air-dried and sieved through 2mm_mesh. The nutrients that were analyzed were OM, Total N, available P, exchangeable K, Ca and Mg as well as Fe, Cu, Mn and Zn.

Analysis Organic of Poultry manure and wood ash

The nutrient composition of powdered poultry manure and wood ash were also determined after ashing in the muffle furnace. Total N was determined by Kjedahl method. For other nutrients, ground samples were subjected to wet digestion using 25 – 5 – 5 ml of HNO_3 – H_2SO_4 – $HClO_4$ acids (A.O.A.C, 1990). The filtrate was used for nutrients determination as done in routine soil analysis. Total P was determined by colorimeter, K by flame photometer and Ca, Mg, Fe, Cu, Zn and Mn by AAS.

Laboratory Incubation Study

A laboratory incubation study to determine the nutrients released from wood ash, poultry manure, single super phosphate, muriate of potash, calcium ammonium nitrate (CAN) and NPK 15:15:15 fertilizers at 30, 60 and 90 days was carried out at the laboratory of the Department of Agricultural Science, Adeyemi College of Education, Ondo. The assertion of Spear *et al.* (1979) was the reason why 90 days was used for this experiment. The experiments performed by Spear *et al.* (1979) on the nutritional requirements of cassava showed that the youngest fully expanded leaf (YFEL) blades at 3-4 months after planting provided the best nutritional indicator for nutrients present in them especially K.

Experimental Procedure and Treatments Application

300 g of air-dried soil sample was weighed into 18 different plastic cups and labeled according to the treatments applied. Poultry manure and wood ash at 1.25 g to represent 10 t ha^{-1} and mineral fertilizer types at 0.6 g to represent 400 kg ha^{-1} were used as treatments in the experiment. Fifty (50ml) of water was added to the content of each container. The containers used for the experiment were covered with foams in order to reduce volatilization of nutrients. The samples were them incubated for three months. During the period of incubation, 50 ml of water was added at two weeks interval till the termination of the maturity period of most arable crops. At the completion of the incubation period, the incubated soil samples were air-dried for nutrients determination.

Soil Chemical Properties

Soil pH was determined using glass electrode pH in 1:2 soil water ratio and 2:1 soil $CaCl_2$ suspension (Adeoye, and Agboola, 1985.) at 30, 60 and 90 days of incubation. Total N was determined by micro Kjedahl method (Bremner, and Mulvaney, 1982). This involves distillation and titration. Available phosphorus (P) was extracted by bray-1-method (Murphy and Rilley, 1962) and determined with colorimeter.

Exchange bases (K, Ca and Mg) were extracted with neutral ammonium acetate (I.I.T.A, 1979.). 10g air-dried soil samples sieved through 2mm diameter sieved was weighed into conical flask and 100ml of 1 mole ammonium acetate was added. Calcium (Ca), Mg, K and Na were determined from the filtrate by atomic absorption spectrophotometer (AAS). Organic carbon was determined by wet oxidation method (Nelson and Sommers, 1982). The result of the titration was multiplied by 1.33 to give percentage organic carbon. Destructive analytical method was used.

Statistical Analysis

The data collected were subjected to descriptive analysis such as means and standard deviation.

Results

The routine soil analysis showed that the soil was generally low in soil nutrients, hence; needed plant nutrients from external source. The soil was slightly acidic, low in N, Ca, K and fairly adequate in cations. In the past, Nigeria soils were not used to be deficient in soil exchangeable K and not usually considered as deficient nutrient especially for crop like cassava but due to continuous cropping it has assumed the status of one of the most limiting plant nutrients.

Table 1: Pre – cropping properties of the experimental site

Soil properties	value
pH (1:1H_2O suspension)	5.71
pH (2: 1.0.1M $CaCl_2$ suspension)	5.50
Organic carbon (g kg^{-1})	7.8
Organic matter (g kg^{-1})	10.1
Total Nitrogen (g kg^{-1})	0.52
C/N ratio	15
Available P (mg kg^{-1})	7.56
Exchangeable bases (Cmol kg^{-1})	
Ca^{2+} ;	2.12
Na^{+} ;	0.28
K^{+} ;	0.20
Mg^{2+} ;	0.27
Exchangeable acidity (Cmol kg^{-1})	1.39
Micronutrients (mg/kg)	
Fe^{2+} ;	2.36
Cu^{2+} ;	0.67
Mn^{2+} ;	5.54
Zn^{2+}	4.91
Sand (g/kg)	820
Silt ‘’	110
Clay ‘’	70
Textural Class	loamy sand
Local classification	Egbeda fasc, Ondo series
USDA soil classification	Alfisols (oxic tropuldalf)

Source of classification Hapsted, (1974)

Poultry manure was higher in OC, N, P, Fe, Cu, Mn and Zn than wood ash while wood ash was higher than poultry manure in exchangeable K, Ca and Mg (Table 2). Wood ash had lower C/N ratio than poultry manure.

Table 2: Nutrient concentration (%) of poultry manure and wood ash

Parameters	Poultry manure	wood Ash
Organic carbon	**20.79**	14.57
Nitrogen	**1.69**	0.73
C/N ratio	12	20
Total P	**3.42**	1.00
K “	1.40	14.00
Ca “	**3.80**	5.43
Mg “	0.60	3.00
Zn “	0.62	0.16
Cu “	0.22	0.36
Fe “	3.26	2.25
Mn “	**3.43**	2.34

Effects of Mineral Fertilizers and Wood ash on Soil pH, OC, total N and available P at 30, 60 and 90 days

Table 3 shows that all the treatments decreased the pH of the soil at 30 days compared with control except wood ash. Application of NPK, SSP and Urea decreased the soil pH as the period of incubation increased. Muriate of potash (MOP) increased the soil pH at 60 days of incubation and decreased the pH at 90 days of incubation while wood ash increased the soil pH throughout the period of incubation. Compared with control, only wood ash and poultry manure increased the soil pH up to 90 days of incubation. Among all the treatments and period of incubation, wood ash had the highest cumulative pH with mean value of 7.62.

The soil fertilized with NPK, MOP and SSP had the highest increase in total N at 60 days after incubation while the total N content of the soil samples fertilized with poultry manure and wood ash increased as the period of incubation increased. Compared with control at 30days of incubation, only NPK and urea significantly increased total N at 60 days, all the treatments increased the total N except urea. NPK fertilizer had the highest increase in total N followed by urea at 60 days after incubation. Urea recorded the highest increase in total N at 90 days of incubation followed by NPK fertilizer. Among all the treatments and period of incubation, urea fertilizer had the highest cumulative total N with mean value of 0.26%.

Available P increased in the soil samples fertilized with addition of poultry manure as the period of incubation increased. The release of available P in NPK, MOP and SSP fertilizers reached its peak at 60 days of incubation while there was slight difference in P mineralization with addition of wood ash and urea between 60 and 90 days of incubation. Relative to control, all the treatments significantly increased available P at 30 and 60 days of incubation. Single superphosphate recorded the highest increase in P at 30 and 60 days of incubation. Among all the treatments and period of incubation, SSP had the highest cumulative P with mean value of 42.2mg/kg.

Table 3: **Effect of selected Mineral Fertilizers, Poultry Manure and Wood Ash on soil pH, OC, total N and available P**

Treatment	Control	NPK	MOP	PM	SSP	WA	UREA
				pH			
Days							
30	5.85	5.75	5.43	5.29	5.26	**7.99**	5.01
60	5.81	5.5	5.68	5.08	5.19	**7.39**	4.48
90	5.86	5.21	5.21	5.96	5.18	**7.47**	4.71
MEAN+SE	5.84±0.1	5.48±0.16	5.44±0.14	5.44±0.27	5.21±0.26	7.62±0.19	4.73±0.15
SD	2.34	0.27	0.24	0.46	0.04	0.33	0.27
				OM			
Treatment	Control	NPK	MOP	PM	SSP	WA	UREA
30	2.3	2.31	2.34	2.32	2.35	2.25	2.36
60	2.31	2.35	2.32	2.76	2.38	2.25	2.36
90	2.31	2.31	2.35	3.23	2.3	2.21	2.36
MEAN+SE	1.31±.00	1.32±.01	1.34±.008	1.77±.26	1.34±.02	1.44±.10	1.59±.67
SD	0.005	0.02	0.02	0.05	0.04	0.18	0.29
Treatmen	Control	NPK	MOP	PM	SSP	WA	UREA
			TOTAL N %				
30	0.13	0.26	0.13	0.16	0.12	0.11	**0.38**
60	0.12	0.26	0.15	0.19	0.12	0.16	0.39
90	0.14	0.23	0.15	0.21	0.13	0.16	0.29
MEAN+SE	.13±.01	.23±.02	.14±.02	.17±.03	.16±.03	.16±.03	.36±.01
SD	0.01	0.03	0.04	0.02	0.06	0.05	0.01
Treatmen	Control	NPK	MOP	PM	SSP	WA	UREA
			AVAILABLE P		**mg/kg**		
30	8.2	15.4	10.2	12.6	**15.2**	9.1	7.82
60	7.3	17.3	7.2	14.1	**19.6**	12.2	7.8
90	6.2	12.1	9.9	16.2	14.3	12.7	9.3
MEAN+SE	7.9 +1.4	13.8+3.5	8.87±.08	23.32+2.2	12.4+5.2	12.33+1.1	7.3+0.5
SD	2.24	6.17	8.76	3.8	8.99	1.95	0.86

MOP = muriate of potash, NPK = NPK15:15:15, PM = poultry manure, SSP = single superphosphate, WA= wood ash

The C/N ratio of the soil samples fertilized with mineral fertilizes, poultry manure and wood ash showed that the C/N ratios were low. The low C/N ratio was expected to favour microbial activities in enhancing mineralization of plant nutrients.

Table 4: Effect of mineral fertilizers, poultry manure and wood ash on soil C/N

Treatment	Control	NPK	MOP	PM	SSP	WA	UREA
				C/N			
Days							
30	13	14	18	14	20	20	9
60	14	11	13	15	11	12	11
90	14	11	11	19	19	16	10

Table 5 below shows the effect of mineral fertilizers, wood ash and poultry manure on soil exchangeable K and Ca. The K content of the soil samples fertilized with NPK fertilizer, MOP poultry manure and WA increased as the incubation period increased. The K content in the soil fertilized with SSP and urea had the highest K mineralization at 2 months after incubation. Among the treatments MOP recorded the highest K followed by wood ash at 30 and 90 days of incubation while the NPK fertilizer recorded the highest K mineralization at 60 days after incubation (Table 5).

The Ca content in the soil samples fertilized with MOP, poultry manure and wood ash increased as the period of incubation increased. There was reduction in Ca content of the soil fertilized with NPK, SSP and urea 60 days after incubation. Wood ash recorded the highest Ca.

Table 5: Effect of Mineral Fertilizers, Wood Ash and Poultry Manure on Soil Exchangeable Calcium and Potassium

			Ca	Cmol/kg			
DAYS	CONTROL	NPK	MOP C mol/kg	PM	SSP	WA	UREA
30	2.81	5.21	5.35	5.87	3.49	6.36	4.78
60	2.91	3.39	5.03	5.95	3.91	**6.65**	3.59
90	2.45	4.96	5.79	6.69	4.6	**9.71**	6.33
MEAN + SE	2.7+.31	4.5 +.9	5.4+.22	6.2+.26	4+.32	7.6+1.1	4.9+.79
			K	Cmol/kg			
DAYS	CONTROL	NPK	MOP	PM	SSP	WA	UREA
30	0.33	0.73	0.75	0.47	0.42	0.7	0.37
60	0.32	0.82	0.77	0.49	0.41	0.79	0.32
90	0.31	0.98	1.78	0.54	0.32	1.34	0.36
MEAN + SE	.32+.001	.84+.07	1.1+0.34	.5+.01	.38+.03	.94+0.2	.35+0.02

Discussion

Wood ash consistently increased the soil pH throughout the incubation period compared with all other treatments. This might be as a result of high potassium and calcium content in the wood ash. This corroborates with the earlier research conducted by Moyin – Jesu (2007) and Ojeniyi et al., (2007) who concluded that wood ash, cocoa pod husk and rice bran applied at 8 t ha^{-1} increased the soil pH. The ability of poultry manure (PM) to increase the soil pH at 90 days might be as a result of high Ca and Mg content of the poultry manure used in the conduct of the experiment. Nguyen (2010) reports that poultry manure improves soil fertility and reduces soil acidity and toxicity (Al) in soil profile. Olatunji et al (2012) recommended poultry manure as a valuable source of plant nutrient and soil amendment whose adoption needed to be encouraged in pasture management as well as other minerals needed for plant use. Olatunji et al (2012) advocated for the use of poultry manure to improve the soil pH and other cations.

On OC mineralization, no major difference was observed at 30 and 60 days of incubation. Researches on OC have shown that mineral fertilizers increase OC (Wei et al., 2011) but; it was observed that there were net losses in OC in the soil samples treated with NPK 15:15:15, MOP and urea fertilizers at 90 days of incubation showing that mineral fertilizers were of little or no benefit for OC. This might be as a result of loss of OC in form of carbon iv oxide. This observation might be different on the field where plants and animal residues are in contact or mixed with mineral fertilizers. This work is in line with the assertion of Guo et al., (2019) who observed that mineral fertilizers did not affect soil OC in the experiment conducted on the effects of long – term fertilization on soil OC mineralization and microbial community structure. Among all the treatments and period of incubation, poultry manure had the highest cumulative OC with mean value of 1.77%.

The low release of potassium (K) in urea and SSP fertilizers might be as a result of inherent P available in the soil because urea and SSP have no K in their formulations. At 60 days of incubation, all the treatments increased K content except urea fertilizer. This research is in line with the earlier research conducted by Ujwala Ranade (2011) who observed that wood ash can increase potassium along with other nutrients.

This research also corroborates the earlier research conducted by Ayeni and Adetunji (2010) that organic wastes increased soil N, P, Mg, K and Ca.. Delaune et al (2004) observed increased in N, P, Ca and K when poultry manure was applied to the soil.

On cassava production, going by Kang (1981), Howeler,(1998), Howeler and Spain (1978) and Vanlauwe *et al.*,(2008) using mean values of the nutrients obtained in the research, the soil pH range was favourabe for optimum production of cassava. The following nutrient values were recommended, OM, 3.1% (high), available P(mg/kg) <2.2 -4 very low, 4-15 low and > 15 high, K (C mol/kg) < 0.10 very low, 0.10 – 0.15 low, 0.15 – 0.25 medium and > 0.25 high. The critical levels of exchangeable Ca (C mol/kg) for cassava production are, < 0.25 very low, 0.25 – 1.0 low, 1 – 5.0 medium and > 5 high (Hagens and Sittibusaya. 1990, Howeler, 1978 and Howeler, 1998).

Relative to control, all the treatments significantly decreased ($P<0.05$) the total nitrogen at 90 days except muriate of potash. The inability of the total N to be increased by SSP and MOP at 30, 60 and 90 days of incubation might be as result of low N content in their formulations. Nitrogen is known to be abundant within pH range of 5.6 – 9, P between 6 – 8 and K 6 - 9. Averagely, the productive soil is expected to have pH value of 5.5 – 7.5 (Sobulo and Osiname 1981, Adeniyan et al., 2006, Ojeniyi, 1995; Ayeni, 2020) Averagely, the productive soil is expected to have pH range 5.5 – 8.5. Hence, the pH recorded in this research is conducive for the release of nutrients that will give optimum yield of cassava. Cassava can perform well from slightly acid to neutral soil (Howeler and Cadavid (1983). Ability of NPK and urea to release total N might be as a result of high amount of N present in NPK and urea compositions that was easily released to the soil within one month of incubation. Han *et al.* (2016) observed that NPK has high nutrient contents and are rapidly taken up by plant. However, alongside with NPK and urea, wood ash and poultry manure increased the total N at 60 days of incubation. This result is in line with the work of Ayeni *et al*., (2015) who observed that burnt agro-wastes increase total N at 90 days of incubation. Despite the fact that the **a**mount of NPK and urea applied to the soil were lower than the rate of wood ash and poultry manure applied to the soil yet NPK and urea performed better than the organic wastes. Chen (2006) affirmed that organic wastes have a number of shortcomings, including low nutrient content, slow decomposition and different nutrient compositions depending on its organic materials.

The available P released to the soil was high in NPK, MOP, SSP and wood ash while P was low in urea and very low control experiment. Calcium was in the medium range for NPK, MOP, SSP and urea and very high for poultry manure and wood ash. The very high Ca in poultry manure and wood ash might result in nutrients antagonism. The soil was originally high in K. Potassium might not be a problem for optimum performance of cassava.

Conclusion

The experiment was targeted at comparing selected mineral fertilizers, wood ash and poultry manure on nutrients release for optimum production of cassava in a nutrients depleted soil. The selected fertilizers vary in nutrients composition and each fertilizer tends to add the corresponding nutrients to the soil. Among the mineral fertilizers, application of NPK 15:15:15 fertilizers had balanced N, P and K release to the soil for a short period while poultry manure added extra Ca and Mg to the soil in addition to N, P and K in balanced proportion and the nutrients were gradually released to the soil. Poultry manure will be the proper choice for enriching the soil with the nutrients for crops like cassava that will spend more than six months in the soil.

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References

Adeniyan, O. N. and Ojeniyi, S.O. (2006). Comparative effectiveness of different levels of poultry manure with NPK fertilizer on soil fertility, nutrient uptake and maize yield. *Moor Journal of Agricultural Research*. 4: 194 – 197.

Adeoye, G.O. and A.A. Agboola, 1985. Critical levels for soil pH, available P, K, Zn and Mn and maize earleaf content of P, Cu and Mn in sedimentary soils of southwestern Nigeria. Fertilizer Resources, 6(1): 65.

Ayeni, L. S., and Adeleye E. O., (2011). Soil Nutrients status and nutrients interactions as affected by Agro wastes and mineral fertilizer in an incubation study in the South West Nigeria. *International Journal of Soil Science.* **(6)**: 60-68.

Ayeni, L. S.; Adetunji, M. T. (2010). Integrated application of poultry manure and mineral fertilizer on soil chemical properties, nutrients uptake, yield and growth components of maize. *Nature and Science*, .2(1): 92-97.

Ayeni, L.S. (2020). Rudiments of Soil Science, Glory Land Publishers, Mokola, Ibadan, 216pp

Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen the two organic manures (cow dung and poultry droppings) Total, In: Methods of soil analysis. A.L. Page *et al*. part 2. Agronomy Monograph 9 edition. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, pp: 595-624.

Centro Internacional de Agricultura Tropical (CIAT). 1979. Annual Report for 1978. CIAT, Cassava Program, Cali, Colombia. pp. A76-84.

Centro Internacional de Agricultura Tropical (CIAT). 1988. Cassava Program. Annual Report for 1986.

Working Document No. 43. CIAT, Cali, Colombia. 254 p.
Chen, J. (2006) . The Combined Use of Chemical and Organic Fertilizers and/or Biofertilizer for Crop Growth and Soil Fertility. International Workshop on Sustained Management of the Soil-Rhizosphere System for Efficient Crop Production and Fertilizer Use, Bangkok, 1-11
DeLaune, P. B., Philip, A. M., Dennis, K. C. Andrew, N., Sharpley,,B. E. H. and Tommy, C. D. (2004) Development of a Phosphorus Index for Pastures Fertilized with Poultry Litter—Factors Affecting Phosphorus Runoff. . Environ. Qual. 33:2183–2191 (2004).
Ezui, K. S., Franke, A. C., Mando, A., Ahiabor, B. D. K., Tetteh, F. M., Sogbedji, J., ... Giller, K. E. (2016). Fertilizer requirements for balanced nutrition of cassava across eight locations in West Africa. Field Crops Research, 185, 69-78. https://doi.org/10.1016/j.fcr.2015.10.005
Guao Z., Han, J., Li, J, Xu, Y., Wang X .2019. Effects of long – term fertilization on soil OC mineralization and microbial community structure. Plos ONE 14(1) : e0211163. DOI; 10.1371/journal pone.0211163.
Hagens, P. and Sittibusaya, C. 1990. Short- and long-term aspects of fertilizer applications on cassava in Thailand. *In*: R.H. Howeler (Ed.). Proc. 8th Symp. Intern. Society of Tropical Root Crops, held in Bangkok, Thailand. Oct. 30-Nov. 5, 1988. pp. 244-259.
Han, Y. L., Song, H. X., Liao, Q., Yu, Y., Jian, S. F., Lepo, J. E., et al. (2016). Nitrogen use efficiency is mediated by vacuolar nitrate sequestration capacity in roots of *Brassica napus*. *Plant Physiol.* 170, 1684–1698. doi: 10.1104/pp.15.01377
Harpstead, M.I. 1974. Classification of some Nigeria Soils. Soil Sc. 16:437-443
Howeler, R.H. 1978. The mineral nutrition and fertilization of cassava. *In*: Cassava Production Course. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. Pp. 247-292.
Howeler, R.H. 1981. Mineral Nutrition and Fertilization of Cassava. Series 09EC-4, Centro Internacional de Agriculture Tropical (CIAT), Cali, Colombia. 52 pp.
Howeler, R.H. 1998. Cassava agronomy research in Asia – An overview, 1993-1996. *In*: R.H. Howeler (Ed.). Cassava Breeding, Agronomy and Farmer Participatory Research in Asia. Proc. 5th Regional Workshop, held in Danzhou, Hainan, China. Nov. 3-8, 1996. Pp. 355-375.
Howeler, R.H. 1998. Cassava agronomy research in Asia – An overview, 1993-1996. *In*: R.H. Howeler (Ed.). Cassava Breeding, Agronomy and Farmer Participatory Research in Asia. Proc.5th Regional Workshop, held in Danzhou, Hainan, China. Nov. 3-8, 1996. pp. 355-375.
Howeler, R.H. and L.F. Cadavid. 1983. Accumulation and distribution of dry matter and nutrients during a 12-month growth cycle of cassava. *Field Crops Research,* 7: 123-139.
Howeler, R.H., 2002. Cassava mineral nutrition and fertilization. In: Hillocks, R.J.T., J. M.;546 Bellotti, A. C. (Ed.), Cassava: biology, production and utilization. CABI, Wallingford, UK,547 Pp. 115-147.
Howeler, R.H., and J.M. Spain. 1978. The Effects of Potassium Manuring on Some Crops in the Tropical Climate. *In:* Suelos Ecuatoriales:

Memorias del V. Coloquio de Suelos, Vol. IX, No.2.
I.I.T.A, 1979. International Institute of Tropical Agriculture Nigeria. Selected Methods for Soil and plant Analysis Revised Edition Manual Series No 1. pp: 70.
IFA. 1992. IFA World Fertilizer Use Manual. International Fertilizer Industry Association, Paris.
Janssen, B.H., 2011. Simple models and concepts as tools for the study of sustained soil551 productivity in long-term experiments. II. Crop nutrient equivalents, balanced supplies of552 available nutrients, and NPK triangles. *Plant and Soil* 339, 17-33.
Jansson, S.L. 1980. Potassium Requirements of Root Crops. *In:* Potassium Requirements of Crops. IPI Research Topic No. 7. International Potash Institute, Switzerland. p. 47-62
Kanapathy -·1974. Fertilizer experiments on shallow peat under continuous cropping with tapioca. Malays. Agric. J. 49(4):403-412.
Kang, B.T. 1984. Potassium and magnesium responses of cassava grown in an Ultisol in southern Nigeria. Fertilizer Research 5: 403-410.
Molindo (2008**)** Determination of the Nutrient Status of a Soil after Incubation withOrganic Residues for Different Days in Benin City, Nigeria**.** World Journal of Agricultural Sciences 4 (6): 731-736.
Moyin – Jesu, E.I. (2007). Use of selected agro industrial biomass for enhancing seed, nitrogen, ash and crude protein quality of amaranthus viridis L. Emirate journal of food and agriculture. 19 (1), 13 – 21
Murphy, J. and J.K.P. Rilay, 1962. A Modified single solution method for the determination of phosphorus in natural waters. Analytical Chemistry Acta, 27: 31-36.
Nelson, D.W. and L.E. Sommers, 1982. Total Carbon, organic matter. In: A.L. Page *et al*. (eds), Methods of soil analysis part 2. agronomy monograph 9 sec edition. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin, pp: 539-5779.
Nguyen Van Sao ; Nguyen Thi Mui ; Dinh Van Binh, 2010. Biomass production of *Tithonia diversifolia* (Wild sunflower), soil improvement on sloping land and use as high protein foliage for feeding goats. Livest. Res. Rur. Dev., 22 (8): 15
Ojeniyi, S.O. 1995. “That our soil may not die”. 10th Inaugural Lecture of Federal University of Technology, Akure. March 23,1995. Pp 5-10.
Ojeniyi, S.O.; Awodun, M. A.; Odedina, S. A. (2007). *East Journal of Scientific Research* Effects of animal manure amended spent grain and cocoa husk on nutrient status, growth and yield of tomato. Middle East *Journal of Scientific Research.*Vol.2; pp. 13-15.
Sittibusaya, K. and Kurmarohita, K. 1978. Soil fertility and fertilization. Bangkok, Thailand, Department of Agriculture. 18p. Paper presented at Workshop on Cassava Production and Utilization, Khon Khaen, Thailand, 1978.
Sobulo, R.A. and A.O. Osiname, 1981. Soils and fertilizer use in Western Nigeria. Resource Bulletin. No. 11. Institute of Agricultural Research and Training, University of Ife, Nigeria.

Spear, S.N., Edwards, D. G. and C.J. Asher, C. J.. 1979. Response of Cassava (Manihot esculenta Crantz) to Potassium Concentration in Solution: Critical Potassium Concentrations in Plants Grown with a Constant or Variable Potassium Supply. Field Crops Research 2:153-168.

Susan, J. K., G. Suja, M.N. Sheela, and C.S. Ravindran. 2010. Potassium: The Key Nutrient for Cassava Production, Tuber Quality and Soil Productivity - An Overview. Journal of Root Crops 36:132-144.

Ujwala, R.M. (2011) Interaction of micronutrients with major nutrients with special reference to potassium. Karnataka J. Agric. Sci.,24 (1) : (106-109) 2011

Vanlauwe, B., P. Pypers, and N. Sanginga. 2008. The Potential of Integrated Soil Fertility Management to Improve the Productivity of Cassava-based Systems. *In:* Cassava: Meeting of the Challenges of the New Millennium: Proceedings of the First Scientific Meeting of the Global Cassava Partnership 21-25 July 2008, Ghent, Belgium. Institute of Plant Biotechnology for Developing Countries (IPBO), Ghent University, Ghent, Belgium.

Wei, G..,Xiaoyuan, Y. and Jingyan, W. (2011)The effect of chemical fertilizer on soil OC removal and CO2 emission- a pot experiment with maize. Plant and Soil 353:(1-2) DOI:10.1007/s1104-0011-1011-08.

PHOSPHORUS ADSORPTION CHARACTERISTICS IN ALAGBA SOIL SERIES UNDER OIL PALM CULTIVATION

Emomu, A., *[1] Ehis-Iyoha, E.[2] and Osaumwense, S. A.[1]
[1]Department of Soil Science and Land Management University of Benin, Benin City,Nigeria.
[2]Department of Agronomy Rubber Research Institute of Nigeria, Iyanomo, Nigeria.
Corresponding author email:emomuadams@gmail.com

ABSTRACT
The study aimed at investigating phosphorus (P) adsorption characteristics in Alagba soil series planted to oil-palm in Benin City, Edo State. Soil samples were collected randomly from four (0-30, 30-60, 60-90, 90-120 cm) depths in 3 replicates, prepared and analyzed for some soil properties using standard methods. P sorption studies was carried out by evaluating the influence of concentration (20-100 mg P kg^{-1}) and time (5-1800 minutes) differential at constant temperature and P adsorbed was determined by difference after equilibration, the concentration differential data was fitted to Freundlich model, while Pseudo-second order kinetics model was used to analyze the time differential data. Genstat statistical package (12th edition), was employed for data analysis and mean separation at $P \leq 0.05$. The results showed that the amount of P adsorbed increased with increasing P concentration and contact time, and was least at the top (0-30 cm) soil depth, possibly due to organic matter and clay trend. freundlich adsorption capacity (a) and intensity (n) values ranged between 28.18-45.71 mgkg^{-1} and 1.98-2.75 Lkg^{-1} respectively, while Pseudo-second order adsorption kinetics rate constant (K_2) was least at 60-90 cm (2.76x10^{-4} mg kg^{-1} min^{-1}) and highest at 90-120 cm (6.6x10^{-4} mg kg^{-1} min^{-1}) soil depths. Average correlation coefficient (R^2) values of 0.767 and 0.972 obtained for Freundlich model and pseudo-second order adsorption kinetic model respectively indicates a good fit to the adsorption data. This research offers practical application for proper P management practice in Alagba soil series.
Keywords: *Phosphorus, Soil series, Models, Adsorption kinetics, Freundlich, Pseudo-second*

1.0 INTRODUCTION

Phosphorus (P) is the second most important essential macronutrient after nitrogen, needed for plant growth (Srinivasan *et al*., 2012). It is a key nutrient for higher and sustained agricultural productivity and limits plant growth in many soils (Scervino *et al.,* 2011). Certain crop species may have rapid growth rates, and only few unfertilized soils can release P quickly enough to sustain such rapid growth rates. Availability of P to plants is particularly poor in tropical soils because of poor P-fertilizer recovery rates. In highly weathered soils, specific phosphate adsorption prevent adequate return of P to soil solution, which inhibits plant P uptake and result in low P-fertilizer recovery (Maluf *et al.,* 2018). Adsorption and precipitation of applied P, by soil constituents is the main soil processes influencing P availability (Santos, 2011; Azu *et al*., 2023). P sorption kinetics on the other hand is the rate of sorption and precipitation of P over time (Azu *et al*., 2023; Santos, 2011). Studies on P sorption status in soils planted to oil palm and P sorption kinetics abounds (Osayande *et al*., 2017; Orhue *et al*., 2021; Azu *et al*., 2023), while reports on P sorption at soil series classification are scanty in literature. Since soil type and depth can contribute to differences in adsorption capacity, evaluation of P sorption and sorption kinetics characteristics particularly in Alagba soils series will form a useful guild for viable P fertilization strategy.

2.0 METHODOLOGY

2.1 Study area, Soil sampling and preparation

The study was carried out in an area locally classified as Alagba soil series planted to oil palm (*Elaeis guineensis*) as at the time of sampling, within Nigerian Institute for Oil-Palm Research (NIFOR), Benin city. The area is located in the rainforest ecological zone, with an elevation of about 132 m, mean annual temperature of 31°C and a bimodal rainfall regime. Auger soil samples were collected randomly from 4 (0-30, 30-60, 60-90 and 90-120 cm) soil depths in 3 replicates, within 06° 33' 44.9", 06° 32' 50.1", 06° 32' 50.2", 06° 32' 47.6" North latitude and 005° 32' 32.1", 005° 36' 32.4", 005° 36' 30.2", 005° 36' 30.1" East longitude. The samples were air-dried, ground, pass through 2 mm sieve and analyzed for selected physical and chemical properties using standard procedures as presented in Table 1.

2.1 P sorption characterization

2.1.1 Phosphorus sorption (concentration differential) experiment

3 g soil was weighed into sets of plastic bottles, equilibrated 30 minutes twice daily, for 6 days in 30 ml of 0.01 M $CaCl_2$ solution containing 0, 20, 40, 60, 80, 100 mg P/L (Nair *et al*. 1984).

2.2.2 Phosphorus sorption kinetics (time differential) experiment

3 g soil was weighed into series of plastic bottles, and horizontally shaken with 25 ml of 0.01 M $CaCl_2$ solutions containing 50 mg P L^{-1}. The suspension was equilibrated for 5, 30, 60, 180, 900 and 1800 minutes time intervals according to procedures of Azu *et al*. (2023).

2.2.2.1 Precaution

The P concentration for sorption experiments was prepared from KH_2PO_4. Three drops of $CHCl_3$ (chloroform) was added during equilibration to inhibit microbial P mineralization.

2.2.3 Colorimetric determination of P in filtrate

The soil suspension after the equilibration (Concentration and time differential) experiment was filtered through Whatman No. 42 filter paper. P in the filtrate was determined by the sulphuric-molybdate blue method and read using the T-80 UV-Vis spectrophotometer (PG instrument Lt) at 880 nm. The difference between the quantity of P added to the soil and the quantity of P in equilibrium solution was calculated as the quantity of P adsorbed ($mgkg^{-1}$) by the soil.

Table 1: Soil properties analyzed, methods adopted and references

Soil properties	Method	Reference
Particle sized distribution	Hydrometer	Bouyoucos (1962), Day (1965).
Textural classification	Textural triangle	soil survey staff, 2003
pH	Glass electrode	Tan, 1996
Organic carbon	Walkley-Black wet oxidation	Walkley and Black (1934)
Total organic Nitrogen	Deduction from soil organic matter	Ibitoye (2008).
Available Phosphorus	Bray 1 extraction, ascorbic acid molybdate blue	Bray and Kurtz (1945), Murphy and Riley (1962).
Total exchangeable bases	Summation	Udo *et al*. (2009).
Exchangeable acidity	1 M KCl extraction	Juo (1979).

2.2.4 P sorption modeling

2.2.4.1 Concentration differential

Freundlich equation was used to model data obtained from P concentration differential sorption experiment, Freundlich models is given as,

$X = aC^{1/n}$ ----------- (1)

Linearizing equation (1) gives

$\text{Log } X = \text{Log } a + \frac{1}{n} \text{Log } Ce$ ------------- (2)

Where, X = Amount of P adsorbed per unit weight of soil (mg P Kg^{-1} soil) at equilibrium,

Ce = Concentration of P in the equilibrium solution (Mg L^{-1}), a = Constant relating to sorption capacity, n = Sorption energy, 1/n = function of strength of adsorption in the adsorption process (Voudrias *et al.,* 2002). The graph was plotted as log X versus log Ce. The parameter a, n and $\frac{1}{n}$ were calculated from the graph of the plot according to the following formula; a = antilogrithm of intercept of the graph, n = $\frac{1}{\text{slope of the graph}}$, $\frac{1}{n} = \frac{1}{\frac{1}{slope}}$.

2.2.4.2 Time differential

Pseudo-second order kinetic model/equation was used to model the P sorption kinetics data, according to Ebelegi *et al.* (2020), Pseudo-second order kinetic model is given as,

$\left[\frac{t}{Qt}\right] = \frac{1}{k_2 Q_e{}^2} + \frac{1}{Q_e}(t)$ -------------------------- (3)

Where; t = time, Qt = amount adsorbed at time t, k_2 = Pseudo-second order adsorption rate constant, Q_e = amount adsorbed at equilibrium. The plot of (t/Qt) against t in equation (3) will give a linear relationship. The initial sorption rate (H_0), Qe and K_2 were calculated from the graph according to the following formula; Ho = $\frac{1}{intercept}$, q_e = $\frac{1}{slope}$ and $K_2 = \frac{Ho}{Q_e^2}$ respectively.

2.3 Statistical analysis

Data collected were statistically analyzed using the Genstat statistical package (12th edition). Duncan multiple range test was used to separate means at 5% level of probability.

3.0 RESULTS AND DISCUSSION

3.1 Some physical and chemical properties of the soils

Some physical and chemical properties of the soil studied are shown in Table 2. The sand,silt and clay showed similar trend as that reported by Orhue and Emomu (2022), the soil pH, ranged between 3.74-4.38 and could be said to be extremely acidic (Chude *et al.,* (2011). This could be due to management practices, like continuous use of inorganic fertilizer. The organic carbon (OC), total organic nitrogen (TON) and available phosphorus (Av. P) were highest at the top soil (0-15 cm) and significantly differs from values obtained from other soil depths. The higher OC, TON and Av. P content at the soil surface could be due to liter fall from the surrounding vegetation and surface application of fertilizer (Ogeh and Ogwurike, 2009). The OC ranged between low to high, TON and Av. P were very low across the soil depths, when compared with the critical values reported by Chude *et al.* (2011), the low TON and Av. P status of the soils may be attributed to extreme soil acidity and low OC content at the subsoil.

Table 2: some soil physical and chemical properties

Depth	pH	OC	TON	Av. P	CEC	sand	Silt	clay	Texture
cm		g/kg		$mgkg^{-1}$	cmol/kg		%		
0-30	4.38^a	11.36^a	0.57^a	0.40^a	0.90^a	84.37^a	4.09^a	11.54^b	LS
30-60	3.87^b	6.07^b	0.30^b	0.39^a	0.81^a	80.86^{ab}	5.22^a	13.92^{ab}	SL
60-90	3.74^b	5.11^b	0.26^b	0.39^a	0.86^a	79.88^{ab}	4.24^a	15.88^{ab}	SL
90-120	3.79^b	5.11^b	0.26^b	0.39^a	0.79^b	75.96^b	6.61^a	17.42^a	SL
Mean	3.94	6.91	0.35	0.39	0.84	80.27	5.04	14.69	

OC= organic carbon, TON= total organic carbon, Av. P= available phosphorus, LS= loamy sand, SL= sandy loam, means with the same letters in the columns are not significantly different at P ≤ 0.05 using Duncan Multiple Range Test.

3.2 Phosphorus adsorption characteristics

3.2.1 Phosphorus Sorption as Influenced by concentration

The P adsorbed by the soils at different concentrations are shown in Table 3. It was observed that the amount of P adsorbed increased with increase in the concentration of P added to the soil, although the percentage P adsorbed differs amongst the different concentration added in line with earlier findings in literatures (Muindi *et al*., 2018; Ayenew *et al*., 2018).

3.2.2 Phosphorus Sorption as Influenced by Time (Kinetics)

The amount of P adsorbed by the soil over equilibrating period (time) of 1800 minutes are shown in Table 4. With respect to depth, P adsorption was least at the soil surface which could be attributed to higher OC at the surface (0-15 cm) soil depth (Asmare *et al*., 2015). The result showed that P sorption increased with increasing incubation time in line with the findings of Azu *et al*. (2023), but at 60 minutes equilibrating time, a slight decrease in P adsorption was observed.

Table 3: P sorption (mg kg^{-1}) at different concentration of P added (mg L^{-1})

Depth	concentration of P added to the soil (mgL^{-1})				
(cm)	20	40	60	80	100
0-30	19.21^{b}	36.82^{b}	57.89^{b}	77.15^{b}	92.79^{b}
30-60	19.77^{a}	37.41^{ab}	58.32^{ab}	77.39^{ab}	93.61^{ab}
60-90	19.88^{a}	38.05^{bc}	58.25^{ab}	77.69^{b}	93.76^{a}
90-120	19.91^{a}	38.29^{c}	58.55^{a}	77.23^{a}	93.45^{a}
Mean	19.69	37.64	58.28	77.49	93.53
Cv	0.40	0.90	0.40	0.40	0.50

means with the same letters in the columns are not significantly different at P ≤ 0.05 using Duncan Multiple Range Test.

Table 4: P sorption (mg kg^{-1}) at different equilibrating time (minutes)

Depth (cm)	**Equilibrating time (minutes)**					
	5	30	60	180	900	1800
0-30	6.72^{a}	7.50^{a}	3.70^{a}	19.60^{a}	15.00a	22.90a
30-60	9.74^{a}	16.70^{b}	10.70^{a}	31.10^{a}	25.20ab	33.00ab
60-90	11.26^{a}	20.00^{b}	13.00^{a}	27.10^{a}	31.00b	40.70b
90-120	9.62^{a}	21.40^{b}	14.70^{a}	33.90^{a}	36.70b	37.40b
Mean	9.33	16.40	10.50	27.90	27.00	33.50
Cv	28.0	24.10	52.40	24.90	25.40	15.70

means with the same letters in the columns are not significantly different at P ≤ 0.05 using Duncan Multiple Range Test.

3.2.3 Phosphorus adsorption isotherm

3.2.3.1 Freundlich model

Freundlich model plotted as Log X against Log Ce, with Log Ce on the x-axis and Log X on the y-axis are presented in Figure 1-4. The plot gave regression equation of varying intercepts, slope and R^2 value from which the Freundlich model parameters were calculated (Table 5). Freundlich adsorption capacity (a) was lowest at 0-30 cm soil depth of and highest at 90-120cm soil depth which could be as a result of higher organic carbon observed at the top soil as organic carbon (Asmare *et al.*, 2015). The P adsorption energy (n) and heterogeneity constant $\left(\frac{1}{n}\right)$ of the soil varied with soil depths, which could be due to differences in some soil properties at various

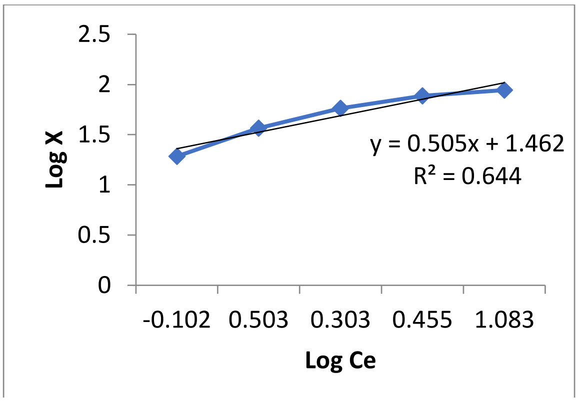

Figure :1 Freundlich model and trendline for 0-30 cm soil depth

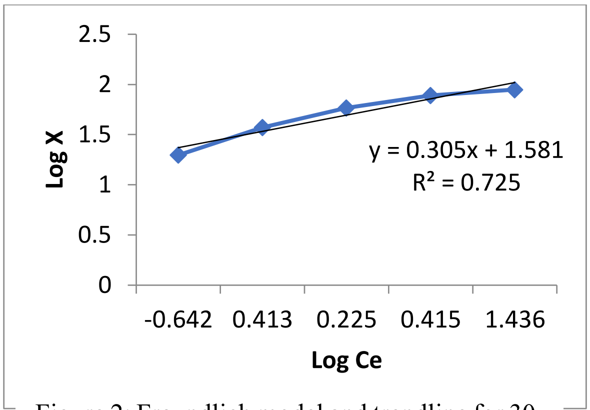

Figure 2: Freundlich model and trendline for 30-60 cm soil depth

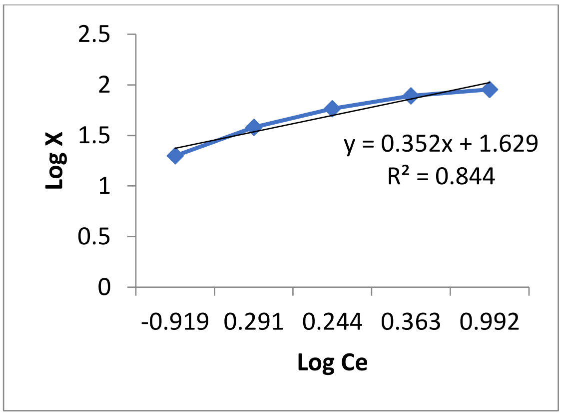

Figure 3: Freundlich model and trendline for 60-90 cm soil depth

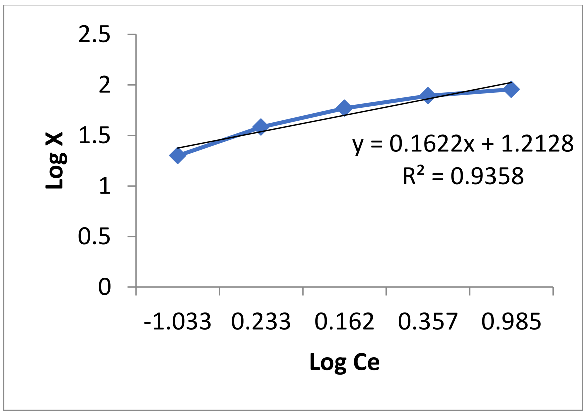

Figure 4: Freundlich model and trendline for 90-120 cm soil depth

Table 5: Freundlich parameter model parameters

Depth cm	a $mgkg^{-1}$	n Lkg^{-1}	$\frac{1}{n}$	R^2	Freundlich equation ($X=aC^{1/n}$)
0-30	28.97	1.98	0.51	0.644	$X=28.97C^{0.51}$
30-60	38.11	3.28	0.31	0.725	$X=38.11C^{0.31}$
60-90	42.56	2.84	0.35	0.844	$X=42.56C^{0.35}$
90-120	44.88	2.99	0.34	0.856	$X=44.88C^{0.34}$
mean	38.63	2.77	0.38	0.767	$X=38.63C^{0.38}$

a= adsorption capacity, n= adsorption energy, 1/n = heterogeneity parameter, R^2 =correlation coefficient.

soil depths. However the variations in P sorption parameters with respect to depth in NIFOR soils have been reported by Orhue and Emonu (2022).

3.2.3.2 Pseudo-second order kinetic model

Pseudo-second order adsorption kinetics model plotted as time divided by amount of P adsorbed

(T/Qt) against time (t), with T/Qt on the y-axis and t on the x-axis are presented in Figure 5-8.

The plots gave regression equation of varying intercepts, slope and R^2 value from which the

Pseudo-second order adsorption kinetics model parameters were calculated (Table 6). The initial sorption rate (H_0), increased with increasing soil depths which could be due to OC trend. It ranged from 0.1564–0.9709 mg min^{-1} in line with findings of Benitez *et al*. (2016).

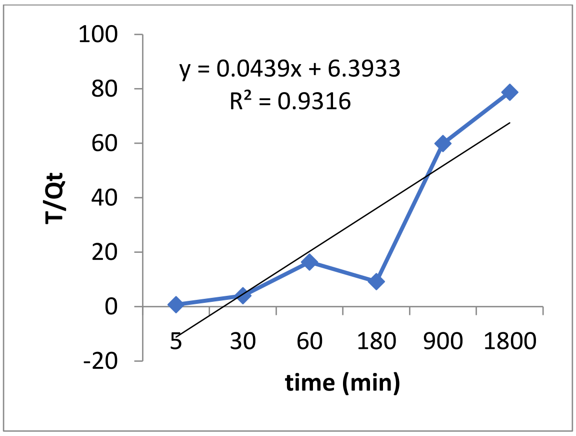

Figure 5: Pseudo-second order kinetic model and trendline for 0-30 cm soil depth

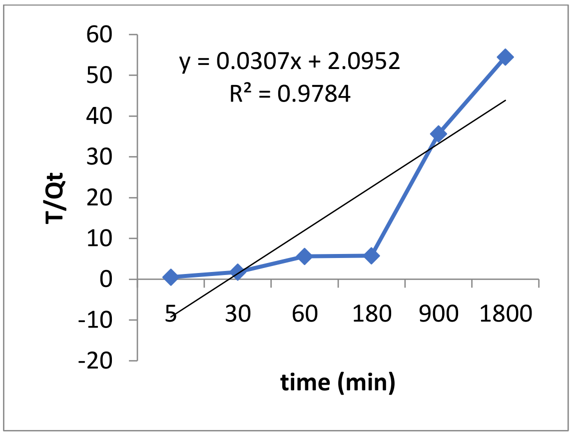

Figure 6: Pseudo-second order kinetic model and trendline for 30-60 cm soil depth

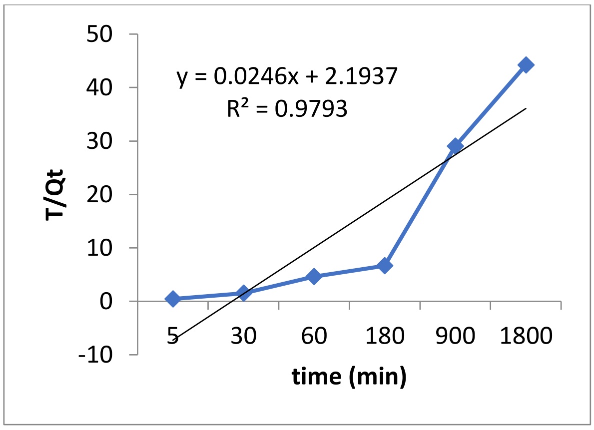

Figure 7: Pseudo-second order kinetic model and trendline for 60-90 cm soil depth

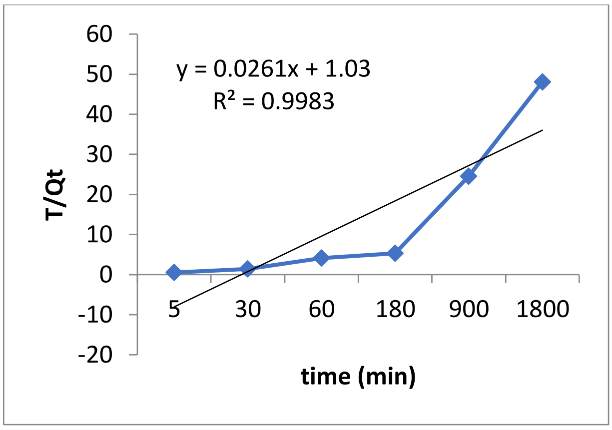

Figure 8: Pseudo-second order kinetic model and trendline for 90-120 cm soil depth

Table 6: Pseudo-second-order kinetic model parameter

Depth (cm)	H_0 (mg min^{-1})	Q_e (mgkg^{-1})	K_2 mg kg^{-1} min^{-1}	R^2	Pseudo-second order kinetic model equation $\left[\frac{t}{Qt}\right] = \frac{1}{k_2 q_e^2} + \frac{1}{q_e}(t)$
0-30	0.1564	22.78	3.01x10^{-4}	0.9316	$\frac{t}{Qt} = \frac{1}{0.1564} + \frac{t}{22.78}$
30-60	0.4773	32.57	4.50x10^{-4}	0.9784	$\frac{t}{Qt} = \frac{1}{0.4773} + \frac{t}{32.57}$
60-90	0.4559	40.65	2.76x10^{-4}	0.9793	$\frac{t}{Qt} = \frac{1}{0.4559} + \frac{t}{40.65}$
90-120	0.9709	38.31	6.60x10^{-4}	0.9983	$\frac{t}{Qt} = \frac{1}{0.9709} + \frac{t}{38.31}$
Mean	0.5151	33.58	4.22x10^{-4}	0.9719	$\frac{t}{Qt} = \frac{1}{0.5151} + \frac{t}{33.58}$

H_0 = initial rate of sorption, Q_e = amount of P adsorbed at equilibrium, K_2 = Pseudo-second-order kinetic rate constant, R^2 = correlation coefficient

4.0 CONCLUSION

Phosphorous sorption increased with increase in the concentration of P in solution while

freundlich adsorption capacity (a) and energy (n) seems to be influenced by soil properties and

depths. P sorption kinetics was influenced by contact (equilibrating) time and the rate of P removal as shown by Pseudo-second order rate constant (K_2) was minimal at the top soil (0-30 cm) when compared to other soil depth. Regression coefficient (R^2) value > 0.64 and > 0.93 obtained for freundlich model and Pseudo-second order kinetic model respectively show that the sorption data fitted well to the models, however it is recommended that the influence of other soil properties, together with the suitability of other sorption models to describe P sorption characteristics be investigated in this soil series.

5.0 REFERENCES

Orhue, E.R. and Emomu, A. (2022). Freundlich, Langmuir and Temkin Isotherm Studies of Silicon Sorption on Soil Derived from Three Parent Materials in Edo State, Nigeria. *JournalofTropical Agriculture, Food, Environment and Extension*, 21(3): 1 - 12.

Asmare, M., Heluf, G., Yli-Halla, M. and Birru, Y. (2015). Phosphorous status, Inorganic phosphorous forms and other physicochemical properties of acid soil of farta district, Northwestern highlands of Ethiopia. *Applied and Environmental Soil Science.* p 11.

Ayenew, B., Tadesse, A.M., Kibret, K. and Melese, A. (2018). Phosphorus status and adsorption characteristics of acid soils from Cheha and Dinsho district, southern highlands of Ethopia. *Environmental System Research*, 1-14

Azu, D. E. O., Osodeke, V. E., Onwuka, M. I. and Osisi, A. F. (2023). Kinetics of Phosphorus Sorption in selected Soils of Southeastern Nigeria. Nigerian Journal of Soil Science. 32(2): 85-94.

Benitez, G.S., Boddu, S. and Torres, R. (2016). Phosphorous sorption kinetics in tropical soil from a fertilizer plant site in puertorico. *Soil Science of America Journal,* 80(2): 320-327.

Bouyoucos, G.J. (1962). Hydrometer method improved for making particle size analysis of soil. *Agronomy Journal*, 54: 464–465.

Bray, R.H. and Kurzt, L.T. (1945). Determination of total, organic and

available forms of phoshorus in soil. *Journal of Soil Science*, 59: 39–45.
Chude, V.O., Malgwi, W.B., Ampu, I.Y. and Ano, A.O. (2011). Federal fertilizer department in collaboration with National Programme for food security, Abuja, Nigeria. *Manual on Soil Fertility Assessment,* p 102.
Day, P.R. (1965). Particle fractionation and particle size analysis. In, Methods of soil analysis Black, C.A. (Ed). *Part 1 Agronomy*, 9: 545–547.
Ebelegi, A.N., Ayawei, N. and Wankasi, D. (2020). Interpretation of adsorption thermodynamics and kinetics. *Open Journal of Physical Chemistry*, 10:166-182.
Ibitoye, A.A. (2008). Laboratory Manual on Basic soil Analysis. *Foladave Nigeria limited.* p 34-35.
Juo, A.S.R. (1979). Selected Methods for Soil and Plant Analysis. Manual Series No. 1, IITA, Ibadan.
Maluf, H.J.G.M., Silva, C.A., Curi, N., Norton, L.D. and Rosa, S.D. (2018). Adsorption and availability of phosphorus in response to humic acid rates in soil limed with $CaCO_3$ or $MgCO_3$. 42(1):7-20.
Muindi, E.M., Mrema, J.P., Semu, E., Mtakwa, P.W., Gachene, C.K. and Njogu, M.K. (2015).LimeAluminium-Phosphorus interactions in the Kenya Highlands.*America Journal Expert Agriculture*, 9(4):1-10.
Murphy, J. and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analytical Chemistry ACTA, 27: 31–36.
Nair, P.S., Logan, T.J., Sharpley, A.N., Sommers, L.E., Tabatabai, M.A. and Yuan, T.L. (1984). Inter laboratory comparison of a standardized phosphorus adsorption procedure. *Journal of Environmental Quality*, 13: 591–595.
Ogeh, J.S. and Ogwurike, P.C. (2006). Influence of Agricultural Land Use Types on Some Soil Properties in Midwestern Nigeria. *Journal of Agronomy,* 5: 387-390.
Orhue, E. R., Emomu, A., Obazuaye, E., Erhayimwen, A. M. and Bepo, A. G. (2021). Phosphorus sorption in soils Overlying Basement Complex Rock, Alluvium, Coastal Plain Sand and Imo Shale Parent Materials. *Asian Journal of Soil Science and Plant Nutrition.* 7(3): 41.54.
Orhue, E.R. and Emomu, A. (2022). Freundlich, Langmuir and Temkin Isotherm Studies of Silicon Sorption on Soil Derived from Three Parent Materials in Edo State, Nigeria. *JournalofTropical Agriculture, Food, Environment and Extension*, 21(3): 1 - 12.
Osayande, P. E., Oviasogie P. O., Orhue, E. R., Awanlemhen, B. E. and Oko-oboh E. (2017). Phosphorus Sorption in Hydromorphic soils Overlaying Alluvium and Coastal plain Sand Parent Materials in Delta State, Nigeria. *Communications in soil science and plant analysis.* 48 (8): 955-962.
Santos, H. C., Fabio, H. T, de O, Ignacio, H. S., Adailson, P. de S. and Valerio, D. da M. S. (2011). Ki-netics of phosphorus sorption in soils in the State of Paraiba. *R. Bras. Ci. Solo* 35: 1301-1310.
Scervino, J.M.,Papinutti, V.L., Godoy, M.S, Rodriguez, J.M., Monica, I.D. and Recchi, M.(2011).Medium pH, carbon and nitrogen concentrations modulate the phosphate solubilization efficiency of Penicilliumpurpurogenum through organic acid production. *Journal Applied Microbiology.*110: 1215-1223.
Soil Survey Staff. (2003). Keys to Soil Taxonomy. 9th Edition, United States Department of Agriculture, United States Department of Agriculture Natural Resources Conservation Service, P. 322.

Srinivasan, R., Yandigeri, M.S., Kashyap, S. and Alagawad, A.R. (2012).Effect of salt on survival and P-solubilization potential of phosphate solubilizing microorganisms from salt affected soils. *Saudi Journal Biology Science.* 19: 427–434.

Tan, I.A.W, Ahmad, A.L and Hameed, B.H. (2008) Adsorption of basic dye using activated carbon prepared from oil palm shell: batch and fixed bed studies. *Desalination.* 225:13-28.

Udo, E.J., Ogunwale, J.A., Fagbami, A., Ano, A.O. and Esu, I.E. (2009). Manual of soil, plant and water resources. Sibon books limited. p 177.

Voudrias, E., Fytianos, F. and Bozani, E. (2002). Sorption Description isotherms of Dyes from aqueous solutions and Waste Waters with Different Sorbent materials, *The international journal of Global Nest.*4(1): 75-83.

Walkley, A and Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter and the proposed modification of the chromic acid wet titration method. *Journal of Soil Science*, 37:29-38.

STATUS AND VARIABILITY OF MICRONUTRIENT WITHIN THE FLOODPLAIN SOILS AT INSTITUTE FOR AGRICULTURAL RESEARCH, SAMARU, NORTHWESTERN NIGERIA

Aliyu J.[1]*, Ibrahim U.[2], Abubakar F.J.[1], Usman I.N. [3]and Isa N.[1]

[1]Soil Science Department, Faculty of Agriculture / Institute for Agricultural Research, Ahmadu Bello University Zaria, Nigeria

[2] Samaru College of Agriculture, A Division of Agricultural Colleges, Ahmadu Bello University, Zaria, Nigeria

[3]Crop Production Technology Department, College of Agriculture Science and Technology, Lafia, Nasarawa State, Nigeria

Corresponding author email:Jamilabintaliyu@gmail.com

ABSTRACT

Micronutrients play an important role in balanced crop nutrition in order to maintain the overall health and vitality of plants. This study was conducted to evaluate the status and variability of micronutrients in floodplain soils located at Institute for Agricultural Research farm, Samaru. Soil samples were collected at genetic horizon from four soil profiles dug within the floodplain. Results indicated substantial spatial variability in micronutrient distribution. Copper (Cu) concentrations (5.02 to 6.26 mg kg^{-1}) were sufficient across all samples, with low variability (standard deviation of 0.70 mg kg^{-1} and coefficient of variation (CV) of 12 %). Iron (Fe) was abundant (mean of 317.69 mg/kg) but exhibited high spatial variability, particularly in P3 and P4. Zinc (Zn) showed high variability (CV of 87.18%), with concentrations decreasing with depth. Manganese (Mn) was sufficient (mean of 30.63 mg kg^{-1}) but highly variable (CV of 158.80 %) across soil profiles. Principal component analysis revealed strong positive correlations between Cu, Fe, and Zn, with organic carbon influencing their availability. Clay content significantly influenced Cu and Fe distribution, while soil pH affected Fe solubility. The variability in micronutrient distribution was linked to organic matter content, clay fraction, and soil management practices. Management strategies regarding sustainable and efficient micronutrient utilization should be adopted.

Keywords: *Nutrient, floodplain, management, distribution, coefficient of variation*

Introduction

Micronutrients in small quantities are applied for healthy growth and development of plants. Micronutrients and macronutrients play an important role in completing the life cycle of plants. Micronutrients are essential for the maintenance of soil health as well as for enhancement of productivity of crops (Rattan *et al.*, 2009). Zinc, copper, manganese, iron and boron are essential micronutrients for speedy growth of plants. Micronutrients play an indispensable role for the biosynthesis of proteins, nucleic acids, gene expression, growth substances, metabolism of carbohydrates and lipids, stress tolerance, chlorophyll and secondary metabolites etc. through their association with other physiologically active molecules and various enzymes (Rengel, 2007). Therefore, the availability of micronutrients is essential for proper crop nutrition and development. Geological substrate and pedogenic systems of management determine the quantity of micronutrients in soils. However, plants are unable to indicate deficiencies because micronutrient availability depends on organic matter content, soil pH, adsorptive surfaces, and various biological, chemical, and physical conditions in the environment.

Availability of micronutrients is influenced by the distribution within the soil profile (Singh and Dhankar, 1989). Land use pattern plays a vital role in the nutrient dynamics and fertility of soils (Venkatesh *et al.*, 2003). Poor drainage affects physicochemical properties of soils resulting in modification of DTPA-extractable micronutrients content and availability to plants for their growth. Knowledge of the pedogenic distribution of micronutrients is crucial because the roots of many plants penetrate subsurface layers of the soil to draw required nutrients.

Soil plays a significant role in defining the agro system of sustainable productivity. Sustainable fertility depends on the ability of the soil to supply essential nutrients to the growing plants. Micronutrient deficiency imposes a severe constraint on productivity, stability and sustainability of soils (Bell and Dell, 2008). Lack of micronutrients may be due to their low content, or soil factors reduce plant growth. Inappropriate management of nutrients leads to multi-nutrient deficiencies in Indian soils (Sharma, 2008). Moreover, continuous negligence of micronutrient application and avoidance of organic manures are the significant causes of scarcity of micronutrients (Srivastava *et al.*, 2017).

Methodology

Study location

Institute for Agricultural Research, Samaru lies within Sabon gari Local Government Area (LGA) in Kaduna State within the Northern Guinea savanna region of Nigeria. Geographically, the study area lies between latitudes 11° 6′ - 11° 22′ N and longitudes 7° 38′ - 7° 53′ E, covering a total land area of 233 ha (Figure 1). The soils are formed on a basement complex formation (Aliyu, 2023), located on the north-central high plain (Ojanuga, 2006). Geologically, Russ (1975) identified the region as rich in high-quality metamorphic sediments, primarily composed of quartzites, which include schist and weathered granites with a notable presence of biotites and phyllites.

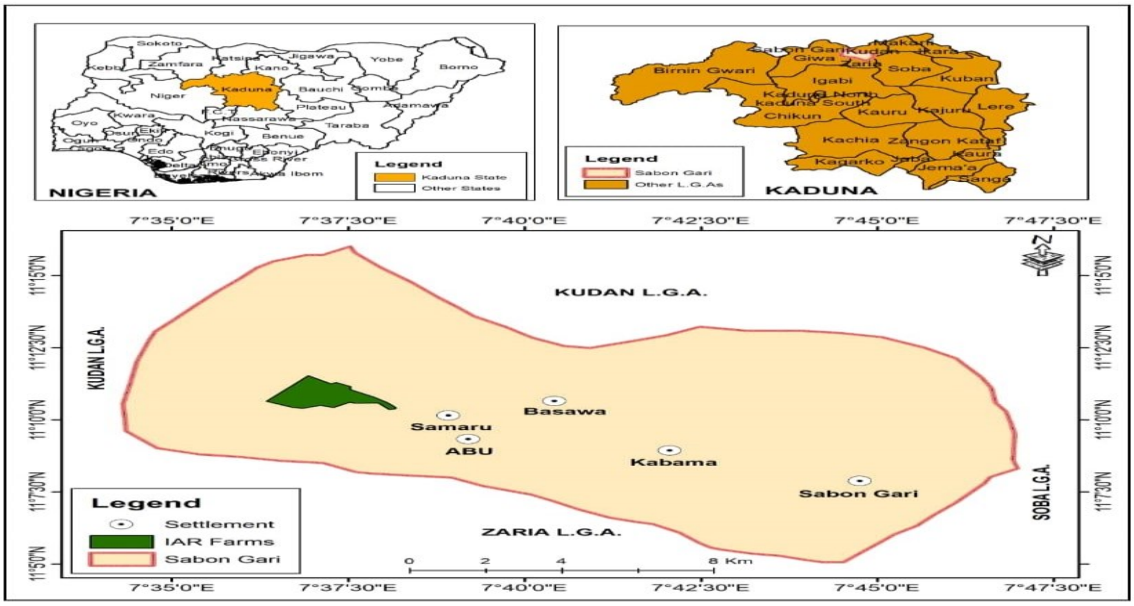

Figure 1: Map showing the location of the study area.

The topography is mainly characterized by gentle slopes and relatively flat terrain, with elevations ranging from 614 to 688 meters above sea level. The main drainage system consists of several tributaries feeding into the Galma River, which originates from the Jos Plateau in the southwestern region of the Shetu Hills. The region's land is predominantly used for crop farming, with maize and cowpea being the main cereal crops. The vegetation is sparse with scattered trees, and the floodplains are utilized for cultivating various crops such as onions, spinach, pepper, tomatoes, carrots, and cabbage (Aliyu 2023).

Samaru is located within a tropical savanna climate, characterized by distinct dry and wet seasons as noted by Abaje et al. (2012). The wet season, following a monsoonal pattern, extends from May to October, while the dry season runs from November to April. The average annual rainfall is 1070.7 mm. Temperatures vary daily, with cooler nights averaging 20°C and hotter days exceeding 33°C, resulting in an overall mean temperature of 27°C (Aliyu 2023). The area is classified as having an iso-hyperthermic soil temperature regime and an Ustic soil moisture regime (Soil Survey Staff, 2014). Relative humidity is typically around 16 % during the dry season and can rise above 72% during the rainy season (IAR, Meteorological Unit, 2021).

Field Observation

Soil colour, an indicator of drainage conditions, was used to delineate the floodplain. Based on this hydromorphic characteristic, the study area was divided into four soil units: P1, P2, P3, and P4. Four profile pits were randomly excavated within the delineated soil units, and soil samples were collected from the identified genetic horizon. Soil morphological properties such as colour, texture, consistence, and structure were used to determine the genetic horizons (Soil Survey Staff, (1996) and (2014)).

Laboratory analysis

The bulk soil samples collected from each genetic horizons were subjected to a series of procedures. First, they were air dried and then ground and sieved to eliminate particles larger than 2 mm in diameter. The resulting material, consisting of particles smaller than 2 mm, was used for laboratory analysis. Particle size distribution was determined by hydrometer method. Available water content was determined by estimating the difference between moisture content at 33 kPa and 1500 kPa. Soil pH was determined in 1:2.5 soil liquid ratios in water and 0.1N $CaCl_2$. Organic Carbon was determined using the wet dichromate oxidation method. Total Nitrogen was determined using modified micro Kjeldahl method; Total available phosphorus was determined using Bray I method; Micronutrients such as Mn, Fe, Cu and Zn were extracted using acid method of 0.1M HCl; Exchangeable bases and cation exchangeable capacity were extracted with 1N NH_4OAc solution, exchangeable K and Na were measured using a flame photometer, exchangeable Ca and Mg were measured using atomic absorption spectrophotometer and CEC was measured by distillation and titration. Base saturation was calculated as the ratio of the total exchangeable bases (Ca, Mg, K, and Na) to the CEC (obtained using NH_4OAc) and expressed as a percentage as shown in the equation below

$$Base\ saturation = \frac{\text{Total exchangeable bases}}{CEC} X100 \qquad \text{Equation (1)}$$

The details of these methods have been described by Agbenin (1995).

Statistical Analysis

Descriptive statistics of the studied soil characteristics include the minimum, maximum, arithmetic mean, standard deviation and co-efficient of variation were computed principal component analysis (PCA) used to reduce the dataset into new variables, which are called principal components (PCs), as well as to avoid multicollinearity between the original variables. These PCs explain most of the variations present in the original variables. The PCA biplot model was used to analyse the relationship between selected soil properties. A biplot was created from the first two principal components. All analyses were computed using R statistical package.

Results and Discussion

Status of soil properties in the study area

A summary of soil physical from a study area, including statistical measures such as minimum, maximum, mean, standard deviation, and coefficient of variation (CV) for various soil parameters is provided in Table 1. The clay content ranges from 80 to 420 g kg^{-1} with a mean of 209 g kg^{-1} and a high standard deviation of 93.49 g kg^{-1}, indicating substantial variability in clay content across the study area. The CV of 44.66 % confirms this variability. Silt content varies between 200 and 540 g kg^{-1}, with a mean of 385 g kg^{-1} and a lower standard deviation of 77.79 g kg^{-1}, suggesting less variability compared to clay. The CV is 20 %. Sand content ranges from 160 to 620 g kg^{-1}, with a mean of 392 g kg^{-1} and a standard deviation of 134 g kg^{-1}, indicating considerable variability. The CV is 34.19 %. Available Water Capacity (AWC) ranges from 1.27 to 4.10 mm cm^{-}, with a mean of 2.48 mm cm^{-} and a standard deviation of 0.95 mm cm^{-}. The CV of 38.50 % shows moderate variability in the soil's ability to retain water.

A summary of soil chemical properties from a study area, including statistical measures such as minimum, maximum, mean, standard deviation, and coefficient of variation (CV) for various soil parameters is provided in Table 2. Organic carbon (OC) ranged from 2.50 to 12.57 g kg^{-1}, with a mean of 7.18 g kg^{-1} and a standard deviation of 3.36 g kg^{-1}. The CV is 46.83%. The mean OC of 7.18 g kg^{-1} is high, indicating rich organic matter content, which is beneficial for soil health and fertility. Total N ranged from 0.84 to 2.35 g kg^{-1}, with a mean of 1.53 g kg^{-1} and a standard deviation of 0.39. The CV is 25.70%. The mean TN of 1.53 g kg^{-1} falls on the border of medium and high, indicating generally good nitrogen levels. Available Phosphorus (AvP) ranged from 2 to 29 mg kg^{-1}, with a mean of 5 mg kg^{-1} and a very high CV of 132 %, indicating extremely high variability in P availability. The mean AvP of 5 mg kg^{-1} falls in the low range, indicating low P availability, which could limit plant growth.

Exchangeable Ca ranged from 1.07 to 7.45 cmol(+)kg^{-1}. Soil pH values range from 3.8 to 4.9, with a mean of 4.27 and a standard deviation of 0.35. The CV was 8.18 %, indicating relatively low variability in soil pH. The mean Ca level of 3.98 cmol(+)kg^{-1} falls in the medium range, indicating moderate soil fertility with respect to calcium and a standard deviation of 2.05 cmol(+)kg^{-1}. The CV is 51.38 %, indicating high variability. Exchangeable Mg ranged from 0.58 to 2.10 cmol(+)kg^{-1}, with a mean of 1.17 cmol(+)kg^{-1} and a standard deviation of 0.52 cmol(+)kg^{-1}. The CV is 44.13 %. Exchangeable magnesium in the study area ranges medium to high based on the rating of USDA (2004) indicating moderate to high soil fertility with respect to magnesium. Exchangeable K ranged from 0.10 to 0.66 cmol(+)kg^{-1}, with a mean of 0.29 cmol(+)kg^{-1} and a standard deviation of 0.17 cmol(+)kg^{-1}, indicating high variability with a CV of 59.80%. The mean K level of 0.29 cmol (+) kg^{-1} falls in the medium range, indicating moderate potassium levels. Exchangeable Na ranged from 0.10 to 1.25 cmol (+) kg^{-1}, with a mean of 0.59 cmol (+) kg^{-1} and a standard deviation of 0.37 cmol(+)kg^{-1}. The CV is 62.40%, indicating high variability. The mean Na level of 0.59 cmol (+) kg^{-1} falls in the medium range, indicating moderate Na content. Cation Exchange Capacity (CEC) values range from 3.80 to 10.50 cmol (+) kg^{-1}, with a mean of 7.49 cmol(+)kg^{-1} and a standard deviation of 2.38 cmol (+)kg^{-1}. The range of CEC falls within the low to medium range, as per the ratings recommended by Esu (1991) indicating low to moderate soil fertility in terms of its ability to hold cations. This parameter has a CV of 31.76%, indicating a moderate level of variability in the soil's ability to hold cations. Exchangeable Sodium Percentage (ESP): ranged from 1.05 to 17.41 %, with a mean of 7.80 % and a high standard deviation of 4.40%, indicating significant variability. The CV of 56.38% confirms this high variability. The mean ESP of 7.80% falls below the critical value of 15 % given by Brady and Weils (2010) indicating moderate risk of sodicity.

Status and variability of Micronutrient in the study area

Table 3 presents the summary statistics of four soil micronutrients (Cu, Fe, Zn, and Mn) across different soil units (P1, P2, P3, P4) at the floodplain of IAR Farm, Samaru.

Available Copper

The mean concentration was 5.83 mg kg^{-1} with a range of 5.02 to 6.26 mg kg^{-1} (Table 2). The values were higher than the critical limit of < 0.2 mg kg^{-1} given by Esu (1991) implying that no sample approaches the deficient ranges. The standard deviation (SD) of 0.70 mg kg^{-1} and coefficient of variation (CV) of 12 % (Table 3) indicates that available Cu content is not well dispersed in the floodplain. According to Wilding (1985) a CV of < 15 % implies that the concentration of available Cu within the study area is less broad. Low variability in all the profiles could be attributed to its low mobility in soil. According to Sun *et al.* (2019) available Cu is the least mobile trace element in soils. It decreases with increase in soil depth in profiles P1-P2 and increase down depth in profiles P3-P4 (Table 3). Similar result was observed by Aliyu (2023) in soils of IAR farm. The decrease in Cu with depth could be attributed to low organic matter content at subsoils. Dhaliwal *et al*. (2019) stated that organic carbon enhanced the availability of Cu through the formation of complexes with organic matter, which prevents Cu from losses through fixation, leaching oxidation and precipitation.

Available Iron

The mean distribution of extractable Fe within the floodplain soil is 317.69 mg/kg and the range is from 36.00 to 796.58 mg/kg Fe (Table 3). All the sample data fit comfortably within the critical limits, implying that the Fe concentration in the soil is satisfactory. According to the critical limit of 4.5 mg kg^{-1} suggested by Esu (1991), all the soil samples exceed sufficient range in extractable Fe and were in the excess limit. Higher concentration of Fe in the study area could be attributed to weathering biotite, goethite and hematite (Schroeder et al., 2002). The SD of 266.97 mg/kg and CV of 84.03 % (Table 3) indicates that, it varied spatially in the floodplain. Available Fe showed the highest variability across most profiles, particularly in P3 and P4, suggesting significant differences in iron content within those profiles. Its concentration showed a decreasing trend with increasing soil depth in profile P1, P3 and P4 (Table 4) which might be due to regular addition of Fe through organic matter in the surface layers. Iron form complexes with organic compounds leading to an increase in Fe concentration in soil solution (Gerke. 2022).

Available Zinc

The mean concentration was 5.58 mg kg^{-1} with a range of 0.70 to 16.21 mg kg^{-1} (Table 2). Using critical standards of Esu (1991), all the samples contained adequate Zn, and soils will not be classified as deficient in Zn. Higher concentration of available zinc was observed in the surface soil (Table 3). The SD of 4.87 mg/kg and CV of 87.18% indicates that they varied spatially in the orchard. According to the ratings of Wilding (1985) a CV > 35 % is considered highly variable. Available Zn showed high variability in most profiles, particularly in P2 and P3, indicating fluctuating Zn levels. It was higher in the surface soil (Table 4) and decreased down the profile. The decrease in available Zn with depth could be attributed to decrease in organic matter content with increasing soil depth. According to Weng *et al.* (2002) and Aliyu (2023) complexation of Zn with organic compounds *increases the solubility and mobility of Zn in soils.*

Available Manganese

The mean concentration was 30.63 mg kg^{-1} with a range of 0.90 to 180.93 mg kg^{-1} (Table 2). According to the critical limit of 4 mg kg^{-1} suggested by Esu (1991), all the soil samples were sufficient in available manganese The values were within range reported on soils of Basement complex rocks of Nigeria (Maniyunda, 2012). Raji (2016) ascribed moderate to high extractable Mn to the ferromagnesian minerals in tropical soils. The SD of 48.64 mg/kg and CV of 158.80 % (Table 3) indicates that available Mn varied spatially in the floodplain. It exhibited high variability in profiles P1, P2, and P3, suggesting significant fluctuations in its content Available Mn was higher in the surface soil (Table 4) and decreased down the profile. The extractable Mn decreased with increase in soil depth following the trend in organic matter distribution.

Relationship between extractable copper and other soil properties

The result from the PCA analysis was used to produce a biplot (Fig. 2). Cu had strong positive correlation with other micronutrients (Fe and Zn), and a weak but positive relationship with Mn as shown by the position and the direction of the arrow. These results are consistent with those obtained by Obasia et al, (2022) in arable soils of Rigachikun-Kaduna in a similar agro-ecological zone. The angle between the Cu and OC arrows is relatively large but not quite 90 degrees, indicating a weak positive correlation. Additionally, the arrow of both Cu and OC point towards the left side of the plot, though in slightly different directions, reinforcing the idea of a weak positive correlation. The positive correlation between Cu and organic carbon could be attributed to the adsorption of Cu^{2+} ions on OM as sorption and formation of complexation with OM thereby influencing the bioavailability of Cu in the soil. According to Dhaliwal et al., (2019) Cu tends to form a stronger inner-sphere complex with SOM and McLaren et al. (1983) observed that Cu was the metal that was preferably associated to the soil organic fraction The relationship between Cu and clay from the PCA biplot showed that the angle between the Cu and clay arrows was relatively small and their arrows are pointing toward a similar direction in the upper left quadrant indicating a positive correlation. A positive correlation between Cu and clay could be attributed to the fact that clay has a large surface area for Cu absorption thereby increasing its availability. Odunze and Kureh (2007) maintained that high clay content influenced the distribution of Cu. The relationship between Cu and pH and CEC from the PCA biplot shows that the angle between the Cu and pH arrows was large, approaching 90 degrees and the directions of their arrow were different indicating that these variables have little to no correlation. The result implies that pH does not affect the distribution of copper in the soil. The non correlated relationship between Cu and Na or K is mainly due to competition for adsorption sites on soil particles. High levels of Na or K can reduce the availability of copper to plants by occupying exchange sites and altering soil conditions.

Relationship between extractable iron and other soil properties

The angle between Fe, OC pH, clay, Cu and Mn, Fe were small, and their arrows are in a similar direction, showing a positive relationship (Figure 2). The significant positive relationship between Fe and organic carbon indicates that organic carbon affects the solubility and availability of Fe. Khurana *et al*. (2024) stated that iron forms stable complexes with organic matter, preventing it from oxidizing and precipitating. Soil pH is among key components that determine the characteristics of Fe in soils. The solubility of Fe compounds varies with soil pH. As the pH increases and becomes more basic, iron (II) compounds ($FeSO_4$), which are more soluble in acidic conditions are oxidized to iron (III) compounds, which are less soluble (Crespo *et al*., 2023). The positive relationship between Fe and clay could be attributed to the fine size fraction of the soil. Clay particles have a high surface area and can adsorb Fe from the soil solution. This adsorption helps regulate the availability of Fe in the soil (Sipos *et al*., 2021).

Relationship between extractable manganese and other soil properties

To determine the relationship between Mn and OC, CEC or clay from the PCA biplot (Figure 2), the angle between the Mn and OC or CEC arrows was relatively small, their arrows point towards similar directions in the upper right quadrant, suggesting that these variables are positively correlated. The correlations between Mn and OC content obtained in this study (Fig 2) agree with those of Mohiuddin *et al*. (2022) who indicated that soil organic matter content played a fundamental role in the control of Mn sorption by soil. Positive relationship between Mn and CEC may be attributed to the retention of more Mn^{2+} on the exchange sites, reducing its leaching and making it available to plants over time. Positive correlation between Mn and clay could be attributed to the clay's large surface area for absorption of Mn. According to Mohiuddin et al. (2022) stated that the surface of fine-textured soils may adsorb the Mn fractions, which make up a significant portion of soil surface area.

Relationship between extractable zinc and other soil properties

PCA biplot shows a positive relationship between Zn (Zinc) and either organic carbon, CEC and clay. The bioavailability of Zn is influenced by clay (John, and Leventhal, 1995), CEC, and organic matter. The majority of bioavailable Zn is adsorbed onto mineral surfaces and forms complexes with organic matter (John, and Leventhal, 1995). Increase in Zn with increase in OC is due to the absorption of Zn to organic matter. Different organic compounds, including aliphatic and aromatic hydrocarbons, significantly contribute to the formation of soluble complexes in soil (John, and Leventhal, 1995). The formation of these Zn organic complexes is influenced by metal content amongst other factors (Mohiuddin *et al*., 2022). This explains why Zn deficiency is common in soils with low metal content and organic matter availability. The positive correlation observed between Zn and the clay fraction of the soil is due to zinc's affinity for clay minerals and sesquioxide surfaces. Several authors, including Lindsay (1995), have highlighted the relatively strong binding of zinc by clays. The negative relationship between zinc and pH (Fig. 2) is due to the decreased solubility and availability of zinc in alkaline soils. As pH increases, Zn tends to precipitate out or form less soluble compounds, reducing its availability to plants.

Conclusion

This research highlighted the substantial differences in the concentration and variability of micronutrients across different soil profiles. While copper, iron, zinc, and manganese were found in sufficient concentrations across the study area, their distribution varied depending on soil properties such as organic matter, clay content, pH, and CEC. Iron exhibited high variability, likely due to differences in organic matter content and redox conditions, which influence its solubility. Zinc and copper concentrations were generally higher in surface soils due to organic matter accumulation, while manganese distribution followed a similar trend. Principal component analysis (PCA) demonstrated strong correlations between micronutrients and key soil properties, emphasizing the role of organic matter in micronutrient availability. Overall, the study underscores the importance of soil management practices that maintain organic matter content, regulate soil pH, and enhance nutrient retention for optimal plant growth.

References

Abaje, I. B., Ati, O. F., and Iguisi, E. O. (2012). Recent Trends and Fluctuations of Annual Rainfall in the Sudano-Sahelian ecological zone of Nigeria: Risks and opportunities. *Journal of Sustainable Society*, *1*(2), 44-51.

Agbenin, J.O. (1995). Laboratory manual for Soil /Plant analyses. Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria

Aliyu, J. (2023). Evaluation of the Impact of Continuous Cultivation on Soil Development and Quality at the Institute for Agricultural Research Farm, Samaru, Nigeria. Thesis submitted to the School of Postgraduate Studies in partial fulfilment of the requirement for the award of the Degree of Doctor of Philosophy.

Bell, R. W. and Dell, B. (2008). Micronutrients for sustainable food, feed, fibre and bioenergy production. International Fertilizer Industry Association (IFA).

Brady, N. C. and Weil, R. R. (2010). *Elements of the Nature and Properties of Soils* (3rd ed.). Pearson.

Crespo, E.B., Reichelt-Brushett, A., Smith, R.E.W., Rose, A.L. and Batley G.E. (2023) Improving the Measurement of Iron (III) Bioavailability in Freshwater Samples: Methods and Performance, *Environ Toxicol Chem*: 42(2): 303–316.0. doi: 10.1002/etc.5530

Dhaliwal, S.S., Naresh, R.K., Mandal, A., Singh, R., Dhaliwal M.K. 2019. Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. *Environmental and Sustainability Indicators*. 1-2, 100007. https://doi.org/10.1016/j.indic.2019.100007

Esu, I. E. (1991). Detailed Soil Survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, Ahmadu Bello University, Zaria.

Gerke, J. (2022). The central role of soil organic matter in soil fertility and carbon storage. *Soil Systems*, *6*(2), 33.

IAR, Meteorological Unit, (2021). The Meteorological Unit of the Institute for Agricultural Research Ahmadu Bello University. Zaria, Kaduna, Nigeria

John, D. A. and Leventhal, J. S. (1995). Bioavailability of metals. *Preliminary compilation of descriptive geoenvironmental mineral deposit models*, 10-18.

Khurana, H. K., Habib, M., Singh, S., Shakya, A., & Bashir, K. (2024). 8 Iron Fortification. *Food Fortification: Trends and Technologies*, 177.

Lindsay, W.L. (1995). "Chemical Equilibria in Soils." John Wiley & Sons.

Maniyunda L.M. (2012) Pedogenesis of a Lithosequence in the Northern Guinea Savanna of Kaduna State, Nigeria Thesis submitted to The School of Postgraduate Studies in partial fulfilment of the requirement for the award of the Degree of Doctor of Philosophy. Submitted to Department of Soil Science, Ahmadu Bello University

McLaren, R.G., Clucas, L.M., and Cressie, N. (1983). The adsorption of copper by soil: Effects of pH and soil composition. *Geoderma,* 31(4), 379-392.

Mohiuddin, M., Irshad, M., Sher, S., Hayat, F., Ashraf, A., Masood, S., Bibi, S., Ali J. and Waseem M. (2022) Relationship of Selected Soil Properties with the Micronutrients in Salt-Affected Soils. *Land*, 11(6), 845;

https://doi.org/10.3390/land11060845

Obasi S. N., Jokthan, G.N., Obasi, C.C., and Madueke C.O. (2022) Micronutrient Dynamics in Relation to Soil Properties in Arable Soils of Rigachikun-Kaduna. *Journal CleanWAS* 6(1)14-22DOI: http://doi.org/10.26480/jcleanwas.01.2022.14.2

Odunze, A.C. and Kureh, I. (2007). Land Use Limitations and Management Option for a Savanna Zone Alfisols. *Nigerian Journal of Soil and Environmental Research*, 7, 70-81.

Ojanuga, A.G. (2006). Management of fadama soils for food security and poverty alleviation.In the proceedings of the 30th Annual Conference of Soil Science Society of Nigeria. University of Agriculture, Makurdi, Nigeria. Pp 32-37.

Raji B.A. (2016) Characterisation and Taxonomic Classification of Basement Complex Soils in Kwara State. *Nigerian Journal of Soil Science*. 26:232-241

Rattan, R.K., Datta, S.P., Chhonkar, P.K., Suribabu, K., and Singh, A.K. (2009). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater - a case study. *Agriculture, Ecosystems & Environment*, 109(3-4), 310-322.

Rengel, Z. (2007) Cycling of Micronutrients in Terrestrial Ecosystems. In: Marschner, P. and Rengel, Z., Eds., Nutrient Cycling in Terrestrial Ecosystems, Springer-Verlag, Berlin, Heidelberg,93-121. http://dx.doi.org/10.1007/978-3-540-68027-7_4

Schroeder, P. A., Le Golvan, J. J. and Roden, M. F. (2002). Weathering of ilmenite from granite and chlorite schist in the Georgia Piedmont. *American Mineralogist*, *87*(11-12), 1616-1625.

Sharma, P. D. (2008). Nutrient management–Challenges and options. *Journal of the Indian Society of Soil Science*, *56*(4), 395-403.

Singh K.M.S., and Dhankar S.S. (1989) Influence of soil characteristics on profile distribution of DTPA-extractable micronutrient cations. *Indian Journal Agriculture Science*. 59:331-334.

Sipos, P., Kis, V.K., Balázs, R. *et al.* Effect of pedogenic iron-oxyhydroxide removal on the metal sorption by soil clay minerals. *Journal of Soils Sediments* 21, 1785–1799 (2021). https://doi.org/10.1007/s11368-021-02899-x

Soil Survey Staff (2006) Keys to Soil Taxonomy. 9th Edition, US Department of Agriculture, NRCS, Washington DC, 281.

Soil Survey Staff. (2014). Keys to soil survey. United States Department of Agriculture Natural Resources Conservation Service Twelfth Edition

Srivastava, A.K., and Malhotra, S.K. (2017). Nutrient use efficiency in perennial fruit crops—A review. *Journal of Plant Nutrition*, *40*(13), 1928-1953.

Sun, Q., Li, T., Alva, A.K. and Li, Y.C. (2019). Mobility and fractionation of copper in sandy soils. *Enviro. Pollut. Bioavailab*. 31 https://doi.org/10.1080/09542299.2018.1558114.

Venkatesh, M. S., Majumdar, B., and Kumar, K. (2003). Status of micronutrient cations under various land use systems of Meghalaya. *Journal of the Indian Society of Soil Science*, *51*(1), 60-64.

Weng, L., Temminghoff, E. J., Lofts, S., Tipping, E., & Van Riemsdijk, W. H. (2002). Complexation with dissolved organic matter and solubility control of heavy metals in a sandy soil. *Environmental science & technology*, *36*(22), 4804-4810.

Wilding L.P., (1985). Spatial variability: its documentation, accommodation and implication to soil surveys. In: Soil Spatial Variability (Eds D.R. Nielsen, J. Bouma). Pudoc Press, Wageningen, the Netherland

Table 1: A summary of soil physical properties of the study area

Statistic	Clay	Silt	Sand	AWC
Units	-------------------g kg^{-1}----------------			mm cm^{-}
Minimum	80.00	200.00	160.00	1.27
Maximum	420.00	540.00	620.00	4.10
Mean	209.33	385.33	392.00	2.48
SD	93.49	77.79	134.02	0.95
CV	44.66	20.19	34.19	38.50

Keys: SD: Standard deviation, CV: Cofficient of variability, AWC: Available water content,

Table 2: A summary of soil chemical properties of the study area

Statistic	Ca	Mg	K	Na	CEC	ESP	AvP	pH	TN	OC
Units	---------------cmol(+)kg^{-1}---------------					%	mg kg^{-1}		---g kg^{-1}-----	
Minimum	1.07	0.58	0.10	0.10	3.80	1.05	1.74	3.76	0.84	2.50
Maximum	7.45	2.10	0.66	1.25	10.50	17.41	29.12	4.88	2.35	12.57
Mean	3.98	1.17	0.29	0.59	7.49	7.80	4.98	4.27	1.53	7.18
SD	2.05	0.52	0.17	0.37	2.38	4.40	6.58	0.35	0.39	3.36
CV	51.38	44.13	59.80	62.40	31.76	56.38	132.22	8.18	25.70	46.83

Keys: SD: Standard deviation, CV: Cofficient of variability, Ca: exchangeable calcium, Mg: exchangeable magnesium, K: exchangeable potassium, Na: exchangeable sodium, CEC: cation exchangeable capacity, ESP: exchangeable sodium percentage, AvP: available phosphorus, TN: total nitrogen, OC: organic carbon

Table 3: Soil micronutrient status at the floodplain of IAR Farm, Samaru

soil profile	Statistic	Cu	Fe	Zn	Mn
		--------------------mg kg^{-1}---------------------			
P1	Minimum	5.02	73.08	1.45	5.94
	Maximum	6.26	364.28	6.56	30.02
	Average	5.83	178.60	3.57	16.30
	Standard Deviation	0.70	161.31	2.66	12.39
	CV	12.00	90.32	74.62	75.97
P2	Minimum	5.28	523.70	1.55	20.48
	Maximum	8.32	696.41	16.21	180.98
	Average	6.44	621.42	8.94	82.84
	Standard Deviation	1.43	73.43	7.40	76.60
	CV	22.22	11.82	82.83	92.47
P3	Minimum	3.32	36.00	0.70	0.09
	Maximum	6.19	255.85	1.99	6.52
	Average	4.39	105.48	1.22	3.91
	Standard Deviation	1.57	133.62	0.68	3.38
	CV	35.72	126.68	55.47	86.45
P4	Minimum	3.19	109.93	3.46	9.50
	Maximum	7.25	796.58	11.22	19.25
	Average	5.80	278.36	6.72	13.49
	Standard Deviation	1.66	293.83	2.80	3.92
	CV	28.66	105.56	41.70	29.08

Table 4: Soil micronutrient status at the floodplain of IAR, Samaru

Soil units	Horizon	soil depth cm	Cu	Fe	Zn	Mn
			------------------------	mg kg^{-1}	----------------	
P1		Latitude 11° 11'30"N		Longitude 007 ° 36'57"E		
	Ap	0-24	5.02	364.28	6.56	30.02
	Btc	24-93	6.26	98.43	1.45	12.95
	Btg	93-123	6.20	73.08	2.70	5.94
P2		Latitude 11° 10'58"N		Longitude 007° 37'33"E		
	Ap	0-20	5.28	523.70	14.33	180.98
	Btc	20-38	5.37	696.41	1.55	20.48
	Bt	38-88	6.78	652.10	3.66	23.46
	Btg	88-150	8.32	613.47	16.21	106.42
P3		Latitude 11 ° 10'50"N		Longitude 007° 37'35"E		
	Ap	0-10	6.19	255.85	1.99	5.13
	Btg1	10-40	3.66	60.23	0.98	6.52
	Btg2	40-60	3.32	0.36	0.70	0.09
P4		Latitude 11° 11'19" N		Longitude 007° 37'12"E		
	Ap	0-24	7.25	796.58	6.28	9.50
	Bt1g	24-57	6.03	231.05	6.21	11.72
	Bg1	57-83	3.19	112.19	11.22	11.33
	Bt2g	83-111	7.17	142.05	3.46	19.25
	Bg2	111-150	5.35	109.93	6.43	15.64

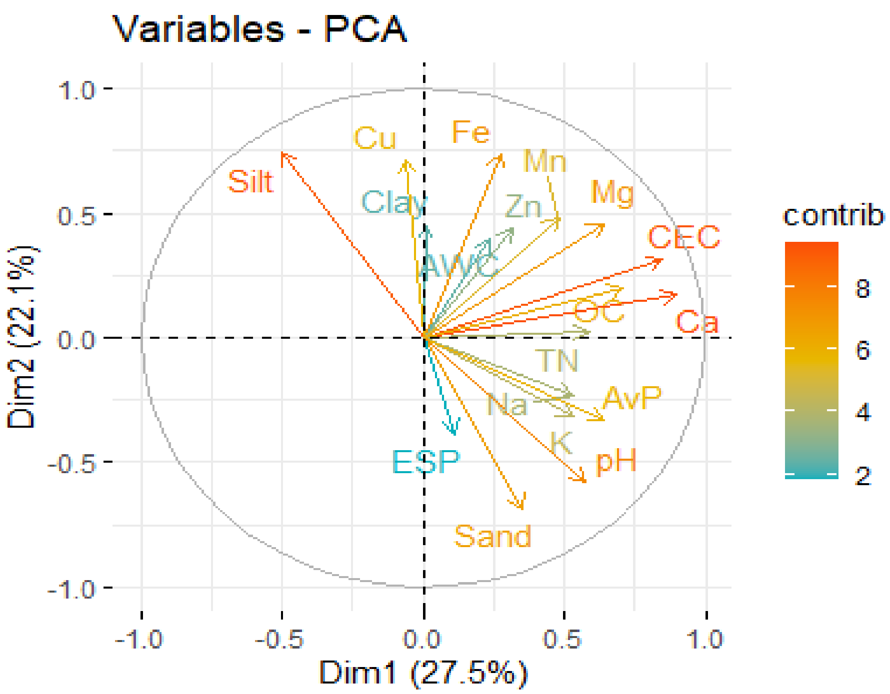

Fig 2: A PCA bi plot showing the relationship between the micronutrients

INTEGRATED SOIL AMENDMENT APPLICATION IN PROBLEMATIC ACID SOILS FOR INCREASED CASSAVA ROOT YIELD IN SOUTHEASTERN NIGERIA

Asadu, C.L.A[1*].; Chude, V[2]. Umeugokwe, P[1]. Azuka, V[1].; Asadu, C.A.[1] and Eze, S.[3]

[1]*Department of Soil Science, University of Nigeria, Nsukka*

[2]*Nigeria Institute of Soils Science, Area 11, Gariki, Abuja*

[3]*Department of Crop Science, University of Nigeria, Nsukka*

Corresponding author email: Charles.asadu@unn.edu.ng

ABSTRACT

The soils of Southeastern (SE) Nigeria are designated problematic acid soils as most of them are acidic and low in nutrient contents. However, due to the importance of cassava in the region, the soils are continually used widely for cassava production. With known average cassava yield in farmers' field of < 9 t ha[1] in SE Nigeria, the Nigeria Institute of Soil Science set to contributing to food security through soil improvement, established a trial in Ohebe Orba in Enugu state in 2020 involving poultry manure (P), lime (L) and NPK mineral fertilizer in order to improve cassava productivity in problematic acid soils in the region. The treatments were four purposively selected soil amendments, poultry (P) only, L+NPK, L+P+NPK, and P+NPK) at recommended rates. The trial involved four farmers and each treatment was replicated twice in each farmer's field. Pre-planting soil data showed that the soils were acidic with an average soil pH of < 5.5 and major nutrients were very low to low. The fresh root yields obtained in 2021 when compared with the national average of 9 t ha[1] revealed that the percentage increases ranged from approximately 70% in plots treated with P only to over 300% in plots treated with P+NPK. These yield increases translated to approximately 15, 22, 23 and 39 t h^{-1} respectively for P only, L+NPK, L+P+NPK and P+NPK. Thus to improve the productivity of acidic soils in SE with respect to cassava production nutrient addition is very necessary.

Keywords: *Problematic acid soils, cassava, nutrient and addition, liming.*

Introduction

The importance of cassava (*Manihot esculenta* Crantz) in the food system of the world particularly in sub-Saharan Africa is well known. Apart from being a food security crop in the sub-region, cassava is grown widely because it tolerates acid soils with low pH and high levels of exchangeable Al and low levels available P; hence it is often grown as the last crop in the production cycle in slash-and-burn systems, just before the field reverts back to bush fallow to recuperate its productivity (Howeler, 2017). Over the past 20 years, the area planted to cassava has increased at a faster rate than that of any other food crop, while total production increased faster than any other crop except for maize. But it has the reputation to degrade the soil by excessive absorption of nutrients and their removal in the harvested products. An average yield of 15 t ha^{-1} of fresh roots with the removal of all plant parts from the field has been reported to remove per ha about 93 kg N, 12 kg P, 81 kg K, 42 kg Ca and 13 kg Mg (Howeler, 2017). This implies that without application of fertilizers or manures, cassava yields will almost invariably decline when the crop is grown continuously for many years on the same field.

In sub-Saharan Africa more than 35 % of variation in root yield was accounted for by soil properties and more than ten soil properties had significant effects on most yield parameters. (Asadu and Nweke, 1999), but in southeastern Nigeria, soil variables accounted for > 70 % of the variation in cassava root yields and harvest index (Asadu *et al*. 2007)

Though Nigeria is the largest cassava producer in the world, with an annual output of 59.5 million Mg fresh cassava roots from 6.8 million hectares of land, cassava yields in Nigeria are low at an average of 8.8 Mg ha^{-1} yr^{-1} fresh roots (FAO, 2019). In Nigeria there are about 4.5 million farmers that cultivate this crop over an area of 7.22 million ha with a yield exceeding 59 million t yr^{-1} but root yields in farmers' fields (8.20–12.22 t ha^{-1}) are lower than those obtained in Asia and Brazil. For example, in Thailand, total production was 31.1 m t ha^{-1}, and the average root yield on 1.39 m ha of land was 22.4 t ha^{-1} in 2019 (FAOSTAT, 2020). The mean root yield obtained from the Collaborative Study of Cassava in Africa (COSCA) which was conducted in sub-Saharan Africa in 1991 ranged from (8.5 t/ha) in the mid to 13.6 t/ha in the low altitude zones (Asadu *et a*l. 2007).

The low cassava yield is due to diseases, pests, weeds, soil fertility, agronomic factors, and socio-economic factors and these factors often combine to account for the low average cassava yield in Nigeria (8.76 t ha^{-1}), which is significantly lower than the global average yield of 11.1 t ha^{-1}, and much lower than the success stories recorded in India (34.2 t ha^{-1}) and Laos (32.1 t ha^{-1}) (Akinwumiju, *et al.* 2020). However, low cassava yield in farmer fields was mainly caused by low soil fertility and suboptimal management practices in Nigeria (Asadu *et al*., 2007).

Cassava is regarded as second most important staple crop in Nigeria after maize (Olutosin and Barbara. 2019.). It is disheartening that Nigeria is the world largest producer of cassava, however, local food and feed demands are not yet met. Again cassava has enormous export potentials and competes favourably in the export markets. There is no doubt that cassava production in Nigeria is witnessing a continuous growth for about 10 years, recording a total production of 59 million tons with 20.4 % world cassava production share in 2017. When compared with other producing countries in Africa and globally, it is also disheartening to know that Nigeria has not yet harnessed to a reasonable extent the export potentials in the cassava sub-sector (starch, flour, ethanol and animal feeds) like other leading countries such as Egypt (ranked among the top 10 leading cassava exporters in 2017) and Thailand ranked number one (Olutosin and Barbara. 2019.)

To increase production requires both intensification on existing land area and expansion into new areas. Cassava is favoured more than other crops when grown in problematic acidic soils but to increase yield on per ha basis requires integrated soil nutrient strategies. To develop technologies for sustainable cassava production in problematic acidic soils of SE, the NISS established trials in order to increase the productivity of such soils which are dominant in SE taking cognizance the strategic importance of cassava in the food system in the area. The objective of the trial was to integrate readily available poultry manure and NPK mineral fertilizer with liming in order to improve the national average cassava yield of approximately nine mt ha^{-1}.

Materials and Methods

Site Description

Location

The trial was at Ohebe Orba, Udenu LGA, Enugu State, Nigeria. Ohebe is located on Latitude 6.89o North; Longitude 7.56 ^{o} East on an elevation of 332 meters above mean sea level. Ohebe is one of the several farming rural communities making up Orba town. Egụ Orba is the main farming community of Orba that produces a lot of cassava and allied products as well as other farm produce (Ikechukwu, 2019)

Climate

The climate is a Tropical wet and dry belonging to the Kopen classification, "Awi" climate which is a tropical climate with distinct dry and wet seasons. The wet season lasts from April till November, with maximum amounts usually in the months of July and September giving rise to a bimodal distribution pattern and a short minor dry season in August referred to as *August break* (Asadu, 2002). The dry season lasts from November to early April. It is severe and prolonged. The mean monthly temperature, calculated from averaged maximum and minimum temperatures, varies between 25^o C in August and 30^o C at the end of the dry season. The absolute maximum is 38^o C and the absolute minimum is 12^{o}C, both occurring during the dry season. Diurnal variations seldom exceed 11^o C. The relative humidity is high in the rainy season; it drops during the dry season, especially during the occurrence of a north-easterly dry wind harmattan which blows intermittently between December and March (Asadu, 2002).

Geology and soils

Three geological outcrops in the study area are Nkporo Shale Formation (oldest), Mamu Formation, and Ajali Formation (youngest) (Nwafor *et al.,* 2017). Erosion has exposed parts of sandy Ajali formation and excavation of sand is ongoing there. The mixed geology has led some soils in area being sandy and some clayey.

Vegetation and present land use

The general vegetation belongs to the derived savanna zone (Keay, 1949) due to the absence of forests that characterize virgin land occupied by tall and large trees. This savannah zone owes its existence to anthropogenic activities involving forest clearing for cultivation and by bush fire. Few of the trees existing now are fire-resistant species leading to small patches of forest in some places sandwiched by a variety of shrubs and grassland. Among the variety of tree species in the area are West African copal tree (*Daniellia oliveri*), dwarf red ironwood (*Lophira lanceolata)*, guinea peach (*Nauclea diderrichii*), oil palms (*Elaeis guineensis)*, and some fruit trees such as mangoes (*Mangifera indica*), cashew (*Anacado ocidental* and oranges (*Citrus* sp)**.** The general land use is mainly agricultural and major crops grown by the farmers are maize (*Zea mais*), yams (*Dioscorea* spp), cassava (*Manihot esculenta* Crantz) and cashew. The farmers depend on seasonal rainfalls to grow their crops.

Establishment of the Trials

Four farmers were selected on September 26, 2020. Land preparation and soil sampling were carried out from October 2 to 09, 2020. Each plot measured 4 m x 5 m and each of the four farmers had two replicates. The mounds were made with local hoes by the farmers according to their usual practice but each plot had 20 mounds to represent 10 000 stands per hectare plant population. The cassava variety used as the test crop was IITA-TMS-IBA980581 and planting was done on October 10, 2020.

Treatments

Four treatments which were purposely selected by the Nigeria Institute of Soil Science (NISS) were Poultry only (P) at 2 t ha^{-1}, Agricultural Lime + NPK (L + NPK) with lime and NPK: 20:10:10 at 1 t ha^{-1} and 400 kg t ha^{-1} respectively, L + P + NPK and P + NPK. Both poultry manure and lime were broadcast on the plots before the mounds were made while NPK was applied by ring method at six weeks after planting. The Reference National Average (RNA) root yield of 9 t ha^{-1} was considered as the control or reference value to compare with treatment effects on root yield.

Soil Sampling and Analysis

Soils were collected at 0-20 cm and 20-40 cm depths in each the farmers plots with the help of soil auger before planting. After air-drying the loose samples and gentle crushing, they were sieved with 2mm sieve.

All the soil analyses were carried following standard laboratory procedures as described by IITA (2015). Briefly, soil particle size distribution was determined by the Bouyoucos hydrometer method) using sodium hexametaphosphate (Calgon) as a dispersing agent. Soil pH was measured in water and potassium chloride (0.1N KCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a Beckman's zeromatic glass electrode pH meter Available P was extracted with Bray (II) solution and measured using a colorimeter. Soil organic carbon content was determined using Walkley-Black's titration method. Total N was determined using Kjeldahl digestion, distillation, and titration method using concentrated sulphuric acid (0.1N H_2SO_4) as the oxidizing agent. Cation Exchange Capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined after extracting with ammonium acetate solution (1N NH_4OAc) at pH 7.0. Exchangeable Na and K in the extracts were determined by Flame photometry while Exchangeable Ca and Mg in the extracts were determined by the titration method using 0.1N EDTA). Cation Exchange Capacity (CEC) was thereafter estimated titrimetrically using 0.1N NaOH). Exchangeable Acidity (EA) was determined by saturating samples with potassium chloride solution (1N KCl) and titrated with sodium hydroxide. Percentage Base Saturation was determined by calculation as follows:

%BS = TEB/CEC × 100;

Where %BS = percentage base saturation; TEB = total exchangeable bases and CEC = cation exchange capacity.

Results and Discussion

Soil physical properties before planting

The soils were dominated by the sand fractions followed by the clay fractions, then the silt fractions. This is a common trend in the particle sand distributions of soils of south-eastern Nigeria. However, the textural classes were sandy loam in all the plots (Table 1). These textural classes dominate the problematic acid soils in the area. The textural classes are considered suitable for cassava.

Table 1. Physical properties of soils of NISS project at Ohebe Orba Enugu State before planting averaged over farmers F1 to F4 fields.

Code	Depth (Cm)	Clay	Silt	Find Sand	Corse Sand	Total sand	Texture
			g kg^{-1}				
F1	0-20	140	30	650	100	750	Sandy loam
F1	20-40	140	30	150	680	830	Sandy loam
F2	0-20	160	30	180	630	810	Sandy loam
F2	20-40	160	30	240	570	810	Sandy loam
F3	0-20	160	50	650	140	790	Sandy loam
F3	20-40	180	90	650	80	730	Sandy loam
F4	0-20	180	110	620	90	710	Sandy loam
F4	20-40	160	70	560	210	770	Sandy loam

Chemical properties before planting

Table 2 shows that all the soil pH values were in the acid range and generally below 5.5 indicating that the soils can exhibit problems associated with soil nutrient availability; hence they can be designated as problematic acid soils. This justified the selection of the area for NISS trials. All the soil nutrients including SOM and available P were low further showing that the soils require nutrient amendments for optimum cassava production (Howeler, 2017). With low TEB and CEC but high TEA, the soils also require liming. The results also support the need for pre-planting soil nutrient determinations because clear nutrient deficiency symptoms only manifest at certain stage of crop growth and correction may difficult leading ultimately to low yields.

Table 2: Chemical properties of soils of NISS project at Ohebe Orba, Enugu State before planting averaged over farmers' F1 to F4 fields.

Code	**Depth**	**pH**		**SOM**	**Total N**	**Exchangeable Bases**				**TEB**	**EA**		**TEA**	**CEC**	**BS**	**AvP**
	(cm)	H_2O	KCl			Na^+	K^+	Ca^{2+}	Mg^{2+}		Al^{3+}	H^+				
				%		cmol kg^{-1}									(%)	mg kg^{-1}
F1	0-20	5.4	4.7	1.15	0.098	0.02	0.06	1.00	0.20	1.28	0.80	0.20	1.00	5.60	22.86	4.66
F1	20-40	5.2	4.1	1.00	0.112	0.02	0.05	0.60	0.80	1.47	0.60	0.40	1.00	6.40	22.97	2.80
F2	0-20	5.5	4.5	0.72	0.140	0.02	0.04	0.60	0.40	1.06	0.20	0.80	1.00	5.60	18.93	7.46
F2	20-40	5.3	4.1	0.86	0.140	0.02	0.05	0.60	0.60	1.27	0.40	0.40	0.80	6.00	21.17	4.66
F3	0-20	5.2	4.3	0.86	0.084	0.02	0.05	0.60	1.00	1.67	0.20	0.60	0.80	5.60	29.82	4.66
F3	20-40	5.1	4.0	0.93	0.112	0.02	0.05	0.80	0.20	1.07	1.00	0.20	1.20	6.80	15.74	4.66
F4	0-20	5.3	4.1	0.79	0.094	0.02	0.05	0.60	0.40	1.07	0.60	0.60	1.20	7.20	14.86	3.73
F4	20-40	5.1	3.9	1.07	0.182	0.02	0.05	0.60	0.40	1.07	0.60	3.60	4.20	6.00	17.83	7.46

Notes: SOM = soil organic matter, TEB = total exchangeable bases, TEA = total exchangeable acidity, CEC = cation exchange capacity, BS = base saturation, AvP = available phosphorus.

Effect of treatments on cassava root yields

The cassava roots were harvested one year after planting and were measured fresh in the field. The values obtained ranged from approximately 15 t h^{-1} as the least from plots treated with poultry manure only to approximately 39 t ha^{-1} from plots treated with combined poultry and NPK mineral fertilizer. The order of effect was P + NPK > L + P + NPK > L + NPK > P > RNA (Table 3). Compared to the RNA, the values obtained translated to approximately 69%, 140 %, 150%, and 330% higher than the RNA in the order P+NPK > L+P+NPK > L+NPK > P only. The classification of soil chemical characteristics according to the nutritional requirements of cassava (Howeler, 2017), pH values in range 4.5-7 were considered medium. All the pH values obtained before planting were above 5.0 with average of 5.23. This may explain why the response to lime addition to poultry manure and NPK were less than that of P + NPK combined. However, the results clearly showed that addition of nutrients to problematic acid soils of SE Nigeria is necessary to improve their productivity

Table 3: Cassava fresh root averaged over the treatments compared with the national/reference value

Reference National Average (RNA)	Poultry (P) only	L + NPK	L + P + NPK	P + NPK
		t ha^{-1}		
9.0	15.2	21.9	22.5	38.8
% over RNA	68.9	143.3	150.0	331.1

Conclusion

The soils of SE Nigeria are acidic and poor in nutrients yet they are used extensively for cassava production leading to average yield from farmers' field far below world average. To improve the productivity of the soils with respect to cassava production nutrient addition is very necessary and integrated nutrient application including liming is recommended. With integrated nutrient application over 300% increase over reference national yield average of 9.0 t per ha is realizable.

References

Akinwumiju, A.S., A.A. Adelodun and O.I. Orimoogunje, 2020. Agro-Climato-Edaphic Zonation of Nigeria for a Cassava Cultivar using GIS-Based Analysis of Data from 1961 to 2017. *Sci. Rep* 10, 1259. https://doi.org/10.1038/s41598-020-58280-4

Asadu C.L.A 2002. Fluctuations in the characteristics of an important short tropical season, 'august break' in eastern Nigeria. *Discovery and Innovation*. 14 (1&2): 92-101.

Asadu, C.L.A. and F.I. Nweke. 1999. The soils of cassava-growing areas in sub- Saharan Africa. COSCA Working Paper No 18. Collaborative Study of Cassava in Africa. RCMD, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.199pp

Asadu, C. L. A. Nweke, F.I. and A.G. O. Dixon 2007. The contributions of soil properties to cassava yield parameters in sub-Saharan Africa. *Agro-Science* 6 (1): 1-16.

FAO. 2019. The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome. License: CC BY-NC-SA 3.0 IGO.

FAOSTAT, 2020. FAO. 2020. World Food and Agriculture - Statistical

Yearbook 2020, Rome. https://doi.org/10.4060/cb1329en

Howeler, R, 2017. Cassava cultivation and soil productivity Chapter 3 in Achieving sustainable cultivation of cassava Volume 1https://www.researchgate.net/publication/318872608_Cassava_cultivation_and_soil_productivity#fullTextFileContent· July 2017 DOI: 10.19103/AS.2016.0014.25.

IITA (2015). Selected Methods for Soil and Plant Analysis. Manual Series No. 3. International Institute for Tropical Agriculture, Ibadan, Nigeria. 126pp.

Ikechukwu, 2019. Location of Ohebe Orba. https://wikipemap.com/map/314477911_Ohebe_Orba

Keay, R.W.J. 1949. An Outline of Nigerian Vegetation. Government Printer, South Africa, .52pp.

Nwafor, N. O., L.I. Mamah, I. C. Okwara, G. A. Alo, I.T. Okolo, I. T. Ndulue.2017. Geological and geophysical investigation of a late maastrichtian coal seam at Eha-Alumona/Orba environs, Anambra Basin, Nigeria. *Petroleum and Coal*. 59(2): 220-233. https://www.researchgate.net/publication/317027779

Olutosin A O. and S. Barbara. 2019. Cassava, a 21st Century Staple Crop: How can Nigeria Harness its Enormous Trade Potentials? *Acta Scientific Agriculture,* 38:194-202.

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SOIL SALINITY ASSESSMENT AT THE SYSTEM OF RICE INTENSIFICATION (SRI) PLOT OF KADAWA KANO RIVER IRRIGATION PROJECT

M.D. Abdullahi,[1] A.A. Ramalam,[2] M.A. Oyebode,[2] O.J. Mudiare [2] and A. Abdulkadir[3]

[1]Samaru College of Agriculture, Division of Agricultural College, Ahmadu Bello University, Zaria, Nigeria.

[2]Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria, Nigeria.

[3]Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria.

Corresponding Author e-mail: mabdullahi556@gmail.com

ABSTRACT

The presence of high salt content in a soil affects the physiological activities of susceptible crops like rice and interferes with transportation of soluble solutes within the root-zone of the plants. This considerably reduces the rice productivity as well as the positive effect of SRI practice; a system that notably doubles rice productivity by over 50%. Irrigation research farms/sites are well known to accumulate salts over time. The objective of this research is to assess the salinity levels of the selected SRI sites that are under intensive rice cultivation and to point out the possible effect of the selected SRI practices on the soil . The assessment of soil salinity was carried out on a two-year experiment at the Institute for Agricultural Research Irrigation site in Kadawa under the Kano River Irrigation Project (KRIP). Soil samples were randomly collected across all the SRI plots at the depth of 0-15 cm and 15-30 cm representing the possible effective rooting depth of the rice crop. Soil salinity indices were determined using standard laboratory analytical methods. The results obtained showed that the mean value of Electrical Conductivity (EC), Sodium Absorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) were 0.30 dS m^{-1}, 2.1 and 12.0 %, respectively, and these were all within the FAO recommended ranges for irrigated soil and hence, have no restriction on the use. Mean EC value of 0.3 dS m^{-1} can be safely used for crops like corn and rice, on most soils with no likelihood of soil salinity development. The SAR of 2.1 is an indication of low sodium in the soil. However, while the mean effect of the soil chemical properties of the area shows a low level of salinity which is not yet detrimental to SRI practice, the ESP >15% in some of the SRI plot is an indication that the soils are affected by some level of adsorbed sodium. Use of soil with a high ESP value and low salinity can be hazardous and may subsequently reduce the soil infiltration rate. Some leaching may be required in the soil with low permeability. Especially at Kadawa; where soil easily get contaminated as a result of overuse of synthetic fertilizer by the rice farmers and continuous inundation of soil which lack a proper field drainage due to a shallow water table of the area. However, the use of gypsum particularly on the soil surface will help to replace excess sodium in sodic soils with calcium.

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Key words: Soil salinity assessment, System of rice intensification, Electrical conductivity Sodium absorption ratio, Exchangeable sodium percentage.

1.0 INTRODUCTION

The System of Rice Intensification (SRI) was developed as a methodology aimed at increasing the yield of rice produced in irrigated farming without relying on purchased inputs. SRI is a designer innovation that efficiently uses scarce land, labour, capital and water resources, protects soil and groundwater from chemical pollution, and is more accessible to poor farmers than input-dependent technologies that require capital and logistical support (Uphoff, 2002). SRI methods can lead to superior phenotypes and agronomic performance for a diverse range of rice genotypes (Lin *et al*., 2006). Its main elements were assembled in 1983 by the French Jesuit Father **Henri de Laulanie** in Madagascar after 20 years of observation and experimentation (Uphoff *et al*., 2002). Under the pressures from a drought and shortages of rice seeds, he started to experiment at his agricultural school near Antsirabe (1500 m elevation). The experiments initially focused on transplanting very young rice seedlings of just 10-15 days old in a fairly wide spacing (25x25 cm^2) of single seedlings. A square planting pattern was used to facilitate mechanized weeding. The rice was not grown in flooded paddies, but in moist soil, with intermittent irrigation which bring about 25-50% water saving without any adverse effect on rice yield (Tajima, 1995). The incorporation of organic manure into the soil can bring beneficial effects to root growth by improving the physical, chemical and biological environments in which root grow (Sidiras *et al*., 2001; Yang *et al*., 2004). Under such conditions Laulaníe observed tremendous increases in tillering and rooting as well as number of panicles and panicle sizes, contributing to spectacular grain yields (Uphoff *et al*., 2002).

The knowledge of soil quality plays a critical role in successful production of crops and in understanding the management changes that are necessary from time to time and for long term productivity.

Overtime the quality of groundwater is constantly changing in response to daily, seasonal and climatic factors (Ackah *et al.,* 2011). It is more prominent in the arid and semi-arid regions where the salt present in the lower soil profile come up with the ground water, especially when the water table rises within 2 m of soil surface (Maina *et al*., 2012). Generally, the rise in groundwater table, where dissolved salt is brought to the surface may development a serious soil salinity problem in irrigated areas. Soil moisture gets evaporated from the soil surface which subsequently left salt behind, this result in gradual increase in salt concentration on the surface and within the root zone (Maina *et al*., 2012). Soil salinity is the total concentration of soluble salts which may retard and sometimes even prohibit the growth and successful development of crops, making the transportation of solutes quite difficult within the plant. Saline soil contains soluble salts, mostly chlorides and sulphate of sodium, calcium and magnesium, in quantities sufficient to interfere with the physiological activities of most crop plants.

The use of irrigation water for crop production often leads to detrimental effects of salinization on the soil in KRIP, which includes possible salts build up in the soil due to continuous use of irrigation water. Possible physical deterioration of soil including loss of soil structure and reduction in organic matter contents of the soil. Possible increase in salinity and alkalinity levels of irrigation soil could be due to overused of synthetic fertilizer by the farmers. For irrigated agriculture to be efficient and worthwhile the assessment of the soil salinity should be one of the priorities.

Continued use of soil for irrigation activity without careful quality assessment and monitoring give rises to accumulation of salts on the soils and consequently affects the crops potential yield (Maina *et al*., 2012). The objective of this research is to assess the salinity levels of the selected SRI sites that were prior under intensive rice cultivation and to point out any possible effect of the soil on the selected SRI practices.

2.0. MATERIALS AND METHODS

2.1. The study area

The experiment was conducted during 2017/2018 and 2018/2019 irrigation farming season (January, 2018 and January 2019) at the Irrigation Research Station, Kadawa, situated at about 50 km from Kano along the Kano - Zaria high way of Nigeria. The Kano River Irrigation Project lies between latitude 11^0 30' to 12^0 03' N, longitude 80^0 30' to 90^0 40' E and 486 m above sea level within the Hadeja Jama're River Basin, covering an area of about 75, 000 hectares. Irrigation water from Tiga dam on the Kano River comes through a 22.5 km canal by gravity flow to the farms. The dry irrigation period normally runs from November to March, and the main irrigation crop is Rice, wheat, which is grown along with maize, onions, tomatoes and other vegetables. The major types of irrigation systems practiced are basin, furrow and other border systems.

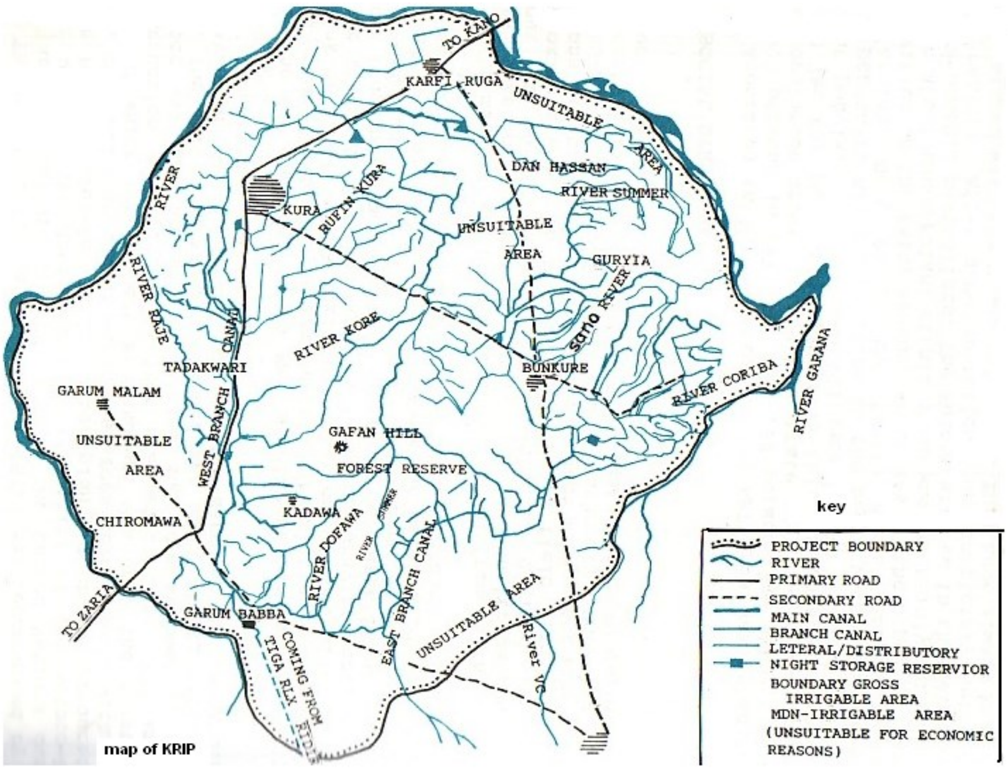

Figure 1: Kano River Irrigation Project (KRIP) Phase I Extension, Nigeria.

2.2. Climatic condition of the study area

The climatic condition is typical of the Sudan savannah ecological zone which divides the years into three distinct periods; the warm rainy season from June to September, the cool dry season from October to February and the hot dry season from March to May. The warm rainy season is the period of precipitation with the highest rainfall in July and August and monthly average of 172mm lasting for maximum period of five months (June to

Sept.). The cool dry season is favourable for the cultivation of many crops from temperate regions such as wheat and various vegetables under irrigation as there is no rainfall during this period. The daily mean air temperature is 26^0c with the maximum value at 42^0c occurring in the month of April/May and minimum of 19^0c in December. The five months period of rainfall and seven months period of dry season allow farmers to have two to three cropping seasons per year using irrigation water and rainfall (Adamu, 2016).

2.3. Soil Condition of the Site

The geology of the project area belongs to the Northern Nigerian complex (NADECO, 1976) which is heterogeneous complex of rocks. The dominant rock types are granitic gneisses and schists. In many places the original material is overlain by alluvial and *Aeolia*n material which resulted into different land forms. Generally, the soils of the project area belong to Eutric Gambisol in FAO/UNESCO system (NADECO, 1976). They are moderately deep and well drained with sandy loam textured surface and sandy clay loam textured subsoil. Most of these soils are under laid by Iron-pan at depth varying between 80-150cm and the whole project area belongs to the Northern Nigeria Basement complex (IAR 1994).

2.4. Data collection and laboratory analysis

Soil samples were randomly collected across all the SRI plots at the depth of 0-15 cm and 15-30 cm representing the possible effective rooting depth of the rice crop. The soil samples were collected using soil auger and conventional core sampler for determining the quality indicators. The soil samples were taken to the laboratory and solutions were filtered for soil salinity analysis. The soil pH was determined using a glass electrode pH meter as described by Kenkel (2013); whereas EC soil extraction by the use of conductivity meter as per methods described by Li and Migliaccio (2010), Exchangeable bases (Ca, Mg, K, Na) or cations and ESP were determined from saturated paste extract; this test package includes extraction of soils with ammonium acetate (NH_4OAc) to measure exchangeable cations and ESP. HCO_3 and Cl were analyzed by titration with standard HCl and $AgNO_3$, respectively. $SO4^{2-}$ was determined using a turbidimetric procedure. NO_3 was analyzed using colorimetric method. Total hardness (TH), ESP and SAR were determined using the following relation:

$$TH = 2.497\,(Ca) + 4.118\,(Mg) \quad (1)$$

$$ESP = \left(\frac{Na}{Na+Ca+Mg+K}\right) \times 100 \quad (2)$$

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad (3)$$

Introduction

The importance of cassava (*Manihot esculenta* Crantz) in the food system of the world particularly in sub-Saharan Africa is well known. Apart from being a food security crop in the sub-region, cassava is grown widely because it tolerates acid soils with low pH and high levels of exchangeable Al and low levels available P; hence it is often grown as the last crop in the production cycle in slash-and-burn systems, just before the field reverts back to bush fallow to recuperate its productivity (Howeler, 2017). Over the past 20 years, the area planted to cassava has increased at a faster rate than that of any other food crop, while total production increased faster than any other crop except for maize. But it has the reputation to degrade the soil by excessive absorption of nutrients and their removal in the harvested products. An average yield of 15 t ha^{-1} of fresh roots with the removal of all plant parts from the field has been reported to remove per ha about 93 kg N, 12 kg P, 81 kg K, 42 kg Ca and 13 kg Mg (Howeler, 2017). This implies that without application of fertilizers or manures, cassava yields will almost invariably decline when the crop is grown continuously for many years on the same field.

From ANOVA table 3; the computed t-statistics of 0.056 of the soil parameters at different sampling point are less than the tabulated value of 1.79, which implies that the difference between soil parameters are not significant at 5% probability level of significance. This suggests that the difference in soil parameters is apparent, that is, it might be due to chance.

3.2. Soil Salinity Measurements

Saline soils are characterized by high concentrations of salts such as (Na^+, K^+, $Ca^{2+,}$ $Mg^{2+,}$ Cl^-SO4^{--}, CO_3^-, and HCO_3^-), but the predominant salts are Ca^{2+} and $Mg^{2+.}$ High salts concentrations increase electric conductivity (EC) to >4 dS/m. The concentration of 4 ds/m measured from soil paste extract is established as the dividing line between salinity and non-salinity in soils. High salinity may lead to white crust formation on the soil surface. In addition, salinity has effects on soil to water and plant to water relationships, and the high level of salts in soil cause osmotic stress to plants, leading to reduce growth plants and productivity (Horneck *et al*., 2007). However, the results displayed in Tables 1 and 2 show that, most of the parameters were within the range that is not likely to cause harm to the crops.

3.4. Electrical Conductivity (EC) / Total Soluble Salts (TSS)

EC is the measure of the ability of soil to conduct electricity while TSS Refer to the total amount of soluble salts in a soil saturated paste extract. A linear relationship exists between TSS and EC within a certain range that can be useful to closely estimate soluble salts in a soil saturated paste extract. According to the U.S. Salinity Laboratory Staff (1954) a saline soil has an EC of the saturated extract of more than 4 ds/m (TSS >2560mg/l), a value that corresponds to approximately 40 mmol salts per litre. However, in term of EC and TSS, the current study recorded a mean value of 0.3 ds/m and 189.76 mg/l respectively which is far away from the permissible value (see table 4 and 5). Mean EC value of 0.3 dS m^{-1} can be safely used for crops like corn and rice, on most soils with no likelihood of soil salinity development.

3.3. Sodium Absorption Ratio (SAR):

Is a widely accepted index for characterizing soil sodicity. Sodic soils have a high level of exchangeable Na^+ which is the dominant cation on the exchange complex. The dispersed clay and silt particles are washed into pores, and reduce air permeability and water infiltration. Usually pH in these soils is >8.5 as a result of hydrolysis of Na_2CO_3 or exchangeable Na^+. In addition, these soils are characterized by slaking and dispersion on wetting and massive hard-setting on drying (Horneck *et al.,* 2007). However, saline-sodic soils are characterized by high soluble salts and high exchangeable Na^+ (Bohn *et al*., 2001), but have a good soil structure and adequate movement for water and air (Horneck *et al*., 2007). The pH of the soils in the study area is less than 8.5% because the soluble salts prevent hydrolysis. The main problem in these soils is occurred as a result of leaching.

When SAR is greater than 13, the soil is called a sodic soil (see table 4). Excess sodium in sodic soils causes soil particles to repel each other, preventing the formation of soil aggregates. This results in a very tight soil structure with poor water infiltration, poor aeration and surface crusting, which makes tillage difficult and restricts seedling emergence and root growth (Horneck *et al*., 2007). The SAR of 2.1 was recorded from the study area which is an indication of low sodium in the soil. The most common characteristics of salt-affected soil is represented in Table 4

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3.0. RESULTS AND DISCUSSION

Table 1: Average Soil Salinity of Kadawa Station, Kano during 2017/2018 and 2018/2019 Irrigation Seasons

Parameters		**Sampling Points**											
	Units	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**	**T_7**	**T_8**	**T_9**	**T_{10}**	**T_{11}**	**T_{12}**
pH	-	6.03	6.98	7.34	6.455	6.185	6.91	6.915	6.335	6.7	7.185	7.22	6.06
EC	(ds/m)	0.253	0.255	0.403	0.311	0.198	0.273	0.421	0.461	0.209	0.270	0.243	0.263
TDS	(mg/l)	161.92	163.2	257.6	198.72	126.72	174.72	269.44	295.04	133.76	172.8	155.2	168
Ca^{++}	(mg/l)	84.08	89.2	108.97	76.32	90.52	74.82	95.17	88.97	123	97.7	81.1	97.59
Mg^{+}	(mg/l)	34.2	43	33.8	61.4	49.6	37.5	40.7	52.3	65.0	33.0	39.0	50.2
Na^{+}	(mg/l)	23.32	19.3	24.18	20.08	20.38	16.08	16.48	25.18	26	22.8	17.52	22.4
K^{+}	(mg/l)	10.94	18.1	17.71	6.26	21.86	13.24	9.31	10.71	21.5	8.6	10.8	13.56
Cl^{-}	(mg/l)	74.6	110	79.75	60.3	74.4	72.9	58.65	79.65	101	42.5	55.5	77.1
CO_3	(mg/l)	1.101	0.013	0.011	0.180	0.325	0.782	0.371	0.433	0.474	0.368	0.141	0.111
$H\ CO_3$	(mg/l)	68.535	98.21	100.71	79.785	59.29	84.95	106.1	73.16	74.225	107.47	93.96	68.72
SO_4^{-2}	(mg/l)	10.2	15.92	7.32	13.9	8.08	10.25	9.18	5.66	5.32	9.82	8.64	16.77
NO_3^{-2}	(mg/l)	11.85	8.22	11.66	13.16	7.87	7.26	16.43	11.78	8.28	3.92	4.86	6.18
TH	(mg/l)	350.79	399.8	411.29	443.42	430.28	341.25	405.24	437.53	574.8	379.85	363.11	450.4
SAR	-	2.48	1.99	2.305	2.055	2.04	1.835	1.695	2.46	2.195	2.295	1.92	2.15
ESP	(%)	15.295	11.385	13.025	12.345	10.53	11.395	10.05	14.195	10.78	14.18	11.925	12.15
Total		855.59	985.57	1076.1	994.69	908.28	854.17	1046.2	1103.9	1153.2	902.76	851.14	991.6

Grand total (G) = $855.59 + 985.57 + 1076.1 + 994.69 + 908.28 + 854.17 + 1046.2 + 1103.9 + 1153.2 + 902.76 + 851.14 + 991.60$ = 11723.11

Table 2: Descriptive statistics of the soil parameters of Kadawa Station, Kano during 2017/2018 and 2018/2019 Irrigation Seasons

Parameters	Units	N	Range	Minimum	Maximum	Mean	SE	Std. Deviation	CV (%)
pH (H_2O)	-	12	1.46	5.88	7.34	6.68	0.146	0.504	0.254
EC	(ds/m)	12	0.26	0.20	0.46	0.30	0.025	0.085	0.007
TDS	(mg/l)	12	161.28	133.76	295.04	189.76	15.776	54.651	2986.747
Calcium (Ca^{++})	(mg/l)	12	48.18	74.82	123.00	92.29	3.954	13.697	187.595
Magnesium (Mg^{+})	(mg/l)	12	32.0	33.00	65.00	44.98	3.103	10.750	115.569
Sodium (Na^{+})	(mg/l)	12	9.92	16.08	26.00	21.14	0.968	3.355	11.254
Potassium (K^{+})	(mg/l)	12	15.6	6.26	21.86	13.55	1.478	5.121	26.221
Cl^{-}	(mg/l)	12	67.5	42.50	110	73.86	5.407	18.730	350.810
Carbonate (CO_3^{-})	(mg/l)	12	1.09	0.01	1.10	0.36	0.093	0.321	0.103
Bicarbonate ($H\,CO_3^{-}$)	(mg/l)	12	48.18	59.29	107.47	84.59	4.712	16.322	266.409
Sulphate (SO_4^{-2})	(mg/l)	12	11.45	5.32	16.77	10.09	1.067	3.696	13.660
Nitrate (NO_3^{-2})	(mg/l)	12	12.51	3.92	16.43	9.29	1.069	3.702	13.706
TH	(mg/l)	12	233.55	341.25	574.80	415.64	17.872	61.909	3832.731
SAR	-	12	1.92	2.48	2.48	2.12	0.070	0.242	0.058
ESP	(%)	12	5.25	10.05	15.30	12.27	0.468	1.622	2.631

Table 3: General ANOVA Summary Table for the soil parameters at different sampling point of Kadawa Station, Kano

Source of Variation	Degree of freedom (df)	Sum of Squares (SS)	Mean squares (MS)	Computed F_c	Tabular (F_t)
					5%
Treatment	11	7883.8	716.71	0.056	
Error	162	2161190	12,864.23		1.79
Total	173	2169073.8			

3.5. Exchangeable Sodium Percentage (ESP)

Is another index that characterizes soil sodicity. By definition, sodic soil has an ESP of >15% (see table 4). However, while the mean value of ESP in the study area was recorded as 12.3% which is not yet detrimental to SRI practice, the ESP >15% in some of the SRI plot is an indication that the soils are affected by adsorbed sodium. Use of soil with a high ESP value and low salinity can be hazardous and may subsequently reduce the soil infiltration rate.

Table 4: Classification of Salt-affected Soil using the Saturated Paste Extraction

Class	EC (ds/cm)	SAR (%)	ESP (%)	pH	structure
Non saline-non sodic	Below 4.0	Below 13	Below 15	Below 8.5	Good
Saline	Above 4.0	Below 13	Below 15	Below 8.5	Good
Sodic	Below 4.0	Above 13	Above 15	Above 8.5	Poor
Saline-Sodic	Above 4.0	Above 13	Above 15	Above 8.5	Fair to Good

Source: adopted from United States Salinity Laboratory Staff, (1954); Horneck *et al*., (2007).

Table 5: Soil Salinity Classes and Crop Growth

Soil Salinity Class	Conductivity of the Saturation Extract (ds/m)	Effect on Crop Plants
Non Saline	0-2	Salinity effect negligible
Slightly Saline	2-4	Yields of sensitive crops may be restricted
Moderately Saline	4-8	Yields of many crops are restricted
Strong Saline	8-16	Only tolerant crops yield satisfactorily
Very Strong Saline	>16	Only a few very tolerant crops yield satisfactorily

Source: fao.org

4.0. CONCLUSION AND RECOMMENDATION

The results obtained showed that the mean value of Electrical Conductivity (EC), Sodium Absorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) were 0.30 dS m^{-1}, 2.1 and 12.3 %, respectively, and these were all within the FAO and NSCS recommended ranges for irrigated soil and have no restriction on the use. Mean EC value of 0.3 dS m^{-1} can be safely used for crops like corn and rice, on most soils with no likelihood of soil salinity development. The SAR of 2.1 is an indication of low sodium in the soil. However, while the mean effect of the soil chemical properties of the area shows a low level of salinity which is not yet detrimental to SRI practice, the ESP >15% in some of the SRI plot indicate soils are affected by adsorbed sodium. Use of soil with a high ESP value and low salinity can be hazardous and may subsequently reduce the soil infiltration rate. Some leaching may be required in the soil with low permeability. Especially at Kadawa; where soil can easily get contaminated as a result of overuse of synthetic fertilizer by the rice farmers and continuous inundation of soil which lack a proper field drainage due to a shallow water table of the area. However, the use of gypsum particularly on the soil surface will help to replace excess sodium in sodic soils with calcium.

REFERENCES

Ackah M., Osel. J., Anim A. and Gyambi E.T. (2011). Assessment of Ground Water Quality for Drinking and Irrigation: The Case Study of Teiman-Oyarifa Community, Ga East Municipality, Ghana.

Adamu I.A. (2016): Simulation of Soil Water Balance Response to Water Stress and Yield of a Furrow Irrigated Tomato Using Aqua-crop. Unpublished PhD Dissertation in the department of Agricultural Engineering, Ahmadu Bello University, Zaria, Nigeria.

Bohn HL, McNeal BL, O'Connor GA. (2001) Salt affected soils. In: *Soil Chemistry.* 3rd ed. John Wiley & Sons Inc.

Horneck D.A., Ellsworth J.W., Hopkins B.G., Sullivan D.M., Steven R.G. (2017) managing Salt Affected Soil for Crop Production. A Pacific Northwest Extention Publication. Oregon State University-University of Idabo- Washington State University.

IAR, (1994). Farmer-Managed Irrigation System: A Diagnostic Analysis of Large Scale Irrigation Projects in Nigeria. Final Technical Report (Phase-I). Institute for Agricultural Research (IAR) ABU Zaria, Nigeria Ford Foundation Grant No. 870-873.

Kenkel j., (2013) Analytical Chemistry for Technicians, Fourth Edition, CRC Press, Taylor and Francis Group, Unitate States.

Lin, X. Q., W. J. Zhou, D. F. Zhu and Y. P. Zhang (2006). Effect of shallow water depth (SWD) irrigation on photosynthesis and grain yield of rice (Oryza sativa L.). Field Crops Research 94: 67–75.

Li Y. and Migliaccio K. (2010) Water Quality Concepts, Sampling and Analyses. First Edition, CRC Press, Taylor and Francis Group, Boca Raton, Unitate States.

Maina M. M., Amin M. S. M., Aimrun W and Sani I (2011). Soil Salinity Assessment of Kadawa Irrigation of the Kano River Irrigation Project (KRIP). Department of Biological and Agricultural Engineering, Faculty of Engineering, University Putra Malaysia, 43400 Serdang Selangor, Malaysia.

NEDECO, (1976). Kano River Irrigation Project, (KRIP) Main Report. Part VIII. Ministry of Agriculture and Natural Resources, Kano, Nigeria, pp: 63.

Sidiras, N., D. Bilalis and E. Vavoulidou (2001). Effect of tillage and fertilization on some selected physical properties of soils (0-30 cm depth) and on the root growth dynamic of winter barley (*Hordeum vulgare* cv. Niki). Journal of Agronomy and Crop Science 187: 167-176.

Tajima, K. (1995). Occurrence and mechanism of drought damage. *In* : T. Matuso, K. Kumazawa, R. Ishii, K. Isihara and H. Hitara (eds.) Science of the rice plant. Physiology. Food and Agriculture Policy Research Center, Tokyo, Japan. pp. 838-849.

Uphoff, N. and Randriamiharisoa (2002). Changes and evolution in SRI methods. In: Assessments of the System of Rice Intensification.

Proceedings of an international conference, Sanya China, April 1-4

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PERFORMANCE OF SOME SELECTED WATER INFILTRATION MODELS IN SANDY LOAM SOILS AS AFFECTED BY SELECTED SYSTEM OF RICE INTENSIFICATION PRACTICES AT KADAWA, KANO RIVER IRRIGATION PROJECTS

M.D. Abdullahi,[1] A.A. Ramalam,[2] M.A. Oyebode,[2] O.J. Mudiare [2] and A. Abdulkadir[3]

[1] Samaru College of Agriculture, Division of Agricultural College, Ahmadu Bello University, Zaria, Nigeria.

[2]Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria, Nigeria.

[3] Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria.

ABSTRACT

Realistic planning towards water management and conservation activities such as irrigation and control of flood and erosion requires sufficient information on the rate at which different soils take up water under different conditions. In this study, eight (8) water infiltration models; which encompasses: four (4) empirical model (Philip (PH), Kostiakov (KT), Modified Kostiakov (MK), and Kostiakov-Lewis (KL); two (2) semi – empirical model (Swartzendruber (SW) and Horton (HT)) and two (2) physically based model (Green-Ampt (GA) and Smith & Parlange (SP); were evaluated for soils under SRI, to determine which models accurately predicted the measured cumulative infiltration. The study was carried out at Kadawa, Kano River Irrigation Project. A field size of 225 m^2 (15m by 15m) was divided into two sub- plots (7.5m by 7.5m); 1A and 1B of control plot. Another plots of same size; 2A and 2B from the total area of 4000m^2 (100 m × 40 m) under SRI was also used. Farm yard manure was applied to the total plot area of 4000m^2 (100 m × 40 m) under SRI at SRI recommended rate of 12.5 tons per hectare (t ha^{-1}). The two plots were later harrowed in order to lose the top soil to a depth of at least 20 cm. One week after the application of farm yard manure; infiltration runs were made using the double ring infiltrometer from 3 points on each sub-plots, and the tests was repeated twice i.e. after first SRI irrigation season (2018) and second SRI irrigation season (2019). Mean results of the first iteration (Plot1A and 2A) were used for the models parameters estimation, and the second mean values from Plot 1B and 2B were used to validate the models performance. With respect to the values of coefficient of residual mass (CRM) four (4) models PH>KT>KL>MK seem to be over-predicting and the remaining four (4) models SW>SP>HT>GA under-predicting the cumulative infiltration in descending order of accuracy. However, with respect to Root Mean Square Error (RMSE), the performance of the models were ranked from best to worst thus: MK > GA > KL > KT> PH > HT >SP >SW with Modified Kostiakov's model having the overall best performance followed by Grent Ampt and Kostiakov Lewis while Swartzendruber was recorded as the worst in term of performance followed by Smith & Parlange, Philip, Horton and Kostiakov models. The use of the model equations derived in this study is best applied to irrigation works where there is ponding such as border and basin irrigation. The usefulness of this infiltration model can be used to design and carefully plan irrigation projects anywhere.

Key words: *Water Infiltration Models, Sandy Loam Soil, System of Rice Intensification (SRI)*

• Corresponding e-mail: mabdullahi556@gmail.com

1.0. INTRODUCTION

System of Rice Intensification (SRI) is a new system of rice cultivation for increasing rice yield (35-100%) with a comprehensive package of practices involving the use of less seed, water, chemical fertilizers and pesticides. SRI practice also aim to enrich soil with organic matter at 10-15t/ha in order to keep it well-aerated to support better growth of roots, inducing larger and better-functioning ***root systems***, as well as more abundant, diverse and active communities of ***soil biota*** that live in association with those root systems (Randriamiharisoa *et al.,* 2006). In SRI practice, the use of organic manure such as; leguminous plants, cow dung, poultry litter, compost, goat yard manure, mushroom, rice husk, wood ash etc. helps and enable the flow of water and nutrients at optimal levels within the root zone depth of plants to achieve high plant growth, yield and yield quality of crops. Moreover, when soils are amended, water infiltration rate is affected amongst other physical properties (Ajayi, 2014).

Water infiltration is the process of water movement from the ground surface into the soil and it is an important component in the hydrological cycle (Haghiabi *et al*., 2011). Infiltration has received a great deal of attention from soil and water scientists/engineers because of the fundamental role of infiltration characteristics in land-surface and subsurface hydrology, irrigation and agriculture, water infiltration into soil is a function of the physical properties of soils, primarily initial soil water content and soil saturated hydraulic conductivity, soil texture and structure, vegetation, and plant root density (Mishra *et. al.,* 2003). Infiltration characteristics of soils can be quantified by direct measurement on the field and/or when field infiltration data are fitted mathematically to infiltration models (Oku and Aiyelari, 2011). Lili *et al.,* (2008) reviewed the commonly used direct methods for measuring soil infiltration which include: single ring and double ring infiltrometers, mariotte-double ring infiltrometer, disc permeameter, rainfall simulator, runoff-on-ponding, runoff-on-out and linear source methods, the results obtained from field infiltration test and soil analysis are used for infiltration modeling.

Infiltration modeling approaches are often separated into three categories: physically based, semi-empirical (analytical), and empirical models. The physically based approaches use parameters that can be obtained from soil water properties and do not require measured infiltration data. The evaluation of semi-empirical models are purely mathematical or graphical, it is called semi-empirical because their evaluation process involves the use of the asymptomatic or steady state infiltration capacity unlike the physically based models that depends strictly on soil water characteristics. Empirical models tend to be less restricted by assumptions of soil surface and soil profile conditions, but more restricted by the conditions for which they were evaluated, since their parameters are determined based on actual field-measured infiltration data (Hillel, 1998; Skaggs and Khaleel, 1982).

Infiltration is a key dynamic process during irrigation events to be considered for irrigation system design, irrigation scheduling, and irrigation system optimization and management (Cuenca, 1989). Although several water infiltration models are in existence, their suitability under specific conditions like those of soils amended with organic manure is not well known (Ajayi, 2014). Therefore, sufficient information on the rate at which different soils take up water under different conditions is required for the realistic planning of water management and conservation activities such as irrigation and control of flood and erosion. It is expected that under particular conditions, one equation will provide better predictions for infiltration than another. This need to be spelt out with definite boundary conditions which equation performs better for different conditions so that they can easily be applied in irrigation and drainage systems design and management (Ajayi, 2014). It is therefore imperative to validate existing models and identify those which best suits specific field conditions. The objective of this study was to study and evaluated eight (8) water infiltration models for soils under SRI in order to determine which model accurately predicted the measured cumulative infiltration and give recommendations.

2.0. MATERIALS AND METHODS

2.1. The study area:

The experiment was conducted during 2017/2018 and 2018/2019 irrigation farming season (January, 2018 and January 2019) at the Irrigation Research Station, Kadawa, situated at about 50 km from Kano along the Kano - Zaria high way of Nigeria. The Kano River Irrigation Project lies between latitude 11^0 30' to 12^0 03' N, longitude 80^0 30' to 90^0 40' E and 486 m above sea level within the Hadeja Jama're River Basin, covering an area of about 75, 000 hectares. Irrigation water from Tiga dam on the Kano River comes through a 22.5 km canal by gravity flow to the farms. The dry irrigation period normally runs from November to March, and the main irrigation crop is Rice, wheat, which is grown along with maize, onions, tomatoes and other vegetables. The major types of irrigation systems practiced are basin, furrow and other border systems. The climatic condition is typical of the Sudan savannah ecological zone which divides the years into three distinct periods; the warm rainy season from June to September, the cool dry season from October to February and the hot dry season from March to May. The warm rainy season is the period of precipitation with the highest rainfall in July and August and monthly average of 172mm lasting for maximum period of five months (June to Sept.). The cool dry season is favourable for the cultivation of many crops from temperate regions such as wheat and various vegetables under irrigation as there is no rainfall during this period. The daily mean air temperature is 26^0c with the maximum value at 42^0c occurring in the month of April/May and minimum of 19^0c in December. The five months period of rainfall and seven months period of dry season allow farmers to have two to three cropping seasons per year using irrigation water and rainfall (Adamu, 2016). The geology of the project area belongs to the Northern Nigerian complex (NADECO, 1976) which is heterogeneous complex of rocks. The dominant rock types are granitic gneisses and schists. In many places the original material is overlain by alluvial and *Aeolia*n material which resulted into different land forms. Generally, the soils of the project area belong to Eutric Gambisol in FAO/UNESCO system (NADECO, 1976). They are moderately deep and well drained with sandy loam textured surface and sandy clay loam textured subsoil. Most of these soils are under laid by Iron-pan at depth varying between 80-150cm and the whole project area belongs to the Northern Nigeria Basement complex (IAR 1994).

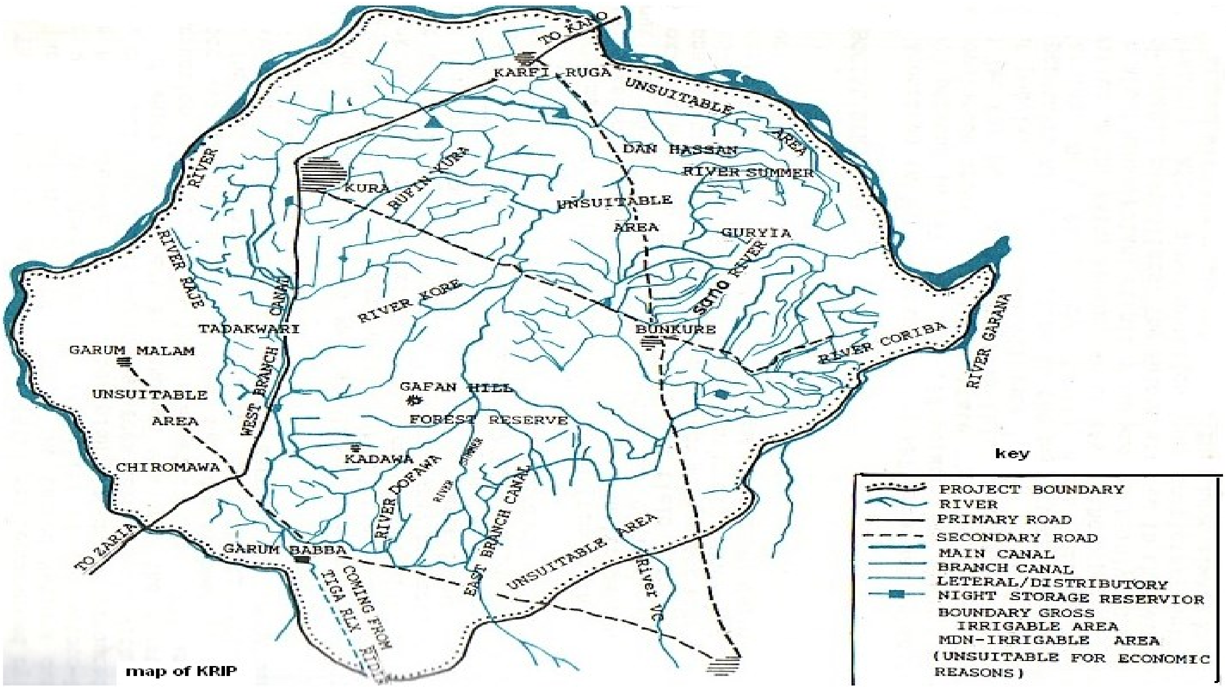


Figure 1: Kano River Irrigation Project (KRIP) Phase I Extension, Nigeria.

2.2. Field Layout

The study was carried out at Kadawa, Kano River Irrigation Project. A field size of 225 m^2 (15m by 15m) was divided into two sub-plots (7.5m by 7.5m); 1A and 1B of control plot. Another plots of same size; 2A and 2B from the total area of 4000m^2 (100 m × 40 m) under SRI was also used. Farm yard manure was applied to the total plot area of 4000m^2 (100 m × 40 m) under SRI at SRI recommended rate of 12.5 tons per hectare (t ha^{-1}). The two plots were later harrowed in order to lose the top soil to a depth of at least 20 cm. One week after the application of farm yard manure; infiltration runs were made using the double ring infiltrometer from 3 points on each sub-plots, and the tests was repeated twice i.e. after first SRI irrigation season (2018) and second SRI irrigation season (2019). Mean results of the first iteration (Plot1A and 2A) were used for the models parameters estimation, and the second mean values from Plot 1B and 2B were used to validate the models performance.

2.3. Infiltration Measurement

The double ring infiltrometer method was used for the infiltration test. The infiltrometer consisted of two rings, outer ring of 40 cm diameter and 40 cm height, and the inner ring 30cm diameter and 40 cm height. The two rings were place in an eccentric position (i.e. the small ring inside and approximately in the middle of the larger ring) on the soil. The two rings were driven into the soil by placing the driving cap on top of them and hitting them with a mallet as to allow simultaneous movement of the rings into the soil, which was stopped at a desired depth. Fresh leaves were placed into the outer and inner rings when pouring water into the rings to prevent soil disturbance. The rings were filled with water with the inner ring to the top and the outer one almost to the top. A stop watch and ruler were used to monitor the desired time and height or depth of water in the inner ring as the water infiltrate into the soil layer. Readings were taken and recorded for the following time interval 5, 10, 15, 25, 35, 45, 60, 90, and 120 minutes.

After three (5) minutes, the drop in water level in the inner ring was recorded on the measuring rod and water added to bring the level back to approximately the original level at the start of the test. The water level outside the ring was maintained similar to the one inside. Test was repeated after 2017/2018 irrigation session and 2018/2019 irrigation session after the incorporation of the farm yard manure **and** infiltration runs were made from 3 points on each sub-plots, and the tests was repeated twice i.e. after first SRI irrigation season (2018) and second SRI irrigation season (2019). The cumulative infiltration depth at the elapsed time was recorded.

2.4. Estimation of Model Parameters

In assessing the performance of the selected models; the parameters of each model was first determined. For each sub-plot(in Plot1A and 2A) the average of the result of three infiltration run was used for model's parameter evaluation and the second average values from Plot 1B and 2B were used to validate the models performance.

2.5. Kostiakov's Equation

The functional relationship between cumulative infiltration *I*, and time *t*, has been given by equation 1.0. The plot of *I* against *t* on a Log-Log graph gives *k* as the intercept of the graph and *a* as the slope. The values of *a* and *k* were now substituted into equations 1.0 and 2.0 at the different elapsed time to get the model generated cumulative infiltration and infiltration rate respectively.

$$I = kt^{a} \qquad [1.0]$$

$$i = akt^{a-1} \qquad [2.0]$$

2.6. Modified Kostiakov Equation

The parameters (*b*, *k* and *a)* of the Modified Kostiakov equation (Eq.3.0) were determined by the method of averages suggested by Davis (1943). First, the cumulative infiltration I was plotted against time (t). The rectifying factor b was obtained by picking two points (t_1, I_1) and (t_2, I_2) arbitrarily from the graph of I against t, on and near the extremes of the smooth curve representing the data. After which, $t_3=\sqrt{t_1 x\, t_2}$ was calculated and $I_3$was read against t_3. The value of b was then determined by using equation 4.0. The value of *b* was subtracted from each value of *I*, to get the rectified cumulative infiltration, the Log-Log plot of the rectified I and elapsed time t, gave *k* as the intercept of the graph and *a* as the slope. The values of *b*, *k* and *a* are now substituted into the equations 3.0 and 5.0 at the different elapsed time to get the model generated cumulative infiltration and infiltration rate respectively.

$$I = kt^{a} + b \qquad [3.0]$$

$$b = \frac{I_1 x\, I_2 - I_3^2}{I_1 + I_2 - 2I_3} \qquad [4.0]$$

$$i = akt^{a-1} \qquad [5.0]$$

2.7. Green and Apmt's Equation

The parameters for the GA equations (Eq. 6.0 and 7.0) were obtained as follows: ΔΘ was obtained by taking the difference between the initial and final moisture content; suction at the wetting front also known as the matric potential was obtained with the formula by Rawls, 1992:

$$i = k_s\left[\frac{\psi\Delta\theta}{I} + 1\right] \qquad [6.0]$$

$$I = k_s t + \psi\Delta\theta\ell\text{n}\left[1 + \frac{I}{\psi\Delta\theta}\right] \qquad [7.0]$$

$$\psi = \exp[6.5309 - 7.32561.\emptyset + 0.001583.C^2 + 3.809479.\emptyset^2 + 0.000344.SC - 0.04989S\emptyset + 0.00165S^2\emptyset^2 + 0.0016C^2\emptyset^2 - 0.0000136S^2C - 0.00348C^2\emptyset + 0.0007995S^2\emptyset]. \qquad [8.0]$$

Where: C is % clay content, S is % sand content, Ø is Porosity

The cumulative infiltration was first calculated by the method of iteration (trial and error) since the value I appears in both the right hand and left hand side of the equation, a suitable assumed value of I was substituted into the equation until the right hand side and the left hand side became the same values, same procedure was done for the time elapsed. The value of I was substituted to get the infiltration capacity.

2.8. Philip's Equation

The fitting parameters S and A for Philip's equation were evaluated and used to simulate cumulative infiltration and infiltration rate by obtaining a linear plot of the transformed cumulative infiltration $It^{-0.5}$ ($cm/hr^{-0.5}$) versus the transformed time $t^{-½}$ was plotted, the slope of the graph represents the parameter A and the intercept is the Sorptivity (S). S and A were then substituted into Eqn 9.0 and 10.0 to obtain the cumulative infiltration and infiltration rate respectively.

$$I = S\sqrt{t} + At \quad [9.0]$$

$$i = \frac{S}{2\sqrt{t}} + A \quad [10.0]$$

2.9. Horton's Equation

The parameters of Horton's equation (Eq.11.0) were obtained by first obtaining a linear plot of i against t, from which f_0 and f_c the initial and final infiltration rate were read. Changing the equation to the form of *linear equation*, the logarithm of both sides of the equation becomes: $ln\left(\frac{i-f_c}{f_0-f_c}\right) = -kt$, the linear plot of $ln\left(\frac{i-f_c}{f_0-f_c}\right)$ versus time (t) gives us the value of k as the slope of the graph. Then the parameters f_c, f_0 and k were substituted into equations 11.0 and 12.0 to get the infiltration rate and cumulative infiltration respectively.

$$i = f_c + (f_0 - f_c)e^{-kt} \quad [11.0]$$

$$I = f_c t + \frac{f_0-f_c}{k}[1 - e^{-kt}] \quad [12.0]$$

2.10. Kostiakov-Lewis Equation

The relationship between infiltration, I, and time, t, as given by Kostiakov-Lewis is given by the equation 13.0. The plot of $(I - f_c t)$ against t on a Log-Log graph or Log I versus Log t on a linear scale gives k as the intercept of the graph and a as the slope. The infiltration rate at any time, t, after the beginning of the test was obtained with equation 14.0. The values k, f_c and a are now substituted into the equations to get the model generated cumulative infiltration.

$$I = kt^a + f_c t \quad [13.0]$$

$$i = akt^{a-1} + f_c \quad [14.0]$$

2.11. Swartzendruber Equation

The parameters of Swartzendruber equation are: f_c, c and d, the value of f_c obtained from Horton's equation was substituted directly with the field measured I and t into equation 15.0, equations containing two variables c and d are obtained depending on the time interval. Thirteen equations were obtained in all, the first seven were added to make one equation and the remaining six were also added according to a method suggested by Michael (1978) for solving analytical equations, two equations were obtained, solving them simultaneously gives us the values of c and d these values were now substituted into equation 15.0 and 16.0 to get the cumulative infiltration and infiltration capacity.

$$I = f_c t + \frac{c}{d}[1 - \exp(-dt^{0.5})] \quad [15.0]$$

$$i = f_c + \frac{c}{2} * \frac{e^{-d\sqrt{t}}}{\sqrt{t}} \quad [16.0]$$

2.12. Smith & Parlange Equation

Smith and Parlange (1978) equation is a physically based equation which closely resembles the Green-Ampt equation in its derivation, to obtain the cumulative infiltrated depth and the corresponding infiltration capacity at the time, the values of saturated hydraulic conductivity k_s, average suction force at the wetting front S_{av}, initial moisture deficit M or $\Delta\theta$ and observed asymptotic/steady state infiltration rate are substituted into equation

17.0 and 18.0, the evaluation is done by iteration same as in Green-Ampt.

$$I = k_s t \left[\frac{C_o}{k_s I} + 1\right]$$
[17.0];

$$i = k_s \left[\frac{C_o}{k_s I} + 1\right]$$
[18.0]

2.13. Model Validation

In order to prove the performance of the models and their parameters, each model was validated by comparing their simulated data with field measured data. The validation of the models was done using: RMSE (root mean square error), R^2 (coefficient of determination), CRM (coefficient of residual mass), MAE (Mean absolute error) and Nash-Suctlife efficiency index. RMSE and MAE criteria are more related to precision; their values decreases with increasing precision (Mahdian and Gallichand 1995). r^2 provides a measure of how well observed outcomes are replicated by the model (Steel and Torrie 1960), it ranges from 0 to 1. The Nash–Sutcliffe efficiencies range from −∞ to 1. An efficiency of 1 corresponds to a perfect match between predicted data and the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, the closer the model efficiency is to 1; the more accurate the model is (Nash and Sutcliffe 1970).The CRM is a measure of the tendency of the model to overestimate or underestimate the measurements. Positive values for CRM indicate that the model underestimates the measurements and negative values for CRM indicate a tendency to overestimate (Hagi-Bishow and Bonnell 2000). For a perfect agreement between observed and predicted cumulative infiltration, values of RMSE, CRM, r^2, MAE and Modelling Efficiency (E) should equal 0.0, 0.0, 1.0, 0.0 and 1.0 respectively. Their respective equations are shown below:

$$R^2 = \frac{\sum_{i=1}^{n}(O_i - \tilde{O})^2}{\sum_{i=1}^{n}(P_i - \tilde{O})^2}$$
[19.0]

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}}$$
[20.0]

$$E = 1 - \left[\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \tilde{O})^2}\right]$$
[21.0]

$$CRM = \frac{\sum_{i=1}^{n}(O_i - P_i)}{n\tilde{O}}$$
[22.0]

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|P_i - O_i|$$
[23.0]

Where: Pi = predicted values, Õ = mean of the observed data, Oi = observed values, n = number of samples.

3.0. RESULTS AND DISCUSSION

The cumulative infiltration and infiltration rate obtained from the field are shown in Table 1 and 2, which represent the mean results of Plot1A and 2A; used for the models parameters estimation, and the second mean values from Plot 1B and 2B used in models validation.

Table 1: Infiltration characteristics for model evaluation

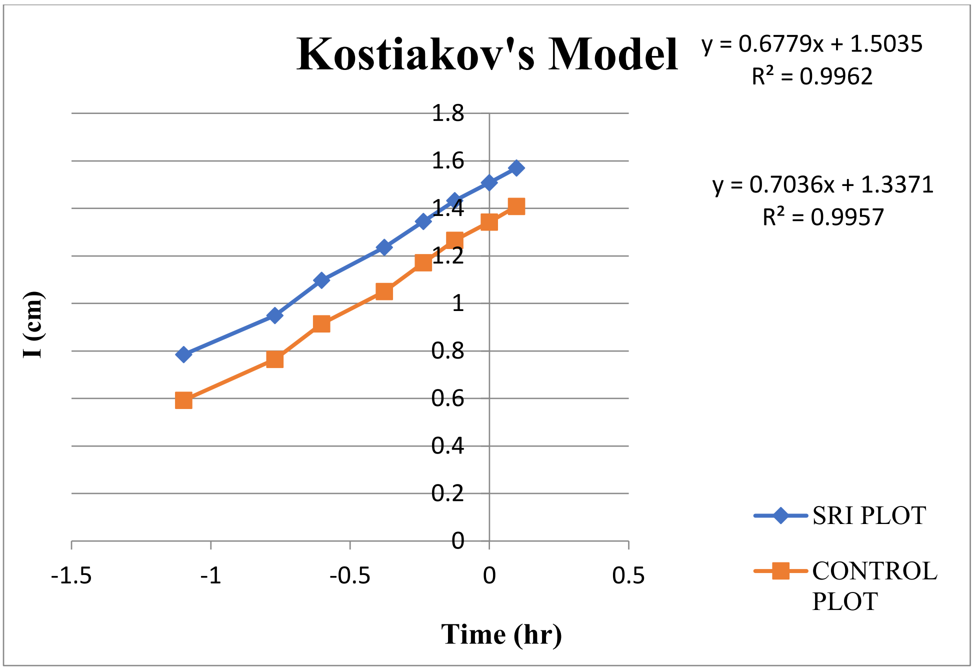
	SRI Plot		Control Plot	
Elapsed Time (min.)	Average Infiltration Rate (cm/h)	Average Cumulative Infiltration (cm)	Average Infiltration Rate (cm/h)	Average Cumulative Infiltration (cm/h)
5	38.9	3.3	36.0	3.0
10	17.2	6.1	11.6	4.9
15	14.4	9.7	9.5	7.3
25	11.2	14.4	7.3	10.3
35	8.5	19.3	6.1	13.9
45	6.7	24.3	4.8	17.5
60	5.0	29.4	3.6	21.1
75	4.0	34.3	2.9	24.7

Table 2: Infiltration characteristics for model validation

	SRI Plot		Control Plot	
Elapsed Time (min.)	Average Infiltration Rate (cm/h)	Average Cumulative Infiltration (cm)	Average Infiltration Rate (cm/h)	Average Cumulative Infiltration (cm)
5	32.8	2.7	31.6	2.6
10	16.1	5.5	12.2	4.7
15	13.6	8.8	9.5	7.0
25	10.5	13.1	7.0	10.0
35	8.3	18.0	5.6	13.2
45	6.6	23.0	4.5	16.6
60	4.9	27.9	3.4	20.0
75	3.9	32.8	2.7	23.3

3.1. Model’s Parameter Evaluation

The process of estimating the model’s parameters and time exponent differs for each model, each model was first transformed into its linear equivalent in which to have dependent and independent variables respectively and the coefficients of the linear functions read from the graphs are the model’s parameters. Figure 2–7 shows the fitting graph for estimating the model’s parameters with the representative power functions of the modeled equations shown in Table 3 to 12.



Fiure 2: The Kostiakov's Model Graph

Table: 3: Kostiakov model's parameters and modeled equations

Sub-plot	The estimated model parameters constant	Modeled equations
SRI	K = 10^1.477 = 29.9916, a=0.8658	$I = 29.9916t^{0.3451}$
Control	K =10^1.3236 = 21.0669, a=0.7852	$I = 21.0669t^{.3918}$

3.2. Modified Kostiakov's Model

Table 4 shows the values of the three parameters (a, k and b) of modified Kostiakov model. To determine rectifying factor, the plotted line graph in figure 3 was used by selecting a pair of points (t_1, y_1) and (t_2, y_2) at the extremities of the line to cover a wide range of interpolated values;

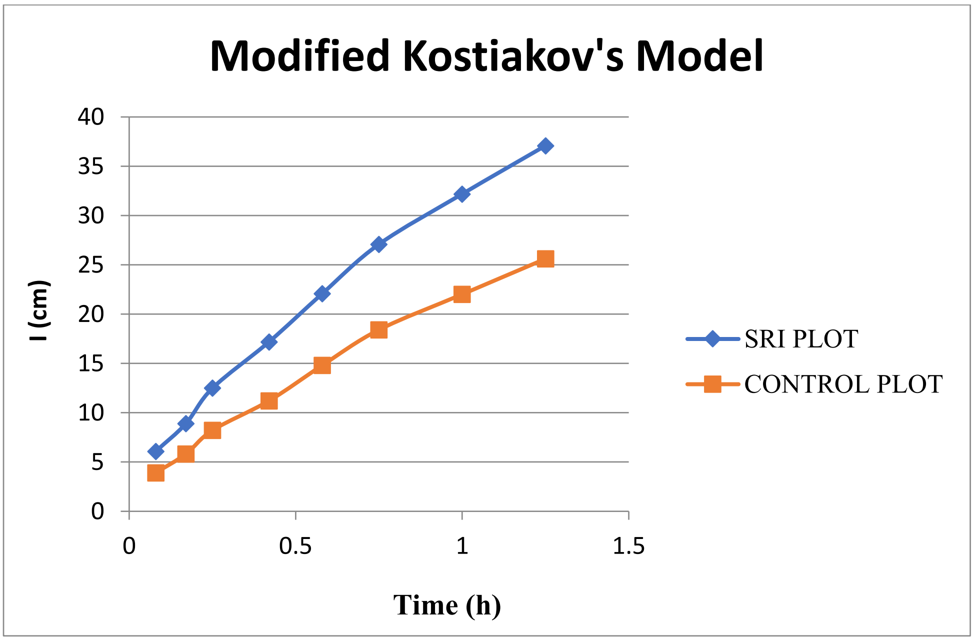


Figure 3: The graph for obtaining rectifying factor (b)

For SRI sub-plot

t_1 = 0.08hr, t_2 = 1.3hr and y_1 = 3.0 cm, y_2 = 34.0cm

$t_3 = \sqrt{t_1 \times t_2} = \sqrt{0.08 \times 1.3} = 0.32hr$

From the graph 4.2 the corresponding value of Cumulative infiltration y_3 at t_3 is 7.5 cm

Therefore, the rectifying factor (b) was computed thus: $\frac{y_1 \times y_2 - y^2{}_3}{y_1 + y_2 - y_3} = \frac{3.0 \times 34.0 - 13^2}{3.0 + 34.0 - 13}$ = - 2.792

For Control sub-plot

t_1 = 0.08hr, t_2 = 1.3hr and y_1 = 3.0 cm, y_2 = 25.0 cm

$t_3 = \sqrt{t_1 \times t_2} = \sqrt{0.08 \times 1.30} = 0.32hr$

From the graph 4.2 the corresponding value of Cumulative infiltration y_3 at t_3 is 13cm

Therefore, the rectifying factor (b) was computed thus: $\frac{y_1 \times y_2 - y^2{}_3}{y_1 + y_2 - y_3} = \frac{3.0 \times 25.0 - 7.5^2}{3.0 + 25.0 - 7.5}$ = - 0.914

Table 4: Modified Kostiakov's adjusted cumulative infiltration table

S/no.	Time(hr)	SRI (I-b)	Control (I-b)
1	0.08	6.092	3.914
2	0.17	8.892	5.814
3	0.25	12.492	8.214
4	0.42	17.192	11.214
5	0.58	22.092	14.814
6	0.75	27.092	18.414
7	1.00	32.192	22.014
8	1.25	37.092	25.614

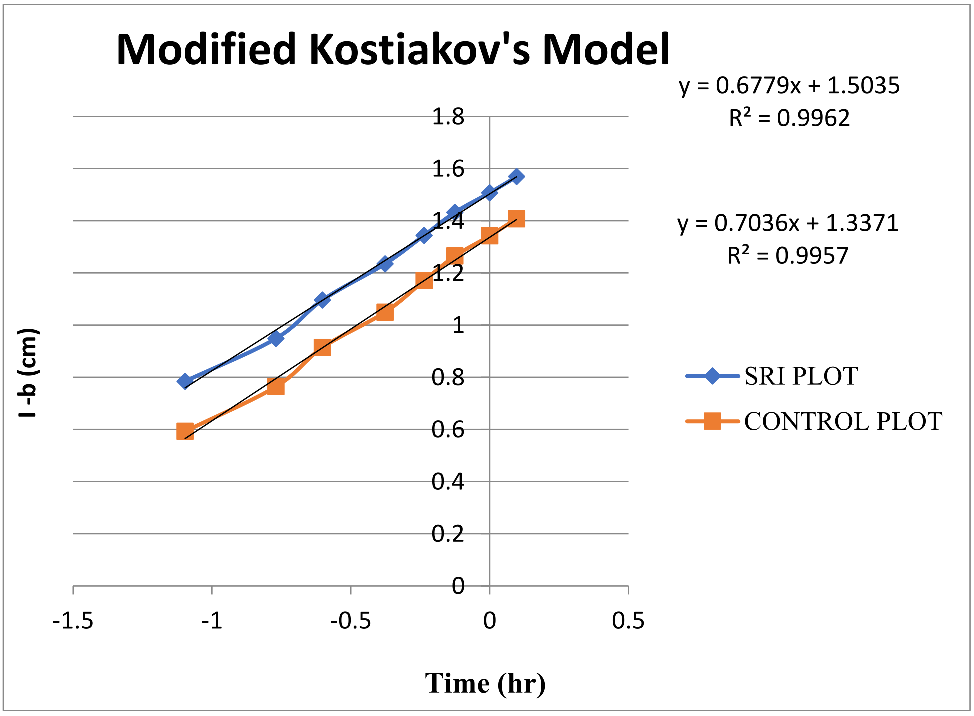


Figure 4: The graph of adjusted cumulative infiltration versus elapsed time to obtain the fitting parameters for Modified Kostiakov's equation.

Table 5: Modified Kostiakov model's parameters and modeled equations

Sub-plot	The estimated model parameters constant	Modeled equations
SRI	K = 31.8787, a = 0.6779, b = –2.792	$I = 31.8787t^{0.6779} – 2.792$
Control	K = 21.7320, a =0.7036, b = –0.914	$I = 21.7320t^{0.7036} – 0.914$

3.3. Kostiakov-Lewis model

The adjusted cumulative infiltration in Kostiakov-Lewis model were computed as in table 6 and the values of the three parameters (*a, k* and f_c) of Kostiakov-Lewis model were evaluated with the aid of graph 5.

Table 6: Adjusted Cumulative Infiltration in Kostiakov-Lewis model

S/no.	Time(hr)	SRI (I - f_ct)	Control (I - f_ct)
1	0.08	2.972	2.768
2	0.17	5.403	4.407
3	0.25	8.675	6.575
4	0.42	12.678	9.082
5	0.58	16.922	12.218
6	0.75	21.225	15.325
7	1.00	25.300	18.200
8	1.25	29.175	21.075

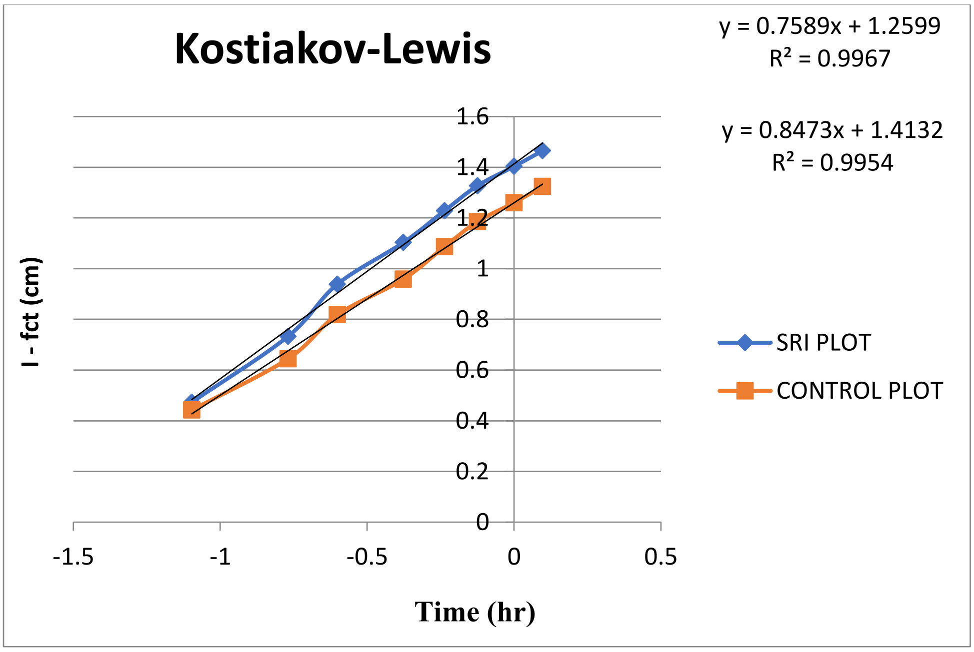


Fig. 5: Adjusted Cumulative Infiltration versus time for Kostiakov-Lewis

Table 7: Kostiakov-Lewis model's parameters and modeled equations.

Sub-plot	The estimated model parameters constant	Modeled equations
SRI	K = 18.1928, a = 0.7589, f_c = 4.1	$I = 18.1928t^{0.7589} + 4.1t$
Control	K = 25.8941, a =0.8473, f_c = 3.0	$I = 25.8941t^{0.8473} + 3.0t$

3.4. Philip's model

The values of the parameters (*A and S*) of Philip's model were evaluated with the aid of graph 6.

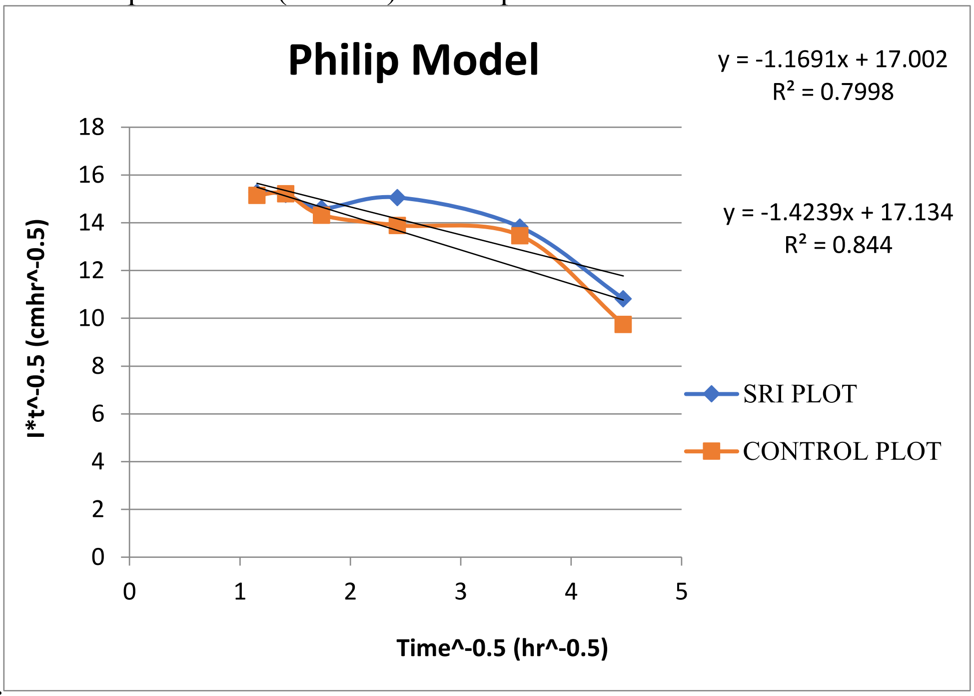


Fig. 6: Philip's parameters

Table.8: Philip's model parameters and modeled equations

Sub-plot	The estimated model parameters constant	Modeled equations
SRI	S =33.687 A= - 6.736	$I = 33.687\ \sqrt{t} - 6.736$
Control	S =22.903 A= - 3.8405	$I = 22.903\sqrt{t} - 3.8405$

3.5. Horton's Model

The values of the model parameters (*f_o, f_c and* k) of Horton's model are as follows, the evaluation process was done with the aid of graph 7.

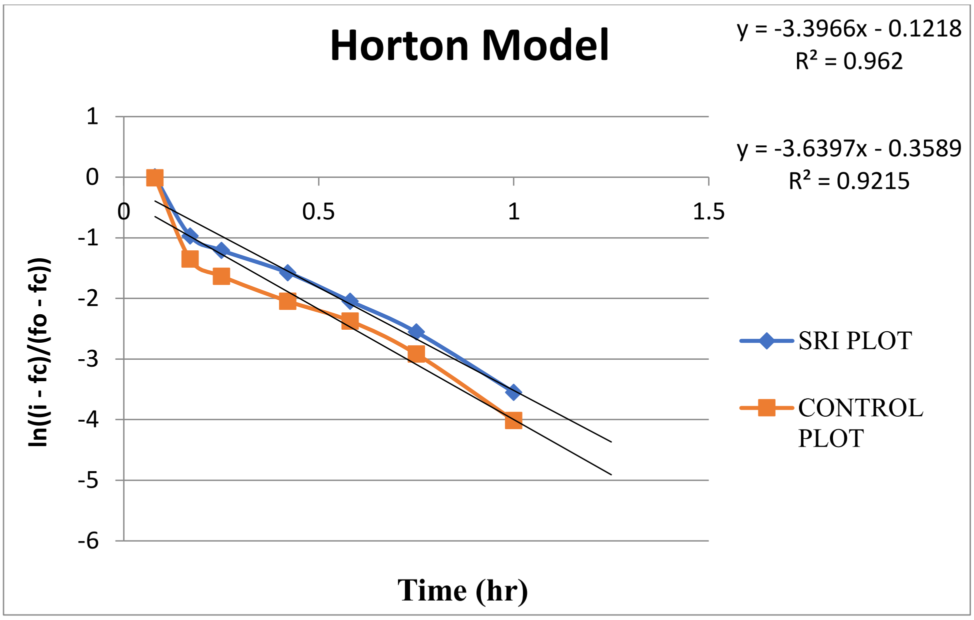


Fig. 7: Horton's parameters

Table. 9: Horton's equation parameters and modeled equations

Sub-plot	The estimated model parameters constant	Modeled equations
SRI	K = -3.3966 f_0 = 38.75 f_c = 4.0	$I = 4t + \frac{34.75}{3.3966}[1 - e^{-3.3966t}]$
Control	K = -3.6397 f_0 = 36.25 f_c = 3.0	$I = 3t + \frac{33.25}{3.6397}[1 - e^{-3.6397t}]$

3.6. Green-Ampt's Model

The parameters for Green-Ampt's model was calculated and tabulated in table 10.

Table.10: Green-Ampt's equation parameters and modeled equations.

Sub-plot	The estimated model parameters constant	Modeled equations
SRI	k_s= 4.1cm/day $\Delta\theta$ = 1.5% ψ= 28.07	$I = 4.1t + 42.11\ell n\left[1 + \frac{I}{42.11}\right]$
Control	k_s= 3.9cm/day $\Delta\theta$ = 2.4% ψ= 11.75	$I = 3.9t + 28.20\ell n\left[1 + \frac{I}{28.20}\right]$

3.7. Swartzendruber's Model

The Swartzendruber's parameters and modeled equations were evaluated and presented in table 11.

Table. 11: Swartzendruber's equation parameters and modeled equations

Sub-plot	Parameter values/estimated constant	Modeled equations
SRI	*c= 0.845 d= 0.167* f_c = *4.0*	$I = 4t + 5.06[1 - \exp(-0.167t^{0.5})]$
Control	*c= 0.872 d= 0.023* f_c = *3.0*	$I = 3t + 37.91[1 - \exp(-0.023t^{0.5})]$

3.8. Smith-Parlange Model

The parameters for **Smith-Parlange** model were computed and presented in table 12 where C_o factor was defined as = $\psi\Delta\theta K_s$

Table 12: Smith-Parlange's model parameters and modeled equations

Sub-plot	Parameter values or estimated constant	Modeled equations
SRI	k_s= 4.1cm/day $\Delta\theta$ = 1.5% ψ= 28.07, Co = 172.63	$I = 4.1\left[\frac{172.63}{4.1I} + 1\right]$
Control	k_s= 3.9cm/day $\Delta\theta$ = 2.4% ψ= 11.75, Co = 109.98	$I = 1.97t\left[\frac{109.98}{3.9I} + 1\right]$

3.9. Simulation of Cumulative Infiltration using the Estimated Parameters

The model parameters estimated and presented in Tables 2 to 12 were then incorporated into the respective models equation and simulation of cumulative infiltration was made for each of the sub-plots using all the eight models and the predicted cumulative infiltration were compared with the measured cumulative infiltration in sub-plot B. i.e. the field-measured data that were not previously used in determining the models parameters. The simulated cumulative infiltrations for the eight models of the two sub-plots are shown in Table 13 and 14 for model validation.

3.10. Model Validation

The Measured and predicted cumulative infiltrations are presented in table 13 and 14.

3.10.1. SRI sub-plots

Table 13: Measured and Model predicted cumulative infiltration under SRI sub-plot

Time(hr)	Obs	KT	MK	KL	PH	HT	GA	SW	SP
0.08	2.7	12.54458	2.961145	4.048516	9.528122	2.753912	3.505078	0.553451	4.51297
0.17	5.5	16.2715	6.798073	7.258209	13.88951	5.16826	6.393692	1.016686	5.508
0.25	8.8	18.58783	9.663585	9.792687	16.8435	6.854075	9.754316	1.405351	5.474227
0.42	13.1	22.23223	14.91322	14.66555	21.83167	9.454399	14.10791	2.199041	6.757042
0.58	18.0	24.85184	19.24378	18.86641	25.65525	11.12362	18.26557	2.924305	7.565845
0.75	23.0	27.15709	23.43838	23.0654	29.1738	12.42975	22.25873	3.681351	8.403086
1.00	27.9	29.9916	29.0867	28.8941	33.687	13.88809	26.39944	4.77823	9.971769
1.25	32.8	32.39241	34.2928	34.42226	37.66321	15.08452	30.21533	5.861804	11.41618
R^2		0.819d	1.043a	0.988b	1.306e	0.622f	0.784c	1.848h	0.840g
RMSE		7.590e	1.181a	1.261b	7.175d	9.263g	1.271c	16.042h	12.017f
E		0.440e	0.986a	0.985b	0.499d	0.165f	0.984c	-1.504h	-0.405g

	KT	MK	KL	PH	HT	GA	SW	SP
CRM	-0.396c	-0.065a	-0.070b	-0.428d	0.418f	0.007e	0.830h	0.548g
MAE	6.631d	1.075a	1.152c	7.059f	6.894e	1.094b	13.672h	9.479g

3.10.2. Control sub-plots

Table 14: Measured and Model predicted cumulative infiltration under Control sub-plot

Time(hr)	Obs	KT	MK	KL	PH	HT	GA	SW	SP
0.08	2.6	7.831254	2.761478	3.003805	6.477947	2.547602	3.16371	1.791306	1.635251
0.17	4.7	10.52181	5.332598	5.438189	9.443149	4.725074	5.182659	2.603484	2.257354
0.25	7.0	12.23809	7.279893	7.378254	11.4515	6.207488	7.469442	3.370628	2.390168
0.42	10.0	14.99649	10.88969	11.14054	14.84284	8.414845	10.42188	4.428461	3.086915
0.58	13.2	17.01813	13.89916	14.41075	17.44241	9.769103	13.56827	5.383374	3.454752
0.75	16.6	18.8213	16.83577	17.69958	19.83458	10.78977	16.54679	6.313474	3.852296
1.00	20.0	21.0669	20.818	22.2928	22.903	11.89514	19.66258	7.444841	4.596157
1.25	23.3	22.99164	24.51244	26.67487	25.60633	12.78856	22.62759	8.527567	5.266747
R^2		0.762d	1.073a	1.304c	1.116e	0.536f	0.888b	1.178g	1.659h
RMSE		4.099e	0.705b	1.638c	3.921d	5.302f	0.455a	8.603h	10.582g
E		0.651e	0.990b	0.944c	0.680d	0.416f	0.996a	-0.539g	-1.329h
CRM		-0.288e	-0.051b	-0.109c	-0.314d	0.311f	-0.013a	0.591g	0.728h
MAE		3.588d	0.616b	1.330c	3.825e	3.789f	0.421a	7.192g	8.858h

Tables 13 – 14 represent the models' simulated cumulative infiltration depth for SRI sub-plot and control respectively. The average coefficients of determination (r^2) between the field-measured and model simulated data were approximately one (1) for most of the model which implies that the models were able to simulate water infiltration in the study area adequately.

However, the Modified Kostiakov (MK) model, Green-Ampt (GA) and Kostiakov-Lewis (KL) models were performed better with a high precision in both SRI and Control sub-plot, having r^2 values of approximately 1 and a lower value of RMSE and MAE of 1.127,0.846; 0.863,0.758; and 1.450,1.241 respectively. However, Modified Kostiakov and Green-Ampt model were excellently applied for SRI and Control sub-plot respectively. Moreover, the other models comprises of Kostiakov (KT), Horton (HT)), Philip (PH), Swartzendruber (SW), and Smith & Parlange (SP) performed poorly.

With respect to coefficient of residual mass (CRM) in SRI sub-plot; four (4) models PH>KT>KL>MK (-0.428>-0.396>-0.071>-0.065 respectively) seem to be over-predicting and the remaining four (4) models SW>SP>HT>GA (0.830>0.548>0.418>0.007 respectively) under-predicting the cumulative infiltration in descending order of accuracy. In Control sub-plot, Five model encompasses KT>PH>KL>MK>GA (-0.288>-0.314>-0.109>-0.051>-0.013 respectively) were over predicting and the remaining three (3) include SP>SW>HT (0.728>0.591>0.311 respectively) seem to be under predicting the cumulative infiltration, all in descending order of accuracy.

However, considering the results of Root Mean Square Error (RMSE) as well as the other indices for the model validation under both sub-plots, the performance of the models were ranked from best to worst thus: MK > GA > KL > KT> PH > HT >SP >SW with Modified Kostiakov's model having the overall best performance followed by Green-Ampt and Kostiakov Lewis while Swartzendruber was recorded as the worst in term of performance followed by Smith & Parlange, Philip, Horton and Kostiakov models. The use of the model equations derived in this study is best applied to irrigation works where there is ponding such as border and basin irrigation. The usefulness of this infiltration model can be used to design and carefully plan irrigation projects anywhere.

The values of E (Nash-Sutcliffe's modeling efficiency) were ranged from -1.504 to 0.986 for the SRI sub-plot and -1.329 to 0.996 for the Control sub-plot. Modified Kostiakov's model with the value of 0.986 followed by Kostiakov-Lewis (0.985) and Green-Ampt (0.984) in SRI model as well as Green-Ampt with the value of 0.996 followed by Modified Kostiakov's (0.990) and Kostiakov-Lewis (0.944) in Control sub-plot gave the closest agreement between observed and predicted values while Kostiakov, Horton, Philip, Smith & Parlange and Swartzendruber model showed the poorest agreement with values of 0.440, 0.418, 0.499, -0.405 and -1.504 in SRI sub-plot and 0.651, 0.416, 0.680, -1.329 and -0.539 in Control sub-plot respectively.

The result of this study agrees with the findings of A.S. Ajayi (2014) on the use of empirical, semi-empirical and physically based models to test the performance of selected water infiltration model in organic amended soil; where he concluded that: Modified Kostiakov and Green-Ampt's model had the best performance in their respective groups using the RMSE indices. The semi-empirical models which are Swartzendruber and Horton's model were poor in their prediction which he put it down to the fact that their parameters lack a consistent physical interpretation and also the process involved in the evaluation of the parameters might be very sensitive to approximation errors and errors due to parallax while determining the initial and steady state infiltration rates from the graph as inputs for the prediction of cumulative infiltration. Furthermore, the performance of a given model can also be affected by the site specific field condition present as well as the accuracy of the input parameters and the assumption made in developing the models.

Moreover, Odofin (2012) showed that modified Kostiakov, Kostiakov and Philip infiltration models were all found to be suitable for simulating water infiltration into an Alfisol subjected to untilled mulched, tilled-mulched and tilled-unmulched management systems at Minna, Nigeria. He further emphasizes that modified Kostiakov model simulated water infiltration more accurately than Philip model while classical Kostiakov model was the least accurate. Furthermore, infiltration data from highly permeable soils under five different land uses on historic Nsukka plains of south-eastern Nigeria showed that either the modified Kostiakov model or modified Philip model could be used for routine characterization of the infiltration process (Mbagwu, 1995). Finally, Mbagwu (1995) recommended the modified Kostiakov equation for routine modeling of the infiltration process on soils with rapid water intake rates. The Kostiakov and modified Kostiakov equations tend to be the preferred models used for irrigation infiltration, probably because it is less restrictive as to the mode of water application than some other models.

4.0. CONCLUSION AND RECOMMENDATION

In this study, eight (8) water infiltration models; were evaluated for soils under SRI in order to determine which models accurately predicted the measured cumulative infiltration. At the end of the study, the performance of the models were ranked from best to worst thus: MK > GA > KL > KT> PH > HT >SP >SW with Modified Kostiakov's model having the overall best performance followed by Grent Ampt and Kostiakov Lewis while Swartzendruber was recorded as the worst in term of performance followed by Smith & Parlange, Philip, Horton and Kostiakov models.

Moreover, Modified Kostiakov and Grent ampt model were seem to be a perfect match to the soil amended by farm manure (SRI sub-plot) and Control sub-plot (purely sandy loam prior to the application of farm manure) respectively. Finally, it was recommended that; the use of the model equations derived in this study should be best applied to irrigation works where there is ponding such as border and basin irrigation. The usefulness of this infiltration model was recommended for use in design and careful plan of irrigation projects anywhere.

REFERENCES

Arab I.A. (2016): Simulation of Soil Water Balance Response to Water Stress and Yield of a Furrow Irrigated Tomato Using Aqua-crop. Unpublished Ph.D Dissertation in the department of Agricultural Engineering, Ahmadu Bello University, Zaria, Nigeria.

Ajayi S.A., (2016): Performance of Selected Water Infiltration Models in Organic –Amended Soils. Unpublished MSc Thesis in the department of Agricultural Engineering, Ahmadu Bello University, Zaria, Nigeria.

Cuenca R.H. (1989) "Irrigation system design: an engineering approach" Prentice Hall, Englewood Cliffs.

Davis, A. (1943). "Empirical Equations and Nomographs" McGraw Hill Book Co. N.Y.

Haghiabi, A. H., M. Heidarpourand, J. Habili(2011). "A new method for estimating the parameters of Kostiakov and modified Kostiakov infiltration equations".World Applied Sciences Journal. 15(1): 129 –135.

Hagi-Bishow M. and R.B. Bonnell (2000). "Assessment of LEACHM-C Model for semi-arid saline irrigation" ICID JOURNAL 2000, VOL. 49 NO.1 29.

Hillel, D. (1998). "Environmental Soil Physics "Academic Press. San Diego, CA.

IAR, (1994). Farmer-Managed Irrigation System: A Diagnostic Analysis of Large Scale Irrigation Projects in Nigeria. Final Technical Report (Phase-I). Institute for Agricultural Research (IAR) ABU Zaria, Nigeria Ford Foundation Grant No. 870-873.

Lili, M., V. F.Bralts, , P.Yinghua, L. Han, and L. Tingwu(2008) "Methods for measuring soil infiltration" State of the art, Int. J.Agric&Biol Eng. 1(1), 22-30.

Mahdian M. H. and J. Gallichand(1995) "Validation of the SUBTOR model for simulating soil water content" transaction of the ASAE Vol 38(2):513 – 520.

Mbagwu, J.S.C. (1995) "Testing the goodness of fit of infiltration models for highly permeable soils under different tropical soil management systems" Soil & Tillage Research 34: 199-205.

Michael, A. M. (1978)."Irrigation, Theory and Practice" Vikas Publ. House.PVT.Ltd. New Delhi.

Mishra, S. K., J. V. Tyagiand V. P. Singh(2003)"Comparison of infiltration models" Journal of Hydrological Processes.17: 2629 – 2652.

Nash, J. E. and J. V. Sutcliffe (1970). River flow forecasting through conceptual models part I — A discussion of principles, Journal of Hydrology, 10 (3), 282–290.

NEDECO, (1976). Kano River Irrigation Project (KRIP) Main Report. Part VIII. Ministry of Agriculture and Natural Resources, Kano, Nigeria,pp: 63.

Odofin, A.J. (2012). "Testing the Accuracy of Three Models for Simulating Water Infiltration into an Alfisol Subjected to Three Land Management Systems at Minna, Nigeria" Volume 7(2); December, 2012 Savannah journal of agriculture

Oku, E. and A. Aiyelari (2011). "Predictability of Philip and Kostiakov infiltration model under inceptisols in the Humid Forest Zone, Nigeria" Kasetsart Journal (Natural Science), 45: 594 -602.

Randriamiharisoa, R., Joeli Barison and Norman Uphoff (2006). Soil biological contributions to the System of Rice Intensification. In: *Biological Approaches to Sustainable Soil systems*, eds. N. Uphoff, A. Ball, E.C.M. Fernandes, H. Herren, O. Husson, M. Laing, C.

Rawls, W. J., R.Ahuja L. Brakensiek D. L. and Shirmohammadi A. (1993)."Infiltration and soil water movement" In Handbook of Hydrology. McGraw-Hill, Inc.

Skaggs, R. W., and R. Khaleel(1982). Chapter 4: "Infiltration. In Hydrologic modeling of Small Watersheds" St Joseph, Mich.: ASAE.

Smith, R. E. and J. Y. Parlange (1978). "A parameter-efficient hydrologic infiltration model" Water Resources Research 14(3): 533-538.

Steel, R. G. D. and J. H. Torrie(1960). Principles and Procedures of Statistics with Special Reference to the Biological Sciences.McGraw Hill

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EFFECT OF TEAK PLANTATION AGE ON SOIL QUALITY AT UNIVERSITY OF ILORIN, KWARA STATE

Ebosele, E. O[1]., Raji, B. A[2]., Dunmoye, A. Y[2]., Olajide, A. A[2] and Abdulrasak, Y. L[2]
[1]Agricultural and Rural Management Training Institute, Ilorin, Kwara State
[2]Department of Agronomy, University of Ilorin, Kwara State.
Email address: ebosele14@gmail.com

ABSTRACT
This study was conducted in 2019 at the University of Ilorin (UNILORIN) Teak Plantation, the study therefore investigated the soil properties of Unilorin teak plantation of three different ages; 11, 9 and 7 respectively. The main objective of this research was to estimate the effect of teak plantation age on soil physical and chemical properties. Stratified random sampling method was used in collecting the samples by hypothetically dividing each plot into three sub-division representing three replications as the plots were not replicated and plot sizes were somehow large. Samples were collected from depths of 0-15 and 15-30cm. Composite samples were taken at respective depth, air-dried, sieved and analyzed in the laboratory using standard techniques. Results obtained from the analysis reveals that soil in the three different ages; 11, 9 and 7 are neutral in soil reaction, moderate level of acidity level, low level of N and P content, moderate level of Mg content. The organic carbon (OC) contents across the year's shows significant increase at age 9 and surface soil. and the site shows a very high sand content. The results of the study also reveal increasing levels of Ca, Mg content and the cation exchange capacity (CEC) decrease as teak age increase. Also, soil reaction, acidity, available P, electrical conductivity (EC), and K contents decrease with increase in teak age. A sustainable soil management practice should be employed to improve SOC, OM, N, P and CEC to avoid soil degradation in the nearest future and further studies has to be conducted to ascertain the viability of the result; this includes the increment of sampling points across the area to reduce the spatial variability error.
Keywords: Stratified random sampling, Teak plantation, Age, Soil properties, depth.

INTRODUCTION

Soil is an unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for growth of land plants (USDA-NRCS 2008). Soils are unique and highly heterogeneous natural body that sustains life. The soil physical state directly influences environment quality and crop production (Arshad *et al.,* 1996). Well-aggregated soils in good physical condition maintain the balance of air and water required to promote many other soil properties (Lowery *et al.,* 1996). The physical properties of soil or its quality which include soil texture, bulk density, porosity, depth, water holding capacity, soil temperature and aggregate stability as well as soil chemical properties has direct and indirect influence on the soil and crops growth on them.

Teak is one of the world's premier hardwood timbers; it is indigenous only to India, Lao, Thailand and Myanmar (Pandey and Brown, 2000). Teak can be produced under diverse conditions, but high productivity can only be expected on good and accessible sites and in many countries, Teak is planted on degraded lands (Enters, 2000). Teak is a large deciduous tree with a rounded crown and under favorable conditions; it can develop into a tall clean cylindered pole of more than 25m in height. Leaves are broadly elliptical and usually 30-60cm long. Teak begins flowering and seeding at a young age, and produce abundant seeds remain viable for many years. The hard thick pericarp of the seed prevents easy germination and a considerable portion of fresh seeds remains dormant in the first year (Jadeja and Nakar 2010). Teak seeds remain viable for many years, teak grows a little slower but has longer life span (Adekunle, 2000). Matured teak trees (wood) are used in building construction, as electricity transmission poles (Amusa & Adedapo 2020), the deep root system reduces soil losses due to erosion especially areas with heavy rainfall (Fernandez-moya et al 2014), the litters serve as source of organic matter to the soil and also helps to maintain the stability of soil chemical properties like pH and cation exchange capacity (Fernandez-moya et al 2014). The University of Ilorin teak plantation was first established in 2008 then in 2010 and 2012 which is the study area of the research. It is therefore necessary to analyze the soil under few selected soil properties i.e., the physical and chemical properties. The objective of the study was to determine the effect of teak age on selected soil physical and chemical properties.

MATERIALS AND METHODS

Site Description

The study was carried out in University of Ilorin Teak Plantation, located on her main campus, covering vast hectares of land (about 650 ha in total). The plantation was first established in 2008 with only 50ha of land supporting about 61,250 stands of teak under the supervision of the set managing committee by the institution. The university is located in the Southern Guinea Savanna Ecological Zone of Nigeria which lies between latitude 8°29’20.9N, 8°29’21.1N and latitude 4°33’11.1E, 4°33’11.9E. It is categorized under the Bi-modal rainfall pattern with high rainfall in June and September and a rainfall break between mid-July and August. The climate of Ilorin is within the Forest and derived Guinea savannah region of Nigeria which has two (2) climate seasons the wet and dry season with the mean annual rainfall of 1585mm (NIMET). The average minimum and maximum temperatures are about 24.6°C and 29.4°C respectively.

Soil Sampling and Preparation

Soil samples were taken from three different ages of *Tectona grandis* (Teak) 11, 9, and 7yrs old) planted in 2008, 2010 and 2012 respectively at the allotted plots for teak plantation on the university of Ilorin main campus. Soil observations were made at 100cm, intervals by auguring to a depth of 0-15 and 15-30cm. stratified random sampling was used in collecting the samples by hypothetically dividing each plot into three subdivisions representing three replications as the plots were not replicated and plot sizes were somehow large. The soil samples were air dried for 24hours. After drying, they were then crushed and passed through a 2mm sieve to separate the gravel portion from the soil portion.

Laboratory Analysis:

The sieved samples were used to analyze the following parameters: particle size, soil pH, cation exchange capacity, organic carbon, total nitrogen and available phosphorus. Particle size distribution was determined by hydrometer by bouyoucus hydrometer method as described by Gee and Bauder (1986). The soil pH was determined in a 1:2.5 soil: water suspension (Thomas, 1996), Organic carbon was determined by the dichromate wet oxidation method (Nelson and Sommers, 1996). Total Nitrogen was analyzed according to the micro Kjeldahl digestion method (Bremmer, 1996). Cation exchange capacity was determined in a 1N Ammonium acetate method. Exchangeable Na and K in the extract were determined by flame photometry while Ca, and Mg by the Versenate titration method. Available P was determined using Bray II method (Olsen and Sommer, 1982). The data were subjected to analysis of variance (ANOVA) and the Least Significant Difference

RESULTS AND DISCUSSION

Effects of teak age on particle size distribution

The results of particle size distribution of the soils are presented in Table 1. Tthe total sand content of all the year ranged from 861.00g/kg to 901.40g/kg. At age 11, the total sand content in the soil was 901.40g/kg. At age 9, the total sand content in the soil was 891.40g/kg. At age 7, the total sand in the soil was 861.0g/kg. And at the depth of 0-15cm the sand content was 899.10g/kg and while at the depth of 15-30cm the sand content was 870.28g/kg. there was significant difference among the soils across the year. This indicate that as the teak ages the sand content increase and as the sand content increase with decrease in depth. these could be as a result of the parent material which the soil was formed. According to Solomon et al 2019, 80% sand content recorded in savannah soils are linked to coarse parent materials.

The silt content of the soil units ranged from 26.65g/kg to 66.50g/kg. At 11, the total silt content was 26.65g/kg, and at age 9, the silt content was 35.00g/kg while at age 7 the silt content was 66.50g/kg. On the surface soil with 0-15cm depth the total silt recorded was 27.78g/kg while at the depth of 15-30cm the silt content was 57.66 across the years. This indicated that as the teak ages the silt content reduces, that is the younger the teak, the higher the silt. It also showed that the silt content increases with increase in depth. The increased silt content could be as a result of weathering that is, breaking down of sand into particles (Solomon *et al* 2019)

The clay content of all the soil units recorded was 72.00g/kg across the years. At age 11, 9 and 7 the clay content was 72.00g/kg with no increase nor decrease recorded. Also, along the soil depth, the clay content was both 72.00g/kg at 0-15cm and 15-30cm respectively. This could be accredited to clay movement in the soil, increased litters on the soil surface (Obasi *et al* 2019)

Table 1: Particle size distribution of soils at the Unilorin teak plantation

Treatment	Particle size Distribution (g kg^{-1})		
	Sand	Silt	Clay
Age (years) (A):			
11	901.4	26.65	72.0
9	891.4	35.0	72.0
7	861.0	66.5	72.0
Mean			
Soil Depth (cm) (D):			
0-15	899.1	27.76	72.0
15-30	870.28	57.66	72.0
Mean			

Table 2. Effect of teak age on soil chemical properties.

The effect of the teak age on soil pH, Soil organic carbon, organic matter, Nitrogen, Available Phosphorus, soil acidity, Cation exchange capacity, Calcium, etc. chemical properties is shown in table 2. As the teak ages, the soil qualities undergo changes both significantly and non-significantly.

Soil pH

The soil pH (H_2O) ranged from 7.07 to 7.26. At age 11, the soil pH values obtained for the surface soils were 7.11, 7.14 and 7.26 at age 11, 9 and 7 respectively. The pH value according to depth were 7.26 and 7.07 at the depth of 0-15cm and 15-30cm respectively. The corresponding subsoil values were 7.04 in 2008, 7.07 in 2010 and 7.10 in 2012 respectively. The soil pH slightly decreased as the teak age increase. The soil reaction in water was as a result of large amount of surface vegetation available for cation adsorption. The difference might be as a result of slight difference in climate of the location of the plantations. Meanwhile, the result is similar to results obtained by Zanin (2005), who reported the teak grows well on the soil with range between 6.5 to 7.7.

Soil Organic Carbon

The soil organic carbon values obtained for the soils were 0.59%, 0.68% and 0.57% at age 11. 9 and 7 respectively. The surface soil value (0.70%) is significantly higher than the subsoil value (0.50)%. The trend shows a decrease of organic carbon content at young age probably as a result of low vegetation and human activities such as burning (Adam *et al* 2019). The soil organic carbon content increases as the teak age increases which might be as a result of decomposed teak leaves on the soil.

Soil Acidity

The soil acidity values obtained for the soils were 0.40, 0.49, and 0.57 at age 11, 9, and 7 respectively. It also showed that at the depth of 0-15 and 15-30cm the acidity was 0.36 and 0.61 respectively. The acidity decreases with increase in teak age, and also increase with with increase in depth. This could be as a result of efficient use of nitrogen, followed by the export of alkalinity. Ammonium based fertilizers are major contributors of soil acidity.

Soil Organic Matter

The soil organic matter values range 0.99%, to 1.2%. at age 11, 9 and 7 the OM were 1%, 1.17% and 1.11% respectively. . The soil organic matter content increases as the teak age increases at the top soil and decreases at the sub soil as the age increases, this could be as a result of the accumulation of teak residue that as gone through the process of decomposition. There were significant differences between the values.

Nitrogen

The nitrogen values obtained was 0.10g/kg at 11, 9-, and 7-years old teak plantation and also across the depth of 0-15cm and 15-30cm. The soils recorded the same value in nitrogen content even with different depth. This could be as a result of mobility of nitrogen in the soil. There were no significant differences between values.

Available Phosphorus

The available phosphorus values obtained ranged from 5.01mg/kg to 5.69mg/kg. At age 11, 9, and 7 the AP were 5.40mg/kg, 5.30mg/kg and 5.38mg/kg respectively. At the depth of 0-15cm the AP increased with 5.69mg/kg compared to at subsoil with 5.01mg/kg. the increased in AP at the surface soil could be as a result of litters on the surface. There were no significant differences between the values; this may be as a result of excessive rainfall which could cause the phosphorus to leach out of the soil.

Soil Electrical Conductivity

The electrical conductivity values obtained for the soil was 0.41 dS/m at age 11, 0.44 dS/m at age 9, and 0.46 dS/m in 7. The corresponding subsoil value was 0.41 dS/m at depth 0-15cm, and 0.46 dS/m at the depth of 15-39cm and 0.49 dS/m in 2012 respectively. The electrical conductivity decreases as the teak age increases, and increases as the depth increased. The result recorded that there was no significant differences between the values.

Exchangeable Base

Sodium

The sodium content values obtained were 0.23 cmol/kg at age 11, 0.24 cmol/kg at age 9, and 0.23 cmol/kg at age 7. The subsoil values and the surface value were

0.23cmol/kg with no significate difference among the soil. All sodium content values recorded were moderate as the teak age increases at the surface soil and subsoil.

Potassium

The potassium content values obtained were 0.94 cmol/kg at age 11, 0.90 cmol/kg at age 9, and 1.26 cmol/kg in at age 7. The soil depth values were 0.98 cmol/kg at the depth of 0-15 and 1.08 at 15-30 depth.. All the potassium content values recorded were ranged from high to very high and it decreases as the teak age increase at both the surface soil and subsoil. There were significant differences between the values.

Calcium

The calcium content values obtained were 0.80 cmol/kg at age 11, 0.76 cmol/kg at age 9, and 0.71 cmol/kg at age 7. The surface and subsoil values were both 0.76 cmol/kg at 0-15cm and at 15-30cm depth. All calcium content recorded were very low and it increases as the teak age increases at the surface soil and subsoil. There were no significant differences between the values.

Magnesium

The magnesium content values obtained were 2.10 cmol/kg at age 11, 2.00 cmol/kg at age 9, and 2.10 cmol/kg at age 7. The Mg content was recorded high on the surface soil value of 2.15 cmol/kg, and 1.97 cmol/kg at the subsoil. The soil magnesium content increases as the teak age increases at the surface soil while it decreases as the teak age increases at the sub soil.

Cation Exchange Capacity (CEC)

The CEC content values obtained across the teak age ranged from 6.50 cmol/kg, to 6.93 cmol/kg . The CEC slightly increase at the subsoil with 6.76 cmol/kg, compared to 6.64 cmol/kg in 2010 (at age 9), at the surface soil.. The soil CEC content decreases as the teak age increases, at the surface soil while it decreases as the teak age increases at the subsoil. All the CEC in the soil samples recorded were low which may be due to absence of clay because clay soil helps to retain large amount of C.E.C. The C.E.C influences the soil's ability to hold onto essential nutrients and provides buffer against soil acidifications and there were no significant differences among the soils. Organic matter content, cation exchange capacity (CEC) and exchangeable cations are higher in soils under natural forest and miscellaneous plantations than in soils under plantations established as monocultures (Prasad *et al.*, 1985, Singh and Totey, 1985, Mongia and Bandyopadhyay, 1992).

Table 2: CHEMICAL PROPERTIES OF SELECTED SOILS AT UNILORIN TEAK PLANTAION

Treatment	Ph	OC	OM	A	N	AP	EC	Na	K	Ca	Mg	CEC
Age (years) (A):												
11	7.11	0.60	1.00	0.40	0.10	5.40	0.41	0.23	0.94	0.80	2.10	6.50
9	7.14	0.68	1.17	0.49	0.10	5.30	0.44	0.24	0.90	0.76	2.00	6.65
7	7.26	0.57	1.11	0.57	0.10	5.38	0.46	0.23	1.26	0.71	2.10	6.93
Soil Depth (cm) (D):												
0-15	7.26	0.70	1.20	0.36	0.10	5.69	0.41	0.23	0.98	0.76	2.15	6.64
15-30	7.07	0.52	0.99	0.61	0.10	5.01	0.46	0.23	1.08	0.76	1.97	6.76

OC: Organic matter, OM: Organic matter, A: Acidity, N: Nitrogen, AP: Available Phosphorous, EC: Electrical conductivity, K: Potassium, Na: Sodium, Mg: Magnesium, CEC: Cation Exchangeable Capacity, NS: Not Significant

CONCLUSION AND RECOMMENDATION

This study verified the effect of teak plantation age on soil physical and chemical properties at the University of Ilorin teak plantation. At the end of the experimental period, it was observed that the soil in 2008(age 11), 2010(age 9) and 2012(age 7) are neutral in their reaction. The acidity level of all soil samples was at moderate level. The soil organic matter content was moderate in all years (11, 9 and 7) The nitrogen content as well as the available phosphorus content of all the samples were low. The calcium content in the soil was very low, the magnesium content in the soil was moderate. The level of the potassium ranged high (0.90cmol/kg) to very high (1.26cmol/kg) as the year of plantation changes when compared with recommended K content in soil (Kane *et al* 2016), K content was highest at age 7, younger teak plantation and decrease as the take ages this could be as a result of sand particles inability to hold K on the soil surface. The organic carbon content in the soils were increasing across the year from 0.57% at age 7 to 0.68% at age 9, compared with recommended SOC threshold of 1.5 – 2.0% (Rattan *et al* 2015) in an ideal agricultural soil, the SOC of the soil in the teak plantation were low aross the years and soil depth.. The soil of all the samples was said to have very high sand content with little proportion of loam and silt.

At the end of the results, it can be recommended that the a sustainable soil management practice should be employed to improve SOC, OM, N, P and CEC and researches has to be re-conducted to ascertain the viability of the result, this includes the increment of sampling points across the area to reduce the spatial variability error.

REFERENCES

Adekunle, V.A.J. (2000). Comparative studies of growth characteristics of Gmelina and Tectona stands and their volume equations. *Journal of Applied Sciences.* 3 (4): 1498-1514

Adam Lawan Ngala, Ismaila Mohammed, and Dimhe James. (2019). Assessment of Some Selected Soil Chemical Properties of Irrigated Farmlands of Jere Bowl Near Maiduguri, Nigeria. *Proceedings of the 43rd Annual Conference of the Soil Science Society of Nigeria*. Pp 70-78

Arshad M.A., Lowery, B. and Grossman, B. (1996). Physical Tests for Monitoring Soil Quality. In: Doran, J.W and Jones, A.J., Eds., Methods for Assessing Soil Quality, Soil Science Society of America Special Publication 49, SSSA, Madison, WI, 123-142.

Bouyoucos, G.J. (1962). Hydrometer method for making particle size analysis of soils; *Soil science society of America proceedings.* 26, 464-465.

Bray, R. H., Kurtz, L. T., (1945): Determination of Total Organic and available Forms of Phosphorus in Soils. *Soil Sc.* 59: pp 39-45.

Enters, T. (2000). Site, Technology and Productivity of Teak Plantations in Southeast Asia. *Unasyla*.51 (201): 55-61.

IITA, (International institute of Tropical Agriculture). (1979). Selected Methods for Soil and Plant Analysis. IITA Manual Series I, IITA, Ibadan, Nigeria, 60pp.

Jadeja, B.A. and Nakar, R.N. (2010). Phenological studies of some tree species from Girnar Reserve Forest, Gujarat, *India. Plant Achieves.* 10 (2): 825-828

Koné, B., Lassane, T., Sylvain, S. Z., & Jacques, K. K. (2016). Characteristics of soil exchangeable potassium according to soil color and landscape in Ferralsols environment. *Cogent Geoscience*, *2*(1). https://doi.org/10.1080/23312041.2016.1199523

Lowery, B., Arshad, M.A., Lal, R. and Hickey, W.J. (1996). Soil Water Parameters and Soil Quality. In: Doran, J.W and Jones, A.J., Eds., Methods for Assessing Soil Quality, Soil Science Society of America Special Publication 49, SSSA, Madison, 143-157.

Mongia, A.D. and Bandyopadhyay, A.K. (1992). Physicochemical changes occurring in soils of tropical forest after clear felling for high value plantation crops. *Journal of Indian Society of Soil Science*. 40(3): 420-424.

Pandey, D. and Brown, C. (2000). "Teak: AGlobal Overview," *Unasylva,* 51 (201): 3-12.

Prasad, K.G., Singh, S.B.,Gupta, G.N.and George, M. (1985). Studies on changes in soil properties under different vegetation. *Indian Forester.* 111(10): 794-801.

Rattan Lal, Wakene Negassa, Klaus Lorenz. (2015). Carbon sequestration in soil, Current Opinion in Environmental Sustainability, Volume 15, Pages 79-86, ISSN 1877-3435, https://doi.org/10.1016/j.cosust.2015.09.002.

Singh, A.K. and N.G. Totey,(1985). Physicochemical properties of Bhata soils of Raipur (M. P.): As affected by plantation of different tree species. *Journal of Tropical Forest.* 1: 61-69.

Solomon R. I., Abdu, N., Yusuf, A. A. and Bello, M.. (2019) Effect of Biochar Amendments on Nitrate Leaching and ZPC in Four Soil Orders from Nigeria's Savanna Zones. *Proceedings of the 43rd Annual Conference of the Soil Science Society of Nigeria.* Pp97-114

USDA-NRCS 2008. What is Soil. https://www.soils.org/files/about-soils/soils-overview.pdf

Zanin. D.K., 2005. Feasibility of teak for Smallholder in Eastern Panama. Submitted in partial fulfillment of the requirement for the degree of masters of science in Forestry. Michigan Technology University US

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GEOSPATIAL ANALYSIS OF THE KARFI SECTOR IN KANO RIVER IRRIGATION PROJECT, KANO STATE, NIGERIA

Ibrahim Yakubu Tudunwada[1]& Suleiman Suleiman Khalifa[2]
[1.]Centre for Atmospheric Research, National Space Research & Development Agency, Anyigba, Kogi State, Nigeria. +2348035945174 iyakuba2@gmail.com
[2.] M.N. Yahaya & Associates, no 10, Bomapai Road, Kano

ABSTRACT

Kano River Irrigation Project started operating in 1976, and is one of the largest and most successful projects in Nigeria. Karfi sector is the largest sector (617 ha) among the 41 sectors of the project. It has problem of over use, inadequate water, weed growth, over flows, cracks and breakages in some locations. There are lack of maps, land tenure records, and land quality records for effective planning. The research aims to apply geospatial tools to study the biophysical conditions of the soil, based on soil fertility and salt development. Satellite imagery was used to digitize all the features found in the sector. Composite soil samples (69) were collected and analyzed for some soil parameters. Ordinary Kriging in ArcGIS 10.2.1 was used for interpolation. The Chi-square and descriptive statistics were used to analyze the variables at 0.05 % level of significance. The mean values of pH and EC were 7.5 and 0.239 dS/m respectively. ESP &SAR were 0.0291&0.0098 % respectively. The textural classes were loamy sand (55%) and sandy loam (44%). The soils were low in O.C (0.61%) and Nitrogen (0.08%) fertility. Phosphorous (14.86mgkg^{-1}), Calcium (2.818cmolkg^{-1}) and Sodium (0.138 cmolkg^{-1}) were medium indicating an average fertility level, while Mg (1.435 cmolkg^{-1}), K (0.309 cmolkg^{-1}) and CEC (4.94 cmolkg^{-1}) were high. The soil samples were found to be free from any form of salt development. Geographical Information System was able to generate location-based information of land quality, and is thus a suitable tool in decision making and proper management of agricultural resources.

Key Words: *Geographical Information Systems, Interpolation, Karfi Sector, Salinity, Fertility*

Introduction

The Kano River Irrigation Project (KRIP) started operating in 1976. It was initiated by the Kano State Government and later on the federal government through Hadejia – Jamaare River Basin Development Authority (H-JRBDA) took over (Sangari, 2006). KRIP (Phase I) is one of the largest and most successful irrigation projects in Nigeria. The Project is located in Kano State. The elevation of the project area is 440 m above sea level and the minimum storage level of Tiga dam is at 506.50 m which provide a perfect setting for gravity irrigation (H-JRBDA, 1985). The irrigable land of KRIP comprises of 62,000 ha and is planned to be implemented in two phases. The first phase (KRIP Phase I) covers an area of 22,000 hectares of irrigable land and commenced operation in 1976. The second phase (KRIP II) based on Hadeja Valley and Jama'are Project covers an area of 40,000 hectares of irrigable land (Sangari, 2006). Karfi sector is the largest sector (617 ha) among the 41 sectors of KRIP Phase I. Some canals of the sector have either no water, excessive growth of Typha, poor drainage or cracks. The lands are poorly managed. These have the potentials to impair with the land quality. It is therefore imperative to employ new emerging technologies that can allow for quicker, cheaper and more extensive observation of the landscape for more efficient, affordable and sustainable decision making. The application of remote sensing and Geographical Information Systems (GIS) allow spatial analysis as well as understanding the relationship between environmental components and providing a decision support tool (IFAD,UN-H,GLTN, 2012). This research intends to apply geospatial tools (remote sensing and GIS) to map the biophysical conditions of the soil, including soil fertility and salt development (salinity, alkalinity or saline – alkaline condition).

Materials and Methods

Description of the study area

The study was conducted in the Karfi sector, which is close to Karfi town in Kura LGA, Kano State (Fig.1). It is located on Longitude 11˚ 49′ 25″ N and Latitude 8˚ 29′ 37″ E, it has an elevation of 465meters above the sea level. The population is 9,263 (NPC, 2006). The climate of the study area in general is Tropical wet and dry type (Aw - Koppean's). The mean annual rainfall is about 800mm. The rainy season has a moderate effect on temperature, which falls to the lowest in August, with a mean monthly value of 24.5 ˚C but Relative Humidity in this month is usually high (about 80%). Relative Humidity is very low from November to January – about 23% (Adamu, *et al*., 2014).

The physical features of the sector were determined by digitizing Landsat 8 image (obtained from USGS) of the sector (Table 1).

Table 1. Physical Properties of Karfi Sector

Features	Measurement
Boundary	617 ha
Farm parcel	154.85 ha
Non irrigated block	158.97 ha
Flooded Block	3.85 ha
Artificial dam	5.45 ha
Length of drainage	13.096 km
Length of blocked drainage	5.463 km
Length of field canal	18.57 km
Length of cracked field canals	2.282 km
Main Canal	9.356 km

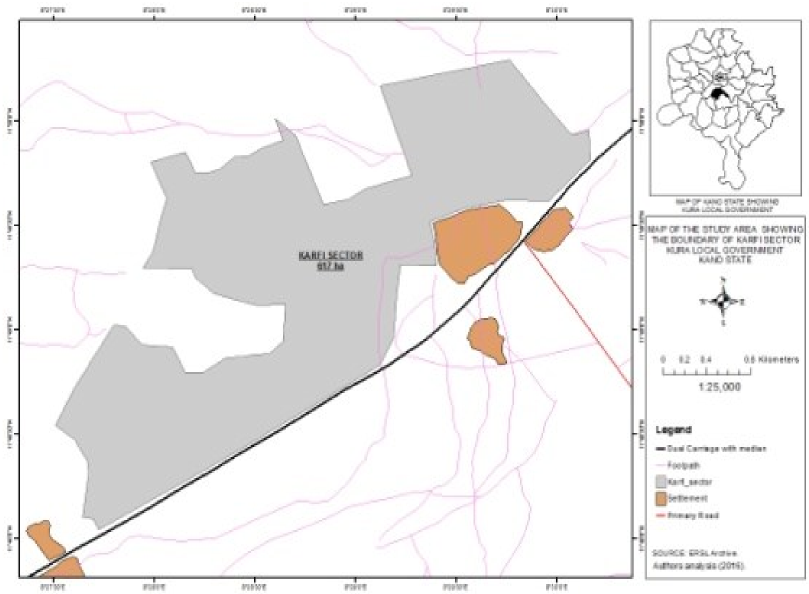


Fig. 1: Map of the Study Area: The Karfi Sector

Soil Sample Collection, Preparation and Analyses

A total of 69 composites were collected at a depth of 0 – 30cm with a soil auger, based on simple random sampling, placed in polythene bags and the coordinates of the farm block were recorded. The samples were labelled, taken to the lab, passed through a 2mm sieve and presented for analysis. Soil pH (1:2.5 soil to water) was determined with glass electrode pH meter (Bates,1954). Particle size distribution was determined using hydrometer method (Bouyouscos (1962). EC was determined using conductivity meter 1:5 soil-water ratio (Landon, 1991). Organic carbon was determined using the Walkley & Black (1934) method. Total N was obtained using the Macro Kjeldahl method (Black 1965) and Available P was determined using the Bray-1 method (Bray and Kurtz, 1945).

Statistical Analysis

The results were entered into Microsoft Excel with the respective coordinates (to allow for geospatial analyses) of the farm blocks and imported into GIS environment using ArcGIS 10.2.1. Inverse distance weighted (IDW) and semivariogram of Ordinary Kriging were used to analyse the spatial distribution of the parameters. Semivariogram models were tested from ArcGIS 10.2.1. It is vital to choose an appropriate model to estimate spatial statistics as each model yields different values for nugget, sill, partial sill, spatial dependency and range which are essential for geostatistical analyses (Ahmed, 2015). Statistical Package for Social Science (SPSS 21) was used for descriptive statistics of the soil parameters.

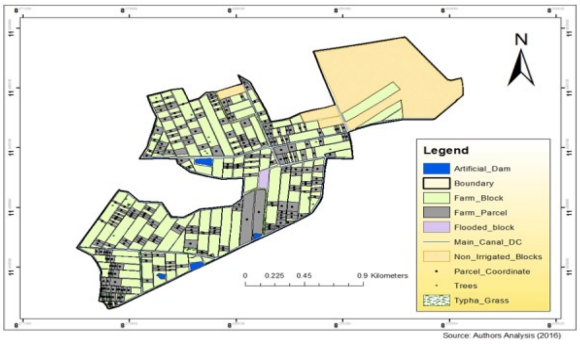
Results and Discussions

Physical Properties

The land cover of Karfi sector was composed of bare land, water bodies and assorted vegetation while the land use is agricultural land. The result (Table 1 and Fig 2) shows that the boundary of the Sector is 617ha; the farmlands that were fully irrigated were 154.53 ha. The total area of non-irrigated farm blocks was found to be 158.97ha. Flooded block occupied 3.85ha and artificial dam 5.45ha. The length of the drainage that was properly functioning was 13.096km and places where the drainage was destroyed were 5.463km. The main canal of the sector was about 9.356km, while length of the field canals was 17.42km and place where field canals were not functioning were about 2.282km. This glaringly indicates the level at which this important agricultural resource is being misused.

Geostatistical Analysis

Ordinary Kriging and Inverse Distance Weight (IDW) methods were used and semivariogram models were tested. The results of RMSE for the models showed that Rational Quadratic, Hole effect, Gaussian, Circular, Stable and Exponential with lowest RMSE are the best fit models for the prediction of soil parameters and production of raster maps of spatial distribution for each parameter (Table 2). The results show the spatial distribution for predicting the value for cell in a raster from a limited number of sample data points.



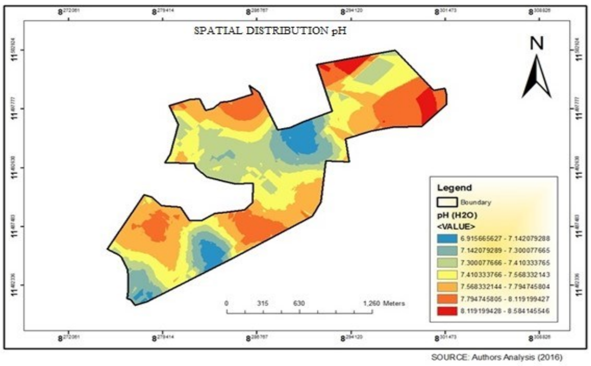
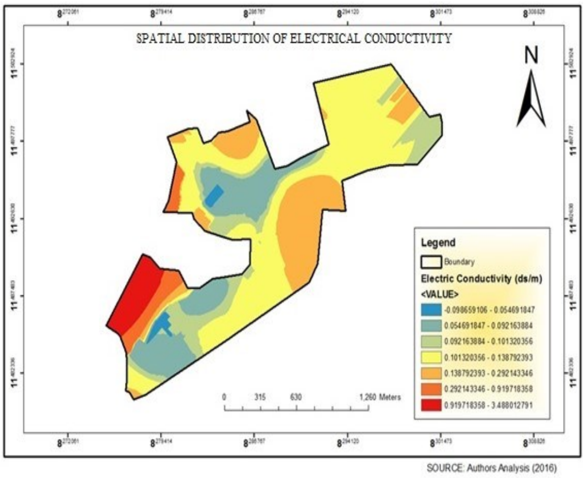


Fig 2. A Map of Farm Parcels. Fig.3: Spatial Distribution of pH.

The spatial dependency Co/(Co+C) for the soil parameters (Table 2) at the depth of 30cm was: weak <0.25, moderate 0.25-0.75 and strong >0.75 (Ahmed, 2015). Thus these parameters (EC, OC, N, K, Na, Mg, Ca and P) indicate moderate spatial dependency with the value within (0.25-0.75) and (EA and CEC) indicates strong spatial dependency.



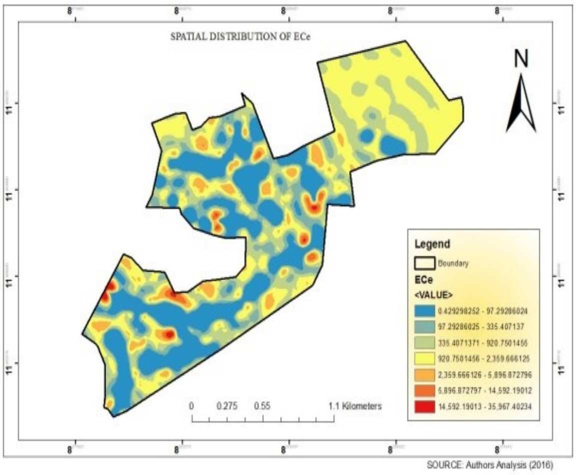
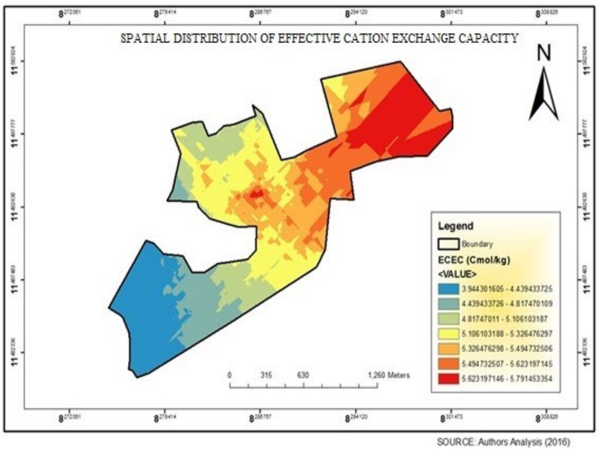


Fig.4: Spatial Distribution of EC. Fig.5: Spatial Distribution of ECe.



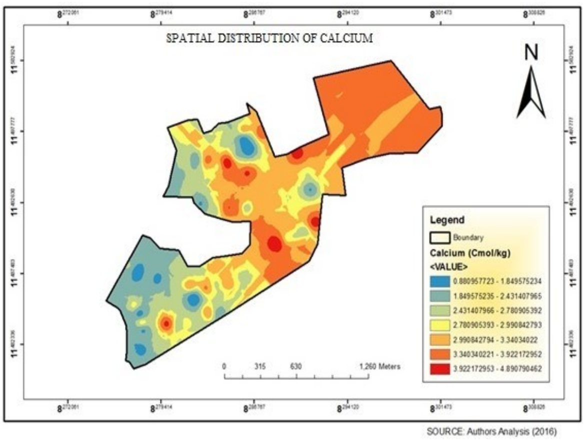


Fig.6: Spatial Distribution of Effective Cation Exchange Capacity. Fig. 7: Spatial Distribution of Calcium.

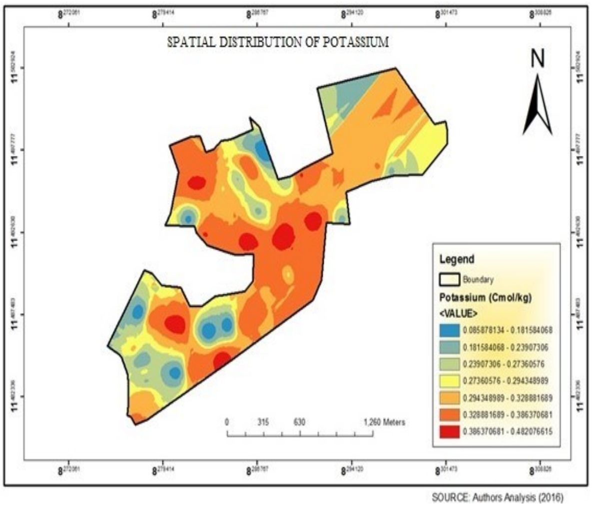


Fig. 8: Spatial Distribution of Potassium.

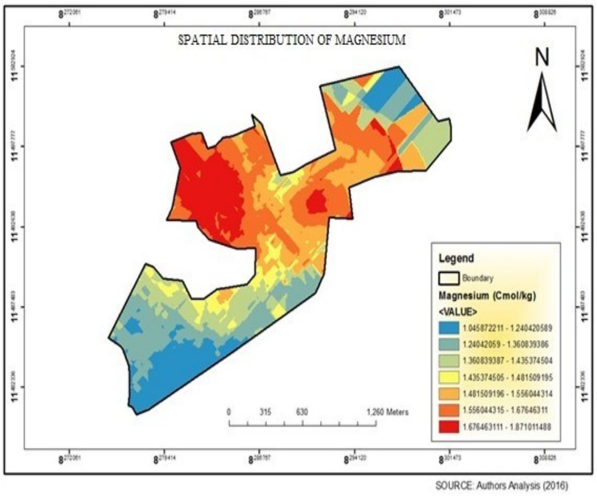


Fig. 9: Spatial Distribution of Magnesium.

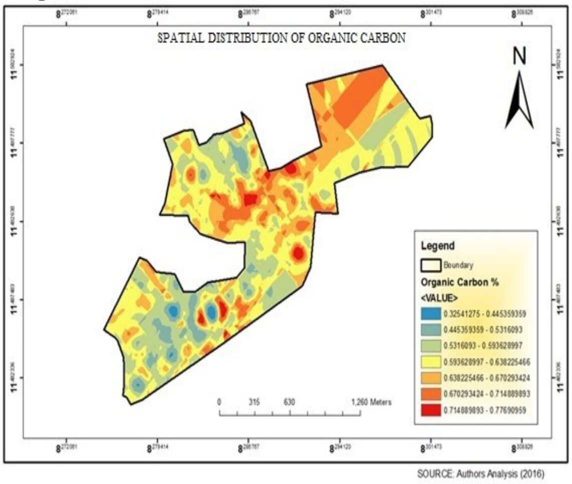


Fig. 10: Spatial Distribution of Organic Carbon.

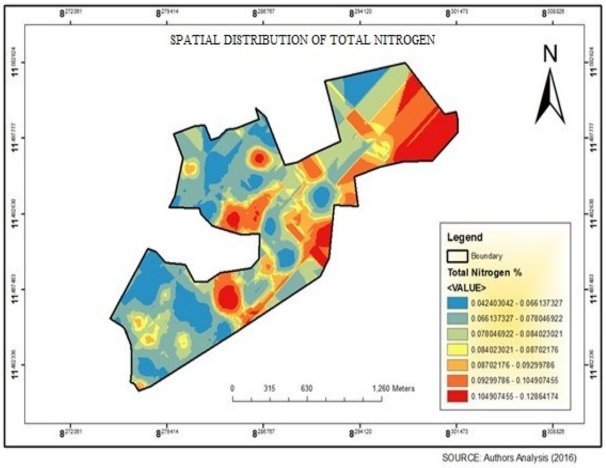


Fig.11: Spatial Distribution of Total N.

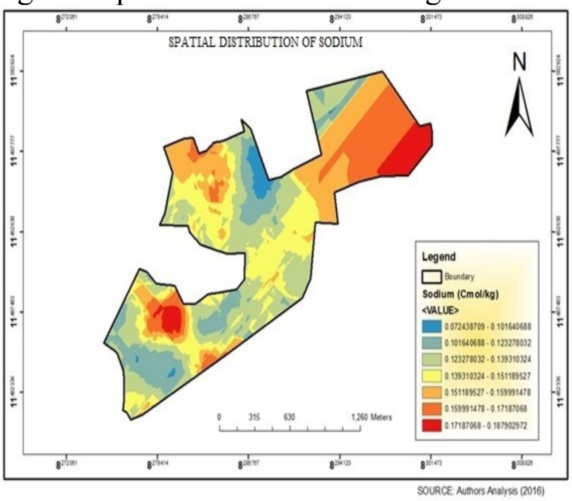


Fig. 12: Spatial Distribution of Na.

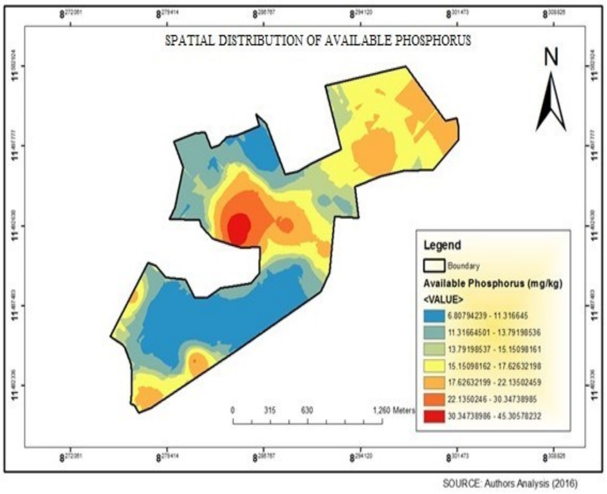


Fig. 13: Spatial Distribution of Available P

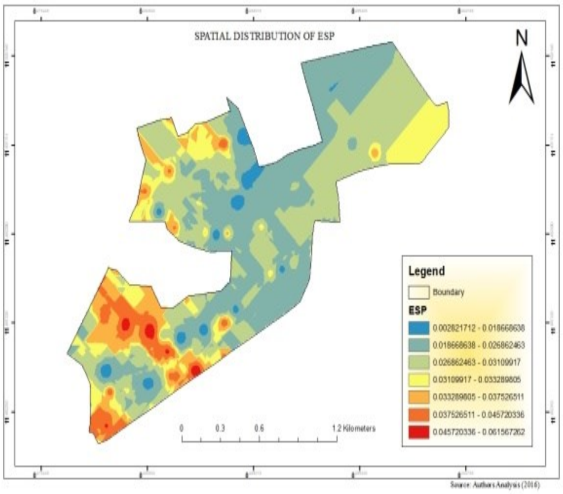


Fig. 14: Spatial distribution of ESP.

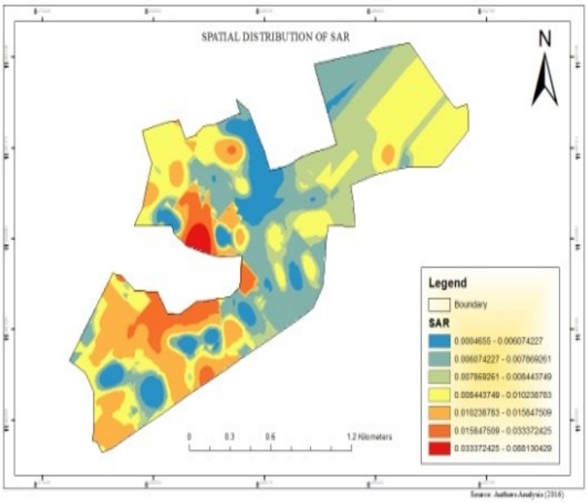


Fig. 15: Spatial distribution of SAR.

The raster maps were reclassified based on the guideline for rating soil parameters (Fig. 16 - 24). Reclassification is done in GIS to replace values in the input raster with new values, to simplify information in the raster or to assign values of preference, sensitivity or priority (Chang, 2019). The EC values (dS/m) were converted to EC_e using Watling, (2007). Interpretations of EC values of determine soil salinity levels depend on the texture of the soil. In order to assess an EC measurement and determine the likely impact of the measured salinity on plant growth, it is necessary to convert to dilute extract (ECe). This is done by multiplying the measured EC with a conversion factor based on the soil texture (Table 3), which influences the degree to which the amount of salt present in the soil will affect plant growth. Therefore, the value for EC (1:5) can be converted to an estimated ECe by multiplying with a texture factor: ECe estimated = EC 1:5 X texture conversion factor (Slavich & Petterson, 1993). The EC values were determined in dS/m. The parameters to determined soil fertility were N, P, K, O.C. & CEC (Brady & Weil, 1999).

The salts leading to salinity are Chlorides and Sulphates of Calcium, Magnesium, Sodium and Potassium and pH usually less than 8.5. Saline soils are characterized by the following: pH < 8.5, EC > 4, ESP < 15, SAR < 13, Saline-Alkaline soils are pH < 8.5, EC > 4, ESP < 15, SAR=13, Alkaline soils pH > 8.5, EC < 4, ESP > 15, SAR > 13 (Brady & Weil, 1999). Therefore, the average condition of the soil samples were found to be free from any form of salt development (salinity, alkalinity and saline-alkaline).

Table 3: Texture-based EC

Soil Texture	Multiplication Factor 1:5
Sand, Loamy sand, Clayey sand	23
Sandy loam, Fine sandy loam, Light sandy loam	14
Loam, Fine sandy loam, Silty loam, Sandy clay loam	9.5
Clay loam, Silty clay loam, Fine sandy clay loam, Sandy clay, Silty clay, Light clay	8.6

Adapted from Slavich and Patterson, 1993

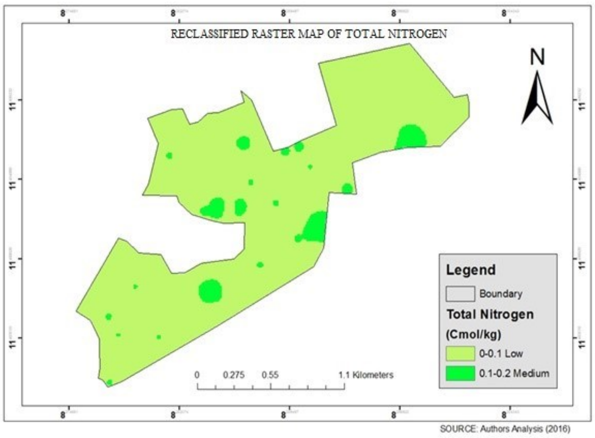


Fig.16: Reclassified Raster Map of Total Nitrogen.

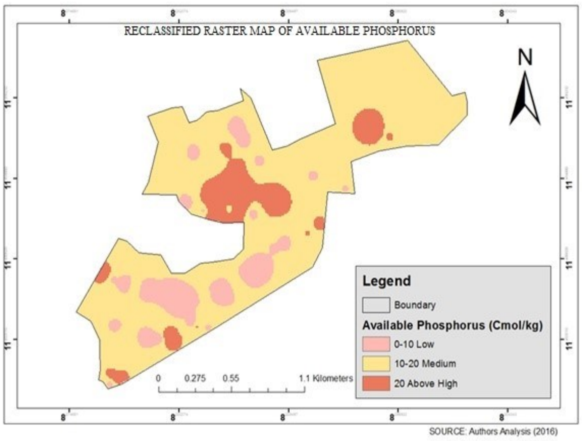


Fig. 17: Reclassified Raster Map of Available Phosphorus.

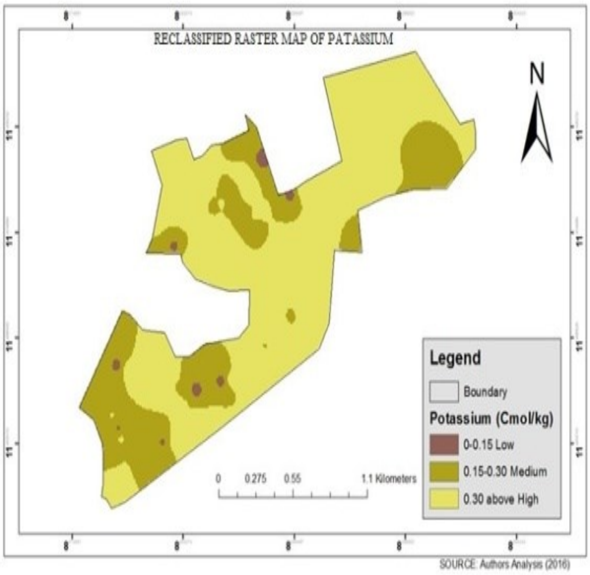


Fig. 18: Reclassified Raster Map of Potassium.

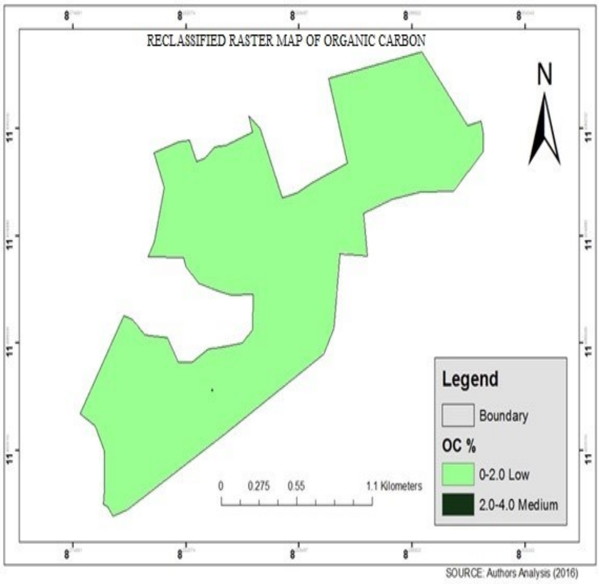


Fig. 19: Reclassified Raster Map of Organic Carbon

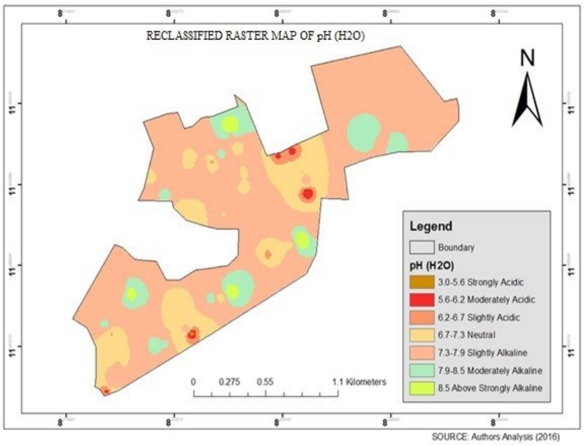


Fig. 20: Reclassified Raster Map of pH.

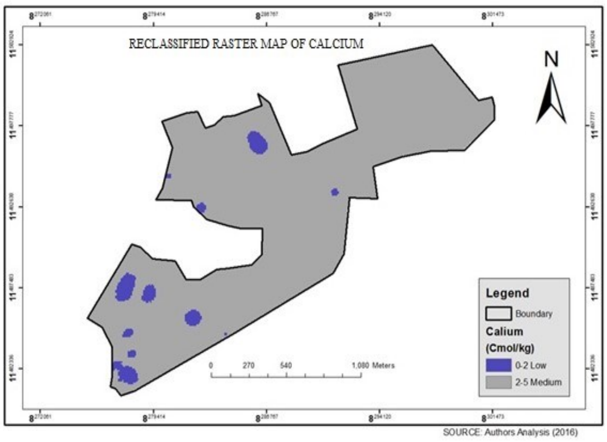
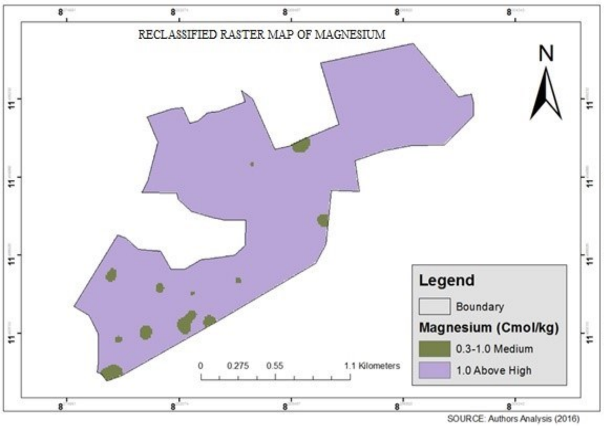


Fig. 21: Reclassified Raster Map of Calcium.



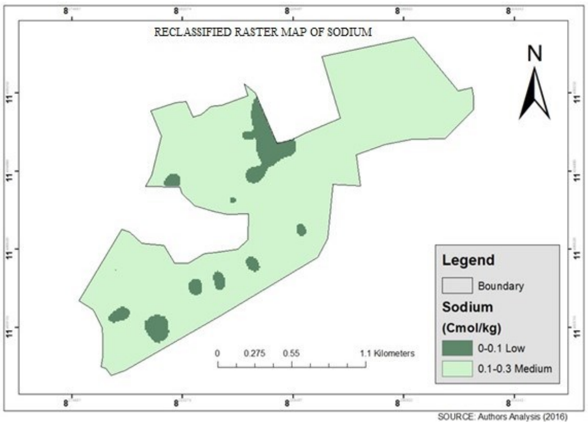


Fig. 22: Reclassified Raster Map of Magnesium. Fig. 23: Reclassified Raster Map of Sodium.

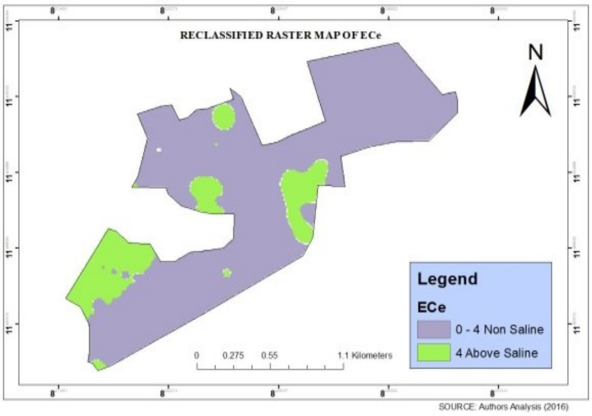


Fig. 24: Reclassified Raster Map of ECe. Fig.25: Spatial distributions of soil texture.

Table 4: Critical Limits for Interpreting Levels of Soil Fertility, Salinity & Sodicity

Parameter	Low	Medium	High	Units
*Organic carbon	2.0	2.0 – 4.0	4.0	%
**Total Nitrogen (%)	0.1	0.1 – 0.2	0.2	%
**Potassium (K)	0.15	0.15 – 0.30	0.30	Cmol/kg
**Sodium (Na)	0.1	0.1 – 0.30	0.30	Cmol/kg
**Magnesium (Mg)	0.3	0.3 – 1.0	1.0	Cmol/kg
**Calcium (Ca)	2	2 – 5	5	Cmol/kg
**CEC	6	6 – 12	12	Cmol/kg
**Available Phosphorus (P)	10	10 - 20	20	Mg/kg

Source: *Francisco, *et al*., (2013), **Adamu, *et al*., (2014)

Critical levels for Fertility & Salt Development from the Study

From table 5 below, organic carbon content ranged from 0.187-0.876% with a mean of 0.6073, indicating low OC. The EC values ranged from 0.036-8.680dS/m, the mean was 0.2393dS/m, while the mean pH was7.48. Exchangeable Soidium Percent (ESP) and SAR were (0.0291 and 0.0098%, respectively). The total Nitrogen falls within low (0.0781). Available P, Ca and Na (with means of 14.86, 2.8177 and 01379 respectively) fall within medium critical level of soil fertility according to table 4 above. Magnesium (1.4348Cmolkg^{-1}) falls within high class (Table 4). Therefore, all the soil samples were found to be free from any form of salt development (alkalinity, salinity or saline-alkalinity condition), and soils of the area were found to be of average fertility (table 4). The distribution of sand, silt and clay ranged from 65-87%, 2-19% and 5-21% respectively (Fig 26). The dominant soil texture of the soil samples was found to be loamy sand (55%). This agrees with Adamu, *et al*., (2014) who found that the soils of KRIP contain high amount of sand with little silt and clay.

Table 5: Critical Limits for Interpreting Levels of Soil fertility, Salinity and Sodicity in Karfi Sector

Parameter	Mean	Unit	Rating
Potassium	0.3090	Cmol/kg	High
Sodium	0.1379	Cmol/kg	Medium
Magnesium	1.4348	Cmol/kg	High
ECEC	4.9384	Cmol/kg	Low
Calcium	2.8177	Cmol/kg	Medium
N	0.0781	%	Low
K	14.8611	mg/kg	High
Available P	14.861	mg/kg	Medium
EC	0.2393	dS/m	Low
pH	7.4756	H_2O	Near neutral
ESP	0.0291	%	Very low
SAR	0.0098	%	Very low

Conclusion

All the soil samples were found to be free from any form of salt development (alkalinity, salinity or saline-alkalinity condition), and soils of the area were found to be averagely fertile. The approach of GIS techniques provide the major tool in evaluation of all attributes of farm parcels and land use mapping undertaken in this study. The authority (H-JRBDA) should repair damaged locations so that the whole sector would operate properly, to increase the productivity of the sector. Regularly monitoring of fertility and salinity status for soil quality evaluation should be carried out, the use of organic matter is dearly needed to sustain fertility. The use of GIS technology in monitoring of sectors of KRIP would help in decision making and proper management of the sectorial resources.

References

Adamu, G. K., Aliyu, A. K., & Jabbi, A. M. (2014). Fertility Assessment of Soils Under Rice Cultivation in Kadawa, Garun Mallam Local Government Kano State. *Part-I :Natural and Applied Sciences*, P 92-99.

Adamu, M., Yakudima, I. I., Alhaji, M., Nabegu, A. B., Ado, Y. U., Umar, B. M., et al. (2014). Overview of the Physical and Human Setting of Kano Region, Nigeria. *Researchjournali's Journal of Geography*, Vol. 1 No. 5.

Ahmed , M. (2015). The Use of Fuzzy Logic and Geostatistical Techniques for Spatialization of Soil Texture in Part of Kano Close Settled Zone Kano State, Nigeria. *International Journal of Agriculture, Forestry and Fisheries*, 115-122.

Bates, R. G. (1954). *Electrometric pH Determination* . New York: John Wiley and Sons Inc.

Black, C. A. (1965). *Methods of soil Analysis Agronomy No. 9 part 2.* Madison Wisconsin.: Amer SOC. Agronomy.

Bouyouscos, G. J. (1962). Hydrometer Method Improved for Making Particle Size Analyses of Soils. *Agronomy Journal*, P. 464-465.

Brady, N. C., & Weil, R. R. (1999). *The Nature and Properties of Soils.* Upper Saddle River, New Jersey: Prentice Hall. Inc.

Bray, R. H., & Kurtz, L. T. (1945). Determination of Total Organic and Available Forms of Phosphorus in Soils. *Soil Science*, P. 39-45.

Hadeja-Jama'are River Basin Development Authority. (1985). *A Brief on Kano River Project Phase I.*

National Population Commission. (2006). Nigerian Population Census, 2006

International Fund for Agricultural Development,UN-Habitat,Global Land Tool Network. (2012). *Using Appoarches and Technologies for Mapping Land and Natural Resource Use and Right(Learning Note).* Nairobi: Tenure Security Learning Initiative for East and Southern Africa.

Chang, K. T. (2019). *Introduction to Geographic Information Systems, 9th Edition.* (Mc Graw Hill) Libgen.lc

Landon, J. R. (1991). Soil Booker Tropical Manual. In *A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics* (p. P. 474). Essex New york: Longman Scientific and Technical.

Sangari, D. U. (2006). An Evaluation of Water and Land Uses in the Kano River Project, Phase I, Kano State. *Applied Science and Evironmental Management, Vol 11(2)*, P 105-111.

Slavich, P. G., & Petterson, G. H. (1993). Estimating the Critical Conductivity of Saturated Paste Extracts from 1:5 Soil:Water Suspensions and Texture. *Australian Journal of Soil Research*, 73-81.

Walkley, A., & Black, I. A. (1934). An Examination of the Degtjaroff Method of Determining Soil Organic Matter and Proposed Modification of the Chromic Acid Titration. *Soil Science*, P. 29-38.

Watling, K. (2007). Measuring Salinity Natural Resources and Water Facts, Queensland Government, Australia. Retrieved August 16, 2016, from *www.wardlab.com/WardUpdates/S oil Fertility Rating.pdf*.

SECTION THREE

Capacity Building in Soil Science and Extension for Sustainable Agriculture "C"

PRACTICES AND TECHNOLOGIES TO MAXIMIZE YIELD AND INCOME AMONG CASSAVA GROWERS IN CROSS RIVER STATE, NIGERIA

***Akpan, I. O., K. I. Ikpi1, K. Alonge, J. Ambi and S. Ada**
[a]*Department of Geography, Faculty of Environmental Science, Nasarawa State University Keffi P.M.B 1022 Keffi Nasarawa State Nigeria*
[b]*Department of Soil Science, Faculty of Agriculture, University of Calabar, Calabar.*
**Corresponding author email:akifem99@gmail.com*

ABSTRACT
Subsistence cassava production, rudimentary farming and low application of modern technologies, results in low production and less income by cassava growers in Cross River State. This study examined the emerging improved farming practices and processing technologies propagated and utilized to support cassava value chain. A cross sectional survey using a multistage random sampling procedure was adopted to choose a sample size of 142 respondents among Biase, Yakurr and Ogoja Local Government Areas which are predominant cassava production clusters in Calabar, Ikom and Ogoja Agricultural Zones of the state, respectively. Data was presented and analyzed using both descriptive statistics, correlation and the multivariate regression model respectively. The results revealed that 31.70 % of the respondent were between ages 46 and 55years. The mean age was 37years with most growers (40.7%) present in Yakurr cluster, Ogoja cluster (33.1%) and Biase cluster (26.1%); have had tertiary education (35.2%) and majority (50.8%) had (4-6) household size with mean household size of 5adults. The well propagated practices include adoption of viable cassava sticks (P>0.01), planting timing (P>0.01), and following crop biophysical requirements during cultivation (P>0.01), while mechanization (P>0.10), fertilizer application (P>0.10), pesticide (P>0.10) and adoption of automated processing equipment (P>0.10), were low. The coefficient of determination shows significant value of cassava yield in Yakurr (R^2 = 0.967), Ogoja (R^2 = 0.864) and Biase (R^2 = 0.826), with annual income ranging from (₦50, 000 to ₦ 250,000) per grower/annum depending on their scope of production. Farm-level capacity building, improving on the farm cultivation and processing equipment are variable ways to maximize cassava output and income among growers.
Keywords: Cross River, cassava growers, farming practices, technologies, value chain

1.0 Introduction
Cassava (*Manihot esculenta Crantz*) is a perennial woody shrub that is grown across the 18 Local Government Areas of Cross River State. The crop is more productive per unit land area and labour than the high yielding staples like rice and maize (Nweke, 2004). Major cassava producing states in Nigeria are Benue, Kogi, Cross River, Ondo, Imo, Akwa Ibom, and Rivers states (Daniels *et al*., 2011) with Cross River State recording 4.4 million tonnes in 2012. Cassava is a major source of biofuel (ethanol), starch, glucose, animal feed and high-quality cassava flour (HQCF) containing carbohydrate, vitamins and iron. It is used as raw material for more than 80 industrial products meant for human consumption (Agwu *et al.,* 2012).

Cassava is not traded internationally in its fresh state because the tubers deteriorate very rapidly (FAOSTAT, 2017). However, since Nigeria has comparative advantage over other countries in cassava production, the government is eager to promote its use as it is rich in starch in the form of carbohydrate, with multiple uses. Cassava is consumed in many processed forms, in the industry and also as livestock feed.

Despite its preeminent position in cassava growing, Nigeria has yet to make much impact on the global cassava market, since most of its produce are consumed domestically. The plant is predominantly used to make a starchy food called garri, and it is also a source for biofuel. Its other products are dry extraction of starch, glue or adhesives, modified starch in pharmaceutical as destrins, as processing inputs, as industrial starch for drilling, and processed foods (Agwu *et al.,* 2012).

Studies by Ohimain (2014) stated that cassava is a higher producer of carbohydrate per hectare than the main cereal crops and can be grown at a considerably lower cost. Cassava processed products can be grouped into either primary (obtained directly from raw cassava root e.g. garri, fufu, starch, chips, pellets etc.) or secondary products (e.g. confectionaries, starch, etc.). But with new initiatives under way aimed at increasing and improving cassava production and developing new ways to use the crop, Nigeria hopes to utilize cassava as part of its strategy to diversify its economy away from petroleum initiatives to boost production. According to a Nigerian Presidential Initiative of July 2002, the cropped area of cultivation of cassava was proposed to be increased to 5 million hectares by the end of 2010 with a projected annual yield of 150 million tonnes resulting in an annual export earnings of US$5 billion. The increased demand for cassava-based products necessitates increased production and yields. Cassava processing as one of the off-farm-level activities among rural growers in the study area is carried out using insufficient semi-automated methods with the made-in-China engine grater, while the use of fully automated technologies seems to be non-existent as at the time of this study. Traditional cassava processing method involves regimented steps like peeling, soaking, grinding, steeping in water and left in the open to ferment, drying, milling, roasting, steaming, pounding and mixing in cold or hot water as the case may be. These is labour intensive but the application of improved processing technology can reduce processing time, labour and encourage further production (Falade and Akingbala, 2021).

According to IITA (2013), it is necessary to device and propagate improved techniques that are capable of increasing the income generating potentials of cassava growers while promoting the marketability of the produce. This study therefore elicits greater insight to the cassava value chain. The aim of this study was to evaluate the cassava growers socio-economic characteristics that trigger the propagation and utilization of improved technologies consistent with improved farming practices to maximize production and household income, with specific emphasis on characterizing cassava growers in the study area, examining the availability and level of propagation including usage of post-harvest and processing technologies and suggest solutions that highlight the relationship between the variables studied in explaining the results. The results would in turn help to suggest ways of enhancing cassava growers' use of these technologies.

2.0 Materials and Methods

2.1 Location of the study

Cross River State lies between Latitude 5°, 32' and 4°, 27'N and Longitude 7°, 50' and 9°, 28'E. The State is situated within the rich tropical rainforest region of Nigeria with the highest level of cassava production put at 5million tonnes in 2012. The state is located in the Southeastern corner of Nigeria and shares a common boundary with the Republic of Cameroon to the East, Benue State to the North, Ebonyi State to the Northwest, Abia and Anambra States to the West and Akwa Ibom State to the South. The state has an area of 20,156 km² with a population of 4.4 million people as at 2023 census (NPC, 2023). Cassava growers from the three agricultural zones of the State namely Ikom, Calabar and Ogoja formed the population for this study. Geographically, the state is mainly divided between the Southern Guinea Savannah in the far north and the tropical rainforest in the majority of the interior of the state.

2.2 Sample Size and Selection of Respondents

A multistage random sampling technique was used to select respondents for the study. In the first stage, three (3) Local Government Areas (LGAs) were selected randomly from each of the three Agricultural Zones. In the Ikom Zone, Yakurr LGA was selected while Biase and Ogoja LGAs were selected in the Calabar and Ogoja Zones, respectively. The basis for the selection was the preponderance of cassava cultivation in these three LGAs. The second stage involved the random selection of eight (8) farming communities from each of the three LGAs previously selected making a total of twelve (24) farming communities. The third stage involved a random selection of six (6) households from each of the twelve farming communities making a total of one hundred and forty-four (144) respondents for the study. The data was cleaned up to accommodate one hundred and forty-two (142) respondents validated for the study. Descriptive survey research design was used, and primary data was collected using the random sampling techniques from a sample size of 142 respondents.

2.3 Data collection

Cassava growers' quantitative data were obtained by interview guide. The data collected included respondents' socio-economic information, farm-level practices and technologies like post-harvest and processing equipment propagated to enhance output and income of growers. Descriptive statistics using percentages, mean and standard deviation were used. Sampling procedure used in the study reflected the three divisions of the state's agricultural zones. This was performed by using the multistage sampling technique to select 142 respondents for this study. From Calabar, Ikom and Ogoja zones, Biase, Yakurr and Ogoja LGAs, respectively were selected via simple random sampling. These LGAs represent high cassava production clusters in the zones. Furthermore, eight communities were randomly selected, while six households were finally randomly selected to constitute a total of 144 respondents upon which 142 respondents were validated.

2.4 Statistical analysis

Descriptive statistics and the multivariate regression (MVP) model were used to describe the socio-demographic characteristics of the cassava growers and how improved farming practices were propagated in the study area *vis-a-vis* post-harvest and processing technologies that are mutually exclusive to allow different growers to propagate more than one components at a time while correlation technique was used to analyze the coefficient of determination and value of cassava yield.

The MVP regression model is stated in the equation bellow;

$$C^{\circ}_{ij} = X_{ij}\,\beta_j + e_{ij}$$

$$C_{ij} = \{1 \text{ if } \mathring{C}_{ij} > 0;\ \{0 \text{ if } \mathring{C}_{ij} \leq 0$$

Equation 1.

e_{ij}, $j = 1, --- J$ are multivariate normal distribution error terms, each with a zero mean and variance-covariance matrix Q. Each of the elements of the principal diagonal of Q has a value of 1, and correlations $\rho_{jm} = \beta_{nj}$ as off-diagonal elements. There are four mutually inclusive strategies from which growers can propagate the practices and technologies in this study. Hence $J = 4$. For the J-equation system $E(ee') = \Sigma * \mathbf{I}_N$.

Where $\Sigma = (\sigma_{ij})$ is 4 x 4 positive-definite matrix and $*$ is the kronecker products of the two matrices (Cameron & Trivedi, 2010)

Where:
C_{ij} = 1 if growers (i) propagate farming practices/technologies (j), 0 otherwise
X_1 = State (1 if Calabar {Biase}, 0 otherwise: Ikom {Yakurr} or Ogoja {Ogoja})
X_2 = Age of cassava growers (years)
X_3 = Sex of the cassava growers (1 for Male, 0 for female)
X_4 = Marital status of growers (1 if married, 0 otherwise)
X_5 = Household size of growers (number of people)
X_6 = Propagation of improved practices (1 if grower propagate improved practices, 0 otherwise)
X_7 = Educational level of growers (primary, secondary or tertiary education attained)
X_8 = Knowledge of biophysical requirements during cultivation (1 if know-how, 0 otherwise)
X_9 = Application of post-harvest processing technologies (1 if technology apply, 0 otherwise)
X_{10} = Availability of automated processors (1 if automated processors are used, 0 otherwise)
X_{12} = Supplementary irrigation systems (1 if supplementary irrigation is adopted, 0 otherwise)

3.0 Results and Discussion

3.1 Socio-demographic characteristics of cassava growers in Cross River State

In responses to the first objective, socio-demographic characteristics (age, gender, marital status, educational level, household size and scope of cassava production) of the cassava growers are summarized thus; the result of the findings (Table 1) revealed that 31.70 % of the respondents were between ages 46 and 55 years, while the mean age was 36.60 years. It is inferred that most of the cassava farmers are middle-aged persons who are active enough to manage their farm effectively even though women constitute 63.4 % as against 36.6 % of men engaged in cassava production in the area. This is an indication that the female component was more involved in cassava production. 71.8 % of the cassava farmers were married, while 17.6 % were single. The high percentage of married people is an indication of the involvement of more responsible adults in the cultivation of cassava. Going through the distribution of the educational level attained, it can be seen that holders of tertiary education had the highest percentage (35.2%) of involvement in cassava farming. Primary occupation of 52.8 % was apportioned for farming. Farmer distribution according to farm location revealed more cassava growers (40.7%) in Yakurr, followed by Ogoja (33.1%) and Biase clusters (26.1%) where growers who were mostly women that concentrate in cassava production as their staple crop. Cassava is fast expanding staple food crops and has gained prominence among farmers while the industrial demand is also rising consistently (FAO, 2018).

Table 1. Socio-demographic characteristics of cassava farmers in Cross River State

Variable	Category	Frequency	Percentage
Age (years)	20– 35	34	23.9
	36 – 45	32	22.5
	46 – 55	45	31.7
	56 – 65	25	17.6
	66 – 75	6	4.2
	Mean (36.6years)		
Gender	Male	52	36.6
	Female	90	63.4
Marital status	Single	25	17.6
	Married	102	71.8
	Divorced	9	6.3

	Widow	6	4.2
Farming Experience	5 – 10	15	7.0
	11 – 15	25	17.6
	16 – 20	70	49.3
	21 – 25	22	15.5
	26 – 30	10	10.6
	Mean (15.5 years)		
Educational level			
No formal Education	0– 1	20	14.1
Primary school	2 – 6	30	21.1
Secondary school	7 – 11	42	29.6
Tertiary institution	12 – 16	50	35.2
Primary occupation	Farming	75	52.8
	Civil servant	40	28.2
	Others	27	19.0
Household size	1 – 3	30	21.1
	4 – 6	72	50.8
	7 – 9	40	28.1
	Mean (5 persons)		
Scope of production	Subsistence	40	28.1
Subsistence	Commercial	30	21.1
Commercial	Both	72	50.7

Source: Field Survey 2023

3.2 Propagation of Farm Practices and following Crop Biophysical requirement during Cultivation

Findings in Table 2 indicate that only 19 % of tractors, 5.6 % of harrowers and 0 % of harvesters were present in the study area, as most cassava growers cannot afford to hire them. However, in other categories, semi-improved tools like power tillers, fabricated cassava peeler and grinding machines and few food processing machines comprised of 77%. The use of rudimentary tools like cutlasses was on a full scale of 100%, while hoes comprised 86% and were very significant as all the cassava growers possessed them. They were mostly used for land preparation, weeding and harvesting of cassava. Adoption of more improved farming tools, harvesters and automated processing equipment enhance growers' efficiency and widen income gaps. According to Moyo (2016), poor management of agricultural lands has affected sustainable production of food in sub-Saharan Africa.

Table 2. Farm implements used

Variables/Location	Frequency				Frequency	
	Biase	Yakurr	Ogoja	Total	(%)	Remark
Cutlasses	40	55	47	142	100	Rudimentary
Hoes	30	50	42	122	86.0	Rudimentary
Harrowers/Ridgers	1	2	5	8	5.6	Mechanized
Diggers	32	30	35	97	68.3	Rudimentary
Tractor	5	12	10	27	19.0	Mechanized
Harvester	0	0	0	0	0	Mechanized
Others	30	40	39	109	77.0	Improved

Source: Field Survey, 2023

3.3 Propagation of Farming Practices and Improving Soil-biophysical Conditions

Findings in Table 3 shows that 93 % of the growers adopted crop rotation without applying any input to improve soil fertility depending on their location. 85 % of growers used bush burning as manure, whereas 42.3 % used chemical fertilizers. This could be explained by farmers' exposure to the advantages of organic amendments or lack of access to government subsidized chemical fertilizers which are diverted for sale at higher market prices. Those using both improved cassava seedlings (74%), local cassava stakes (88%), Ridging/mounds (88%) and planting timing (98.6%) during cultivation were very high, indicating that growers actually took ownership of their well acquainted subsistence farming, rudimentary practices and low technological development across the study area more so that the use of insecticides (47%) and weather forecasting technology (50%) is actually utilized, but insufficiently propagated. Investment in modern inputs such as, irrigation facilities, hybrid cassava stakes, chemical fertilizers and agro-chemicals would greatly improve the quality and quantity of cassava output and enhance income of growers in the study area. According to Ofem *et al*. (2023), the quality and quantity of soil organic carbon influences cassava production in Yakurr LGA, particularly because it improves soil management, increases cassava yield and also enhances infiltration rate of the soils.

Table 3. Farming Practices and Improving Soil-biophysical Conditions

Variables/Location	Frequency				Percentage	
	Biase	Yakurr	Ogoja	Total	(%)	Propagated
Improved Cassava stake	30	40	35	105	74.0	Very high
Local Cassava stake	50	35	40	125	88.0	Very high
Ridging/mounds	40	45	40	125	88.0	Very high
Planting timing (March-November)	40	50	50	140	98.6	Very high
Weather forecast	15	30	26	71	50.0	High
Soil Amendment (Crop rotation)	40	50	42	132	93.0	Very high
Organic manure (Bush burning)	30	45	35	120	85.0	High
Fertilizer application	20	20	20	60	42.3	Low
Use of insecticides	12	30	25	67	47.2	Low
Weed control (hoeing/hand picking)	42	50	50	142	100	Very high
Irrigation system	2	5	1	8	6.0	Very low

*Multiple responses

3.4 Use of Post-Harvest and Processing Technologies among Growers

Transportation of harvested cassava roots to local grinding stations, back home for processing and final marketing has become a big huddle as 56.3% (Table 4) of growers conveyed their produce on their heads trekking distances, on bikes and bicycles or even pushed in wheelbarrows. There are instances where growers choose to selloff harvested cassava at farm-gates to willing buyers at lower prices to reduce drudgery associated with post-harvest and processing challenges. This stressful and tedious activity due to the bulky and weighty nature of cassava roots constitutes the need for improved-farm to market-roads especially with the abundance of China fabricated grinding machines (96%) in the locality. 82 % of growers processed their cassava roots straight to the market so as to maximize income by selling them at higher prices especially in situations where Garri and other products are in high demand. Packaging of cassava produce (26%) was relatively low, implying the absence of mechanized farming, harvesters and automated processing technologies across the study area.

Table 4. Post-harvest and Processing Technologies Propagated

Variables/Location	Frequency				Percentage	
	Biase	Yakurr	Ogoja	Total	(%)	Remark
Accessible farm roads	25	30	35	80	56.3	Available
Use of Harvester	0	0	0	0	0	Not Available
Grinding Machine	41	50	45	136	96.0	Abundant
Automated processors	0	0	0	0	0	Not Available
Packaging of produce	10	15	12	37	26.1	Relative/low
Cassava Market	30	41	45	116	82.0	Abundant

*Multiple responses

3.5 Processed Products from Cassava Roots

Results from Table 5. indicate that 99% of the growers processed their cassava into Garri to give the product a longer shelf life and make transportation and storage easier, 45.8% processed into Fufu to improve on the nutritional state of the cassava, 38.7% processed into Tapioka to sell faster as a ready snack consumed with cocoa nut or African pear, and 28.2% processed into cassava cake to promote local delicacy and cultural heritage during festivals and carnivals. However, 43% processed for animal feeds, while 7% dried and processed into starch. The shelf- life of Garri and ready market determine its ease of packaging and transportation compared to other products. Cassava is considered food for the poor, and has been a widely criticized crop for its propensity to deplete soil nutrients and open the farmland to erosion (Hershey et al., 2001).

Table 5. Processed products from cassava Roots in Cross River State

Variables/Location	Frequency				Percentage	
	Biase	Yakurr	Ogoja	Total	(%)	Remark
Garri	42	52	46	140	99.0	Very high
Tapioka	15	30	10	55	38.7	Low
Fufu (Akpu)	20	20	25	65	45.8	Medium
Fried cassava cake	10	20	10	40	28.2	Low
Starch	2	3	5	10	7.0	Very low
Animal feed	15	20	25	60	43.0	Medium

*Multiple responses

3.3 Cassava Production and Yield in Cross River State

Assessment of the cassava production (Table 6) and yield (using independent variables) from 2001-2022 in Cross River State (Figure 3.2) shows the trend line option of the linear equation with significant increase in yield across the study area. However, in Yakurr, the coefficient of determination (R^2 = 0.967) indicates significant value of Cassava yield, followed by Ogoja (R^2 = 0.864) and Biase (R^2 = 0.826) coming slightly below that of the crop yield in Ogoja (Table 7). Although there is high Cassava production in Cross River State, the quantities of the mass production or harvest as growers struggle to exceed 200tonnes per annum. The production dependence on the propagation of farming practices and farm input. If there is increase in agricultural input, the quantity might exceed the present harvest of the cassava crop. Most farmers are small-scale cassava production involved in mixed cropping and mixed farming systems to guarantee constant food supply (Abdul-kareem & Şahinli, 2017).

Table 6. Quantity of Cassava Harvested in Cross River State

Cassava Harvested	**Biase**		**Yakurr**		**Ogoja**	
(Tonnes)	Frequency	(%)	Frequency	(%)	Frequency	(%)
< 50	52	36.6	50	35.2	48	33.8
50 – 100	40	28.2	42	29.6	46	32.4
101 – 150	40	28.2	35	24.6	38	26.8
151 – 200	8	5.6	10	7.0	7	4.9
>200	2	1.4	5	3.5	3	2.1

Source: Field survey (2023)

Table 7. Linear Trend line equation of Cassava Production and Yield in Cross River State

Agricultural Zone	Growers Cluster	Cassava Production	R^2 Significant Yield
Calabar	Biase	y = 2.433x – 4863	R^2 = 0.826
Ikom	Ogoja	y = 1.346x – 2692	R^2 = 0.864
Ogoja	Yakurr	y = 3.832x – 7670	R^2 = 0.967

Author's Analysis (2023)

3.4 Income Generated by Cassava Growers in Cross River State

Table 8 shows that the highest income obtained by growers from their Cassava Production in Cross River State is between ₦50,000- ₦150,000 (61.2%) and upward of ₦151,000 - ₦250,000 naira (15%) depending on their scope of cultivation. It implies that on the average, individual growers obtained additional income of between ₦50, 000 - ₦150, 000 and an upward of ₦ 250,000 per grower/annum. However, it might be more if farmers had access to improved farming inputs for increase production over time.

Table 8. Income Earned from Cassava by the Growers in Cross River State

Income Earned	**Biase**		**Yakurr**		**Ogoja**	
(₦)	Frequency	(%)	Frequency	(%)	Frequency	(%)
< 50,000	45	31.7	30	21.1	40	28.2
50,000 – 100,000	50	35.2	36	25.4	53	37.3
101,000 – 150,000	40	28.2	36	25.4	34	23.9
151,000 – 200,000	5	3.5	25	17.6	10	7.0
201,000 – 250.000	2	1.4	15	10.5	5	3.5

Source: Field survey (2023)

Table 8. Propagation of practices and Technologies to maximize yield and income.

Explanatory Variables	Fertilizer/Soil amendment	Supplementary irrigation	Weather forecasting	Planting timing
State (C/River dummy)	*0.268 (0.148)	***0.590 (0.188)	***0.816 (0.195)	0.175 (0.148)
Age of growers	-0.005 (0.007)	0.011 (0.009)	-0.001 (0.007)	***0.023 (0.007)
Marital status (married dummy)	-0.171 (0.189)	-0.108 (0.527)	-0.140 (0.204)	-0.154 (0.192)
Sex (female dummy)	0.129 (0.136)	0.094 (0.191)	0.151 (0.153)	0.173 (0.142)
Household size	$3.0e^{-4}$ (0.018)	-0.026 (0.021)	-0.031 (0.018)	*-0.032 (0.018)
Educational level	0.229 (0.159)	-0.188 (0.250)	0.144 (0.223)	***0.182 (0.209)
Adoption of viable cassava stake	***-0.624 (0.157)	-0.325 (0.214)	-0.041 (0.167)	0.225 (0.160)
Following crop biophysical requirements at cultivation	**0.361 (0.142)	***0.663 (0.172)	***0.485 (0.146)	*0.250 (0.141)
Use of pesticides	*0.366 (0.210)	0.257 (0.232)	-0.188 (0.217)	0.230 (0.204)
Mechanization dummy	-0.201 (0.429)	-0.139 (0.545)	0.103 (0.458)	-1.088 (0.437)
Harvesting /post-harvest technology dummy	0.090 (0.148)	0.266 (0.185)	*0.288 (0.159)	-0.173 (0.149)
Automated processors dummy	-0.030 (0.030)	0.010 (0.022)	0.000 (0.030)	-0.023 (0.009)
Constant	-0.201 (0.429)	-0.139 (0.545)	0.103 (0.458)	-1.088 (0.437)
Log likelihood Wald Chi square Prob > X^2	-862.837 135.16 0.0000			
Standard error in the parenthesis	***-*Coefficients significant at 1%* **- *Coefficients significant at 5%* *- *Coefficients significant at 10%*			

Source: Authors computation

4.0 Conclusion and Recommendation

The availability, level of propagation and usage of improved farming practices and processing technologies among growers were examined in this study. More women were involved in cassava production, processing and marketing than men. Most of them were married, and have had tertiary education. Households with 4-7 persons were highest and mostly households with children. Most of the farmers fell within an active age range of 31 to 50 years and relied on their families for labor, while hired labor was minimal. Findings indicated that the majority of members in each of the households were involved in the cassava value chain activities, attesting that the majority of growers actually propagated and used improved technologies though some were at infinitesimal levels.

It is therefore highly recommended that the socio-demographic variables (Gender, age, marital status, household size, level of education of growers and scope of production) be regarded as vital tools in deciding and promoting the propagation of improved practices and technologies towards maximizing yield and income by cassava growers. Farm-level capacity building, improving on the farm cultivation inputs and processing equipment are variable ways to maximize cassava output and household income in the study area.

Reference

Abdul-kareem, M. M. & Şahinli, M. A. (2017). Demographic and socio-economic characteristics of cassava farmers influencing output levels in the Savannah Zone of Northern Ghana. African Journal of Agricultural Research, 13(4): 189-195. DOI: 10.5897/AJAR2017.12268

Agwu, N. M., Nwachukwu, I. N., & Anyanwu, C. I. (2012). Climate variability: Relative effect on Nigeria's cassava productive capacity. *Rep. Opin*, *4*, 11–14.

Cameron, A. C., & Trivedi, p. k (2010). *Microeconomics using Stata.* Revised edition. College Station, TX: Stata Press.

Daniels, A., Udah, A., Elechi, N., Oriuwa, C., Tijani, G., & Sanni, A. (2011). Report on Cassava

Value Chain Analysis in the Niger Delta. Foundation for Partnership Initiatives in the Niger Delta (PIND), 1st Floor St. James Building, 167. Abuja (Nigeria).

FAO (2018). Food Outlook - Biannual Report on Global Food Markets – November 2018.

Rome, p. 104. License: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/ca2320en/CA2320EN.pdf.

Hershey, C., Henry, G., Best, R., Kawano, K., Howeler, R.H., & Iglesias, C. (2001). Cassava in Asia: Expanding the Competitive Edge in Diversified Markets. A Review of Cassava in Asia with Country Case Studies on Thailand and Vietnam. Validation Forum on the Global Cassava Development Strategy (2001, Rome, Italy) Proceedings, vol. 3. Food and Agriculture Organization of the United Nations (FAO); International Fund for Agricultural Development (IFAD), Rome, IT, pp. 1–62.

Ofem, K. I., Effiong, J. E., Okoye, B. E., Aberagi, F. V., Elemi, E. D. &i Abam, P. O. (2023).

Characterization, fertility capability and land suitability classifications for cassava production in Ugep-Yakurr Local Government Area, Cross River State – Nigeria. *Journal of Agriculture, Forestry & Environment, 2023, 7(1): 12 - 32*

Ohimain, E. I. (2014). The Prospect and Challenges of Cassava Inclusion in Wheat Bread

Policy in Nigeria. *International Journal of Science, Technology and Society*, 2, 1:6-17.

Falade, K. O., Akingbala, J. O (2011). Utilization of cassava for food. *Food Rev. International*

27:51-83.

FAOSTAT (2017) Production, crop, cassava, 2010 data, *Food and Agricultural Organization*

FAO; Rome. [Google Scholar]

IITA, (International Institute for Tropical Agriculture) (2013) Annual Report

Moyo, S. (2016). Family Farming in Sub-saharan Africa: its Contribution to Agriculture, Food

Security and Rural Development (No. 150). Working Paper.

National Population Commission (NPC). (2023). National Population Census, 2023.

Nweke, F. I. (2004). New Challenges in the Cassava Transformation in Nigeria and Ghana –

IFPRI, Washington.

SECTION FOUR

Advances in Soil Science & Policy Brief "D"

IMPACT OF AGGREGATE STABILITY ON PLANT AVAILABLE MOISTURE CONTENT IN BAUCHI STATE

[1]*Ekle, A.E., [2]Babaji, G.A., [2]Hassan, A.M., [2]Voncir, N.
[1]Department of Soil Science Technology, Federal College of Land Resources Technology, Kuru, Jos, Plateau State, Nigeria
[2]Department of Soil Science, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria
Corresponding author email:ekleademu7@gmail.com

ABSTRACT
Soil quality, aggregate stability, plant available moisture content and pore structure of any soil can be influenced by management practices but the manipulability of this structure largely depends on soil properties such as texture and water quality. This study investigated the comparative impact of aggregate stability on plant available moisture content between soil derived from basement complex and sandstone geology in Bauchi State. Composite samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm from four locations each in four local government areas of the State. The local governments were Toro, Bauchi, Darazo and Alkaleri. Nested design was used in this study. Aggregate stability, soil texture and plant available moisture content were assessed using standard procedures. The result revealed that soil derived from basement complex parent material had significantly ($p < 0.05$) larger aggregate stability compared to soil derived from sandstone parent material. Findings also revealed that plant available moisture content was significantly ($p < 0.05$) higher in soil derived from sandstone compared to soil derived from basement complex parent materials. Further research is recommended to explore management practices such as the use of organic manure aimed at promoting aggregate stability that will improve plant available moisture in soil derived from basement complex geology in the Bauchi State to increase crop production in the area.
Keywords: Aggregate stability, management practices, parent material, Plant available moisture, texture.

Introduction

Large scale soil and water conservation and management against disaster and risk requires very often a thorough understanding of the transport processes inthe unsaturated zone and the integration of this knowledge into holistic management and engineering approaches. While a fairly adequate description of these processes has been aided at the local experimental level by the present availability of accurate measuring techniques and devices, it is still difficult to make reliable predictions on their evolution, particularly at the space and time scales of interest for environmental planning.In that connection, soil pores display a number of important characteristics related to the storage, conductivity and movement of soil water and gases.Thevolume of pore-space, size, shape, type and continuity of pores and distribution in soil are the main factors that influence water storage, infiltration, hydraulic conductivity and surface (water runoff) and subsurface water movement in soil. The unsaturated condition of soil water content is a major state in nature after irrigation process or rainfall. The quantitative application of the theory of unsaturated flow to field or laboratory flow system requires knowledge of the hydraulic conductivity and water characteristic of the soil involved (Klute, 1972).

An effective use of waste, run-off and drainage water in arid and semi-arid zones with limited water resources could be a viable practice to reduce fresh water requirement. Therefore, in time of various climate changes scenario, to assess alternative water sources is particularly critical to control amount and pollution of fresh water bodies. Use of alternative water sources in semi arid soils may; offer opportunity for ground water recharge and alleviate the shortage of water, assist to increase financial gain since plants act as a treatment during evapo-transpiration, alter quantity and distribution of soil micro-organisms, modify soil physical and chemical properties, affect soil structure and physical condition, run off generation and erosion (Jiao *et al*., 2010; Levy *et al*., 2011). Soil aggregate and structure stability is one of the vital physical parameters employed in agricultural and environmental studies, which involved irrigation and drainage management, erosion, run-off and water pollution. One of the core characteristics that affected soil structure are the soil texture and water quality, which is expected to be modified with application of different water resources, because of their contribution on solution electrolyteconcentration and composition (Levi, *et al*., 2003).

The difficulty to quantify the impact of soil properties and water type on soil structure stability has been commonly recognized. The effects of water quality on structure and macropore continuity of soil with different texture and property are not clearly understood (Levi *et al*., 2003; Bronick and Lal 2005). These difficulties could be associated with a number of physical and chemical mechanisms of soil aggregate breakdown by water such; slaking, breakdown caused by compression of entrapped air during fast wetting, breakdown by differential swelling, breakdown by impact of raindrops, physic-chemical dispersion because of osmotic stress upon wetting with low electrolyte water(Le Bisonnais, 1996). These mechanisms differ in the type of energy involved in aggregate disruption and in aggregate size distribution of the disrupted products, and hence in the type of soil and soil properties affecting the mechanisms. Changes in the macro pore system of the soil appear to be the prevailing factor for soil physical properties, infiltration and hydraulic conductivity decline and sealing and run-off generation during irrigation and precipitation. Soil structure deterioration and decreases in infiltration may result in surface run-off, which leads to surface contamination by the effluents and soil erosion. Most of the studies mentioned a significant decrease in soil permeability after the application of rain, run-off or waste water (Shainberg*et al*., 2002; Green *et al*., 2003). The aim of this study is to reveal the impact of aggregate stability on plant available moisture in the study area.

Materials and Methods

Geographical Location of Bauchi State.

Bauchi State occupies a total land area of 49,119km^2 representing about 5.3% of Nigeria's total land mass and is located between latitudes 9^{o}30^1 and 12^o 30^1 North and longitudes 8^o 45^1 and 11^o 0' East. The state is bordered by seven states; Kano and Jigawa to the north, Taraba and Plateau to the south, Gombe and Yobe to the east and Kaduna to the West.

Climate of the Study Area

The state experiences two main seasons; rainy and dry season. The rainy season usually commenced from May and ends in September with minimum rainfall of about 700mm per annum in the north to a maximum of about 1300mm per annum in the South. The vegetation is typically Sudan Savanna type comprising widely dispersed trees (Ibrahim, 2010).

Geology of Bauchi State.

Lithologically, soils in Bauchi State are formed from Basement Complex Rock (BCR) and the Sedimentary Rocks comprising the Kerri-Kerri Formation (KKF) and the Chad Formations (CF)

(Macleod *et al*., 1971). The BCR covers most part of the State. Bauchi is basically composed of crystalline rocks, basement complex mostly Precambrian to the early Paleolithic in age. The rocks include the mixture of granites, gneisses, pegmatite and some amount of charnokite at the margin around the area of Alkalere. Granites are coarse grained and are composed of quartz, alkali, feldspar, biotite and muscouite with ancestry horn bled and haematite. Pegmatite veins within the gneisses are composed of potash feldspar and very large crystal may form. A charnokitic rock occurs around the margin where it forms small out crops. Bauchi metropolis lies within the undifferentiated basement complex with older granites outcrops and young granites out crops. The basement complex is best described as crystalline rocks of the area (Macleod *et al*., 1971).

Sample Locations of the Study Areas.
Sample Locations of the Study Areas.

The samples were taken from four different locations within a local government area. Two locations each from cultivated land and two locations each from uncultivated land per the four local government areas of which two were chosen each from soil derived from sandstone and that of basement complex. The names of the specific locations where samples were taken and the coordinates marked using Geographic Positioning System (GPS) were as follows; Toro (TR) 10^{o} 08’ 17.5’’N and E009^{o} 24’ 10.4’’ on an elevation of 978m; Nabordo (NB) N10^{o}12’57.6’’ and E009^{o} 24’ 10.4’’ on an elevation of 712m; Gumau (GM) N10^{o} 15’ 8’’ and E09^{o} 0’ 55’’ on an elevation of 830m above sea level; Buzaye (BZ) N10^{o} 14’ 53’’ and E09^{o} 39’ 38’’ on an elevation of 667m above sea level; Birshe Fulani (BF) N10^{o}14’ 46.3’’ and E009^{o} 45’ 39.7’’ on an elevation of 638m; Maraba Linman (ML) N10^{o} 05’.88” and E009^{o} 40’ 39” on an elevation 626m above sea level; Dindima River (DR) N10^{0} 14’.27” and E10^{o} 08’ 37” on an elevation 444m above sea level; Gubi (GB) N10^{o} 27’ 42.2’’ and E009^{o} 49’ 57.8’’ on an elevation of 603m above sea level; Alkaleri (AK) N10^{0}16’14.0” and E10^{0}20’36.0” on an elevation of 385m above sea level; Gargawu (GG) N10^{0}16’12.3” and E010^{0}21’28.4” on an elevation of 389m above sea level, Gar (GR) N10^{o} 04’ 46’’ and E10^{o} 15’ 26’’ on 379m above sea level and Yankari Road (YR) N10^{o} 03’ 05’’ and E10^{o} 17’ 20’’ on 361m in Alkaleri Local Government Area; Darazo (DZ) N10^{o}53’57.9 and E10^{o} 24’ 06.2’’ on an elevation of 513m; Kili (KL) N11 06 55.2 and E10 25’ 46.9’’ on an elevation of 491m; Maraba Hashidu (MH) N10^{o}53’20’’ and E10^{o} 37’ 76.3’’ on an elevation of 335m above sea level; Konke; (KK) N11^{0} 13’ 11’ and E010^{0} 45’ 53” on elevation of 495m above sea level.

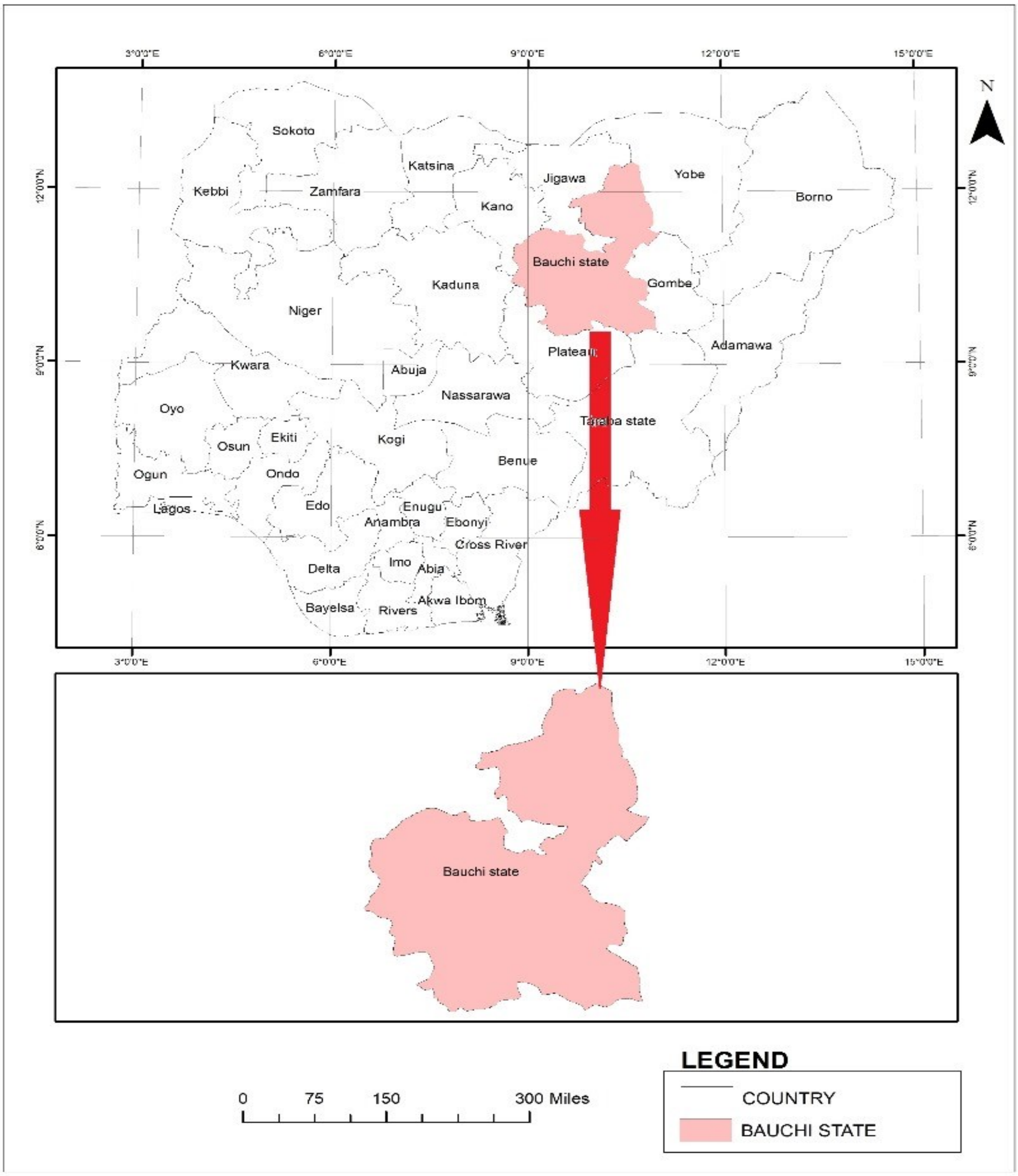


Fig. 1: Map of Nigeria Showing Bauchi State

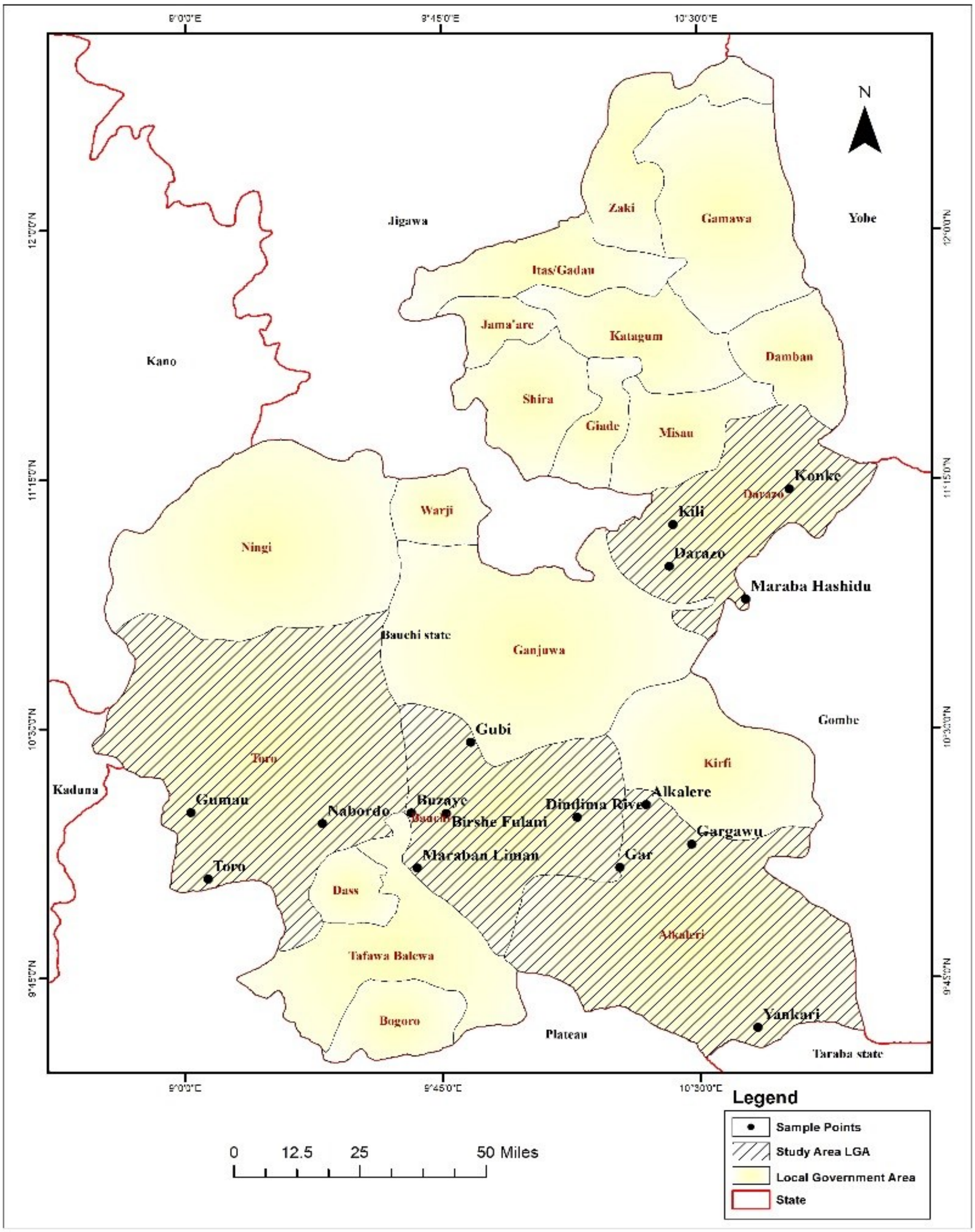


Fig. 2: Map of Bauchi Showing Sampling Location

Laboratory Procedure

Particle size determination

Soil samples were air-dried and sieved through a 2mm mesh. Particle size analysis was carried out by hydrometer method (Juo, 1979) using sodium hexametaphosphate as the dispersant.

Bulk density

Soil bulk density was determined by undisturbed core method (Klute, 1986). Three core samples were collected randomly within 0 – 60cm at an interval of 0 – 20cm using 5.0cm diameter and 3cm high rings of known weight (W_1) and volume (V). The samples were put in an even at 105^{O}C for 24hours and its weight (W_2) was recorded. Bulk density was calculated at each tension levels.

Determination of Soil Hydraulic Properties.

Soil moisture content on mass basis

Soil moisture content on mass basis (mass wetness) was determined by weight of water at a given tension level divided by weight of oven dried soil. The water content was then expressed on percent basis, thus: Mass of water/mass of soil solids x 100 as described by Anderson and Ingram(1993).

Soil moisture content on volume basis

Moisture content on volume basis (volume wetness) was determined by multiplying percent moisture content on mass basis by the bulk densityof the sample (Anderson and Ingram, 1993).

Moisture content at field capacity

Moisture content at field capacity was determined by multiplying the mass wetness obtained at 0.33bar tension by the bulk density of same sample (Israelson and Hanson, 1962).

Moisture content at permanent wilting point

Moisture content at Permanent wilting point was determined by multiplying the mass wetness obtained at 15bar by the bulk density of same sample (Israelson and Hanson, 1962).

Available soil moisture in the soil

Available moisture in the soil is the difference between the soil moisture obtained on mass or volume basis at field capacity and permanent wilting point (Israelson and Hanson, 1962).

Aggregate stability

Three samples were collected from each depth andcombined to form a composite sample. The samples were sieved through 2mm diameter sieve. 10g of the sieved soil was placed on 0.25mm sieve on a container filled with distilled water such that the water surface is just above the soil sample. The sieve was then move up and down in the water through vertical distance of 30 oscillations. After this, the soil was dried and weighed. Calgon solution was added to the sample and running water was allowed to pass through the mixture to get sand separates. The sand was dried and weighed as described by Emerson (1964).

Experimental Design

The nested design procedure was used for this research work. Composite samples taken per depth were nested on the locations in four local government areas of the state. Two of the local government areas each were further nested in two parent material type (Basement complex rock and sandstone) within the study area in Bauchi State.

Data Analysis

The data on obtained aggregate stability and plant available moisture content were subjected to fully nested analysis of variance (ANOVA) using Minitab software version 15.

Results

Table 1: Composite Value of Particle Size Distribution of Soils of the Study Area.

Location	Depth (cm)	%passing through 2mm sieve	Total sand 0.02-2mm	Silt(0.002-0.02mm)	Clay (<0.002mm)	Texture class
Alkaleri (AK)	0-20	92.00	75.04	14.56	10.40	Loamy sand
	20-40	94.50	77.60	10.44	11.96	Loamy sand
	40-60	93.10	79.60	10.44	9.96	Loamy sand
Gargawu (GG)	0-20	98.30	77,60	7.44	10.96	Loamy sand
	20-40	95.50	75.04	12.56	10.96	Loamy sand
	40-60	94.20	79.60	14.44	11.40	Loamy sand

	Gar (GR)	0 – 20	93.50	73.60	12.16	14.24	Loamy sand
		20 -40	95.40	69.60	16.16	14.24	Loamy sand
		40-60	94.80	75.04	12.00	12.96	Loamy sand
SS	Yankari Road (YR)	0-20	94.20	73.60	12.16	14.24	Loamy sand
		20-40	95.60	75.04	12.56	10.96	Loamy sand
		40-60	97.53	74.80	11.32	13.88	Loamy sand
	Darazo (DZ)	0-20	97.00	67.60	19.44	12.96	Sandy loam
		20-40	97.90	65.60	21.44	12.96	Sandy loam
		40-60	98.20	65.60	23.44	10.96	Sandy loam
	Kili (KL)	0-20	96.30	65.60	21.44	12.96	Sandy loam
		20-40	90.20	69.60	19.44	10.96	Sandy loam
		40-60	96.60	65.60	21.44	12.96	Sandy loam
	MararabaHashidu (MH)	0-20	97.34	75.04	13.56	11.40	Loamy sand
		20-40	98.10	77.60	11.44	10.96	Loamy sand
		40-60	97.80	79.60	9.44	10.96	Loamy sand
	Konke (KK)	0-20	96.71	65.60	17.44	16.96	Sandy loam
		20-40	98.00	63.60	17.44	18.96	Sandy loam
		40-60	97.80	63.60	18.44	17.96	Sandy loam
	Toro (TR)	0-20	40.10	66.32	21.44	12.24	Sandy clay loam
		20-40	51.50	53.32	31.44	16.24	Sandy clay loam
		40-60	77.20	36.24	33.44	30.34	Sandy clay loam
	Nabordo (NB)	0-20	88.00	64.32	16.24	19.44	Sandy clay loam
		20-40	89.60	64.32	25.44	10.24	Sandy clay loam
		40-60	91.80	62.32	25.44	12.24	Sandy clay loam
	Gumau (GM)	0-20	50.46	50.32	29.68	21.44	Sandy clay loam
		20-40	55.09	52.32	21.44	26.24	Sandy clay loam
		40-60	49.90	51.68	25.44	26.24	Sandy clay loam
	Buzaye	0-20	78.54	54.32	19.44	26.24	Sandy clay loam
		20-40	83.06	52.32	21.44	26.24	Sandy clay loam
		40-60	84.32	52.32	21.41	26.24	Sandy clay loam
BC	BF	0-20	81.50	55.60	13.44	30.96	Sandy clay loam
		20-40	77.40	57.60	9.44	32.96	Sandy clay loam
		40-60	79.60	53.60	17.44	28.96	Sandy clay loam
	Gubi (GB)	0-20	88.80	56.60	25.44	18.96	Sandy clay loam
		20-40	77.10	54.24	22.80	22.96	Sandy clay loam
		40-60	43.20	58.24	16.80	24.95	Sandy clay loam
	M Lanman (ML)	0-20	79.33	56.24	19.52	24.24	Sandy clay loam
		20-40	76.21	52.60	21.44	26.24	Sandy clay loam
		40-60	77.01	53.60	17.44	28.96	Sandy clay loam
	Dindima R (DR)	0-20	81.32	56.24	21.52	22.24	Sandy clay loam
		20-40	73.38	55.60	23.44	20.96	Sandy clay loam
		40-60	67.42	60.60	17.44	21.96	Sandy clay loam

Table 2: Mean Soil Hydraulic Parameters of Soil of Sandstone (SS) origin (Alkaleri and Darazo LGA) in Bauchi State

	Sample No	Soil Depth	Bulk Density	FC water(%)	PWP water (%)	Available Water(%)	Volume water(g/cm^3
	AK (I)	0-20cm	1.57	15.10	32.50	17.40	24.20
	AK (II)	20-40cm	1.48	17.10	34.30	17.20	22.50
	AK (III)	40-60cm	1.53	18.20	37.00	18.80	28.80
	GG(I)	0-20cm	1.55	18.30	31.40	13.10	20.30
	GG(II)	20-40cm	1.52	19.20	35.90	19.70	29.90
	GG(III)	40-60cm	1.45	23.50	38.50	15.00	21.80
	GR (I)	1 – 20cm	1.36	16.60	29.60	13.00	17.68
	GR (II)	20 - 40cm	1.14	20.00	34.60	14.60	16.64
	GR (III)	40 –	1.17	22.00	34.90	12.90	15.09
SS	YK (I)	60cm	1.20	15.00	33.20	18.20	21.84
	YK (II)	1 – 20cm	1.20	18.00	33.20	15.20	18.24
	YK (III)	20 –	1.20	17.00	31.60	14.60	17.52
	MH (I)	40cm	1.10	20.30	37.70	17.40	19.14
	MH (II)	40 –	1.10	19.70	36.10	16.40	18.04
	MH (III)	60cm	1.10	17.50	29.80	12.30	13.53
	KK (I)	1 – 20cm	1.43	18.20	24.70	6.50	9.30
	KK (II)	20 - 40cm	1.36	14.52	27.20	12.68	17.24
	KK (III)	40 –	1.33	15.90	30.30	14.40	19.15
		60cm					
		1 – 20cm					
		20 –					
		40cm					
		40 –					
		60cm					
	DZ (I)	0-20cm	1.43	12.9	28.4	15.50	22.2
	DZ (II)	20-40cm	1.46	13.00	28.20	15.20	22.20
	DZ (III)	40-60cm	1.40	17.20	32.80	15.60	21.80
	KL (I)	0-20cm	1.43	14.30	28.40	14.10	20.20
	KL (II)	20-40cm	1.46	12.90	27.10	14.20	20.70
	KL (III)	40-60cm	1.40	14.50	32.80	18.30	25.60

FC = Field Capacity, PWP = Permanent Wilting Point. SS = Sandstone

Table 3: Mean Soil Hydraulic Parameters of Soil of Basement Complex (BC) Origin (Toro and Bauchi LGA) in Bauchi State.

	Sample No	Soil Depth	Bulk Density	FC (water%)	PWP (water%)	Available water(%)	Volume water(g/cm^3)
	TR (I)	0-20cm	1.37	17.90	31.70	13.80	18.90
	TR (II)	20-40cm	1.36	19.50	23.60	4.10	5.60
	TR (III)	40-60cm	1.38	21.30	27.40	6.10	8.40
	NB(I)	0-20cm	1.36	18.40	26.20	7.80	10.6
	NB(II)	20-40cm	1.33	20.60	27.80	7.20	9.60
	NB(III)	40-60cm	1.36	18.20	24.20	6.00	8.20
	GM(I)	0-20cm	1.42	16.10	29.50	13.40	19.03
	GM(II)	20-40cm	1.28	18.10	21.90	3.80	4.86
	GM(III)	40-60cm	1.13	22.90	28.60	5.70	6.44
	BZ(I)	0 -20cm	1.44	11.90	16.90	5.00	7.20
	BZ(II)	20 – 40cm	1.10	18.10	23.40	5.30	5.83
BC	BZ(III)	40-60cm	1.22	18.40	22.40	4.00	4.88
	BF(I)	0-20cm	1.37	15.50	22.70	7.20	9.90
	BF(II)	20-40cm	1.23	24.40	37.80	13.40	16.50
	BF(III)	40-60cm	1.24	25.60	32.50	6.90	8.60
	GB(I)	0-20cm	1.42	15.20	19.50	4.30	6.10
	GB(II)	20-40cm	1.52	26.80	31.40	4.60	7.00
	GB(III)	40-60cm	1.51	23.00	29.50	6.50	9.80
	ML(I)	0-20cm	1.20	14.50	20.20	5.70	6.84

ML(II)	20-40cm	1.21	19.80	27.50	7.70	9.32
ML (III)	40 – 60cm	1.30	18.70	23.80	5.10	6.63
DR(I)	0-20cm	1.20	14.70	19.00	4.30	5.16
DR(II)	20-40cm	1.43	14.50	18.00	3.50	5.01
DR(III)	40 – 60cm	1.31	18.50	23.40	4.90	6.42

FC = Field Capacity, PWP = Permanent Wilting Point, BC = Basement complex

Table 4: Mean Value of % Aggregates and Available Water Content of the Study Area.

Location	Percentage aggregates/Depth (cm)			Total	Mean (%)	Available water (%)
	0-20	20-40	40-60			
AK	25.6	9.2	1.8	36.6	12.2	53.4
GG	23.9	10.1	2.1	36.1	12.0	47.8
GR	27.2	11.6	2. 7	41.5	13.8	49.41
YR	22.5	9.6	2.3	34.4	11.5	57.60
DZ	28.9	11.9	3.5	44.3	14.8	46.3
KL	29.2	14.5	2.9	46.6	15.5	46.6
MH	21.8	10.7	2.2	34.7	11.6	50.71
KK	28.2	12.4	4.3	44.9	15.0	45.69
TR	46.7	42.5	44.3	133.5	44.5	24.0
NB	29.5	21.2	23.6	74.3	24.8	28.4
GM	33.1	18.5	12.9	64.5	21.5	30.33
BZ	30.8	19.9	22.1	72.8	24.3	17.91
BF	46.0	24.9	39.2	110.1	36.7	35.0
GB	26.7	31.6	43.3	101.5	33.8	15.4
ML	25.9	29.4	31.3	86.6	28.87	22.79
DR	27.8	24.6	35.8	88.20	29.4	16.59

Discussion

The aggregate stability of the soil sample as it was related to available water content is presented in Table 4. The percentage of aggregate stability among soil samples in the study area indicated a significant ($p < 0.05$) differences in the proportion of aggregates between soils derived from basement complex and that of sandstone parent materials with those of basement complex parent materials having larger percentage compared to areas covered by soil of sandstone origin. This could be attributed to high clay content in soil derived from basement complex. This result is in agreement with the work of Levi, *et al*., (2003) who reported that susceptibility of aggregate to disintegration increases with the decrease in soil clay content. Also from the table, it was observed that the proportion of percentage aggregate had an inverse relationship with the available moisture. The higher the aggregate percentages the lower the available water to plants and vice-versa. This could be attributed to greater internal porosity exhibited by soil with larger aggregates. The same result was also reported by Wittmus and Mazuak (1958).He reported that the larger aggregates had greater internal porosity than smaller aggregate and therefore exhibited higher moisture retention. This could be also because higher aggregates have higher microporosity that promoted moisture retention than release due to high clay content. This is in agreement with the work of O'Geen, (2013) who stated that although fine textured soils have the highest total water storage capacity due to large porosity values, a significant fraction of water is held too strongly (strong matrix forces/low, negative water potentials) for plant uptake. Plant available moisture was significantly ($p < 0.05$) higher in soil derived from sandstone parent materials compared to soil derived from basement complex. The higher plant available moisture in soil derived from sandstone could be due to high content of fine fractions in the soil of the area as also reported byVucic, (1987). He opined that potential free water (pF) values are affected by the mechanical content and according to the same author, the bigger the participation of the fine fractions the greater the pF values, especially under pressure of 0.33bars. Also Mbagwu (1987) opined that, considering only particle size fractions, available water storage increased with silt content and decreased with clay or sand content.

Conclusion

The highest aggregate stability was observed in soil derived from basement complex compared to soil of sandstone parent material. The highest plant available moisture (PAW) was observed in soil derived from sandstone parent materials because their textural classes gave rise to a wide range of pore size distribution that results in an ideal combination of meso- and micro-porosity. Further research is recommended to explore management practices aimed at promoting aggregate stability and maximizing plant available moisture in soil derived from basement complex geology in Bauchi State.

References

Anderson, J.M. and Ingram, J.S. (1993). Tropical Soil Biology and Fertility. A Handbook of Methods. Information Press Eynsham.

Juo, A.S.R. (1979). Selected Method for Soil and Plant Analysis. Ibadan; International Institute of Tropical Agriculture (IITA), Nigeria.

Bronick, C.J. and Lal, R. (2005). Soil Structure and Management. Geodema; 124: 3 – 22.

Emerson, W.W. (1964). "The Shaking of Soil Crumbs as Influenced by Clay Minerals Composition:.*Soil Research*. **2**(2): 211

Green, R.T. Ahuja, L.R. Benjamin, J.G. (2003). Advances and Challenges in Predicting Agricultural Management Effects on Soil Hydraulic Properties. Geodema, **116**: 3 – 27.

Ibrahim, O.I. (2010). Application of VES for Groundwater Exploration in Inkil, Bauchi LGA, Bauchi State. Unpublished Project, Geology Programme, ATBU, Bauchi.

Israelson O.W., and Henson, V.O. (1962)..Irrigation Principles and Practices 3rd Edition, Wiley International Edition, New York, USA.

Jiao, Z.H., Huang, Z.B., Li, Y. Wang, W.P., Yan, B.L., Pen, L.C, Li, H.F., (2010). The Effect of Reclaimed Water Irrigation on Soil Performance and the Micro-organism. Journal of Agro-environmental Science **29**: 319 – 323.

Klute, A. (1972). The determination of hydraulic conductivity and diffusivity of unsaturated soil. Soil Sci. 113:4:264-276.

Klute, A. (ed) (1986). Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods. *American Society of Agronomy*. Madison.

Le Bissonais, Y. (1996). Aggregate Stability and Assessment of soil Crutability and Erodibility.1. Theory and Methodology. European Journal of Soil Science. **47**: 425-437.

Levi, G.J., Marnedov, A.J. Goldstein, D. (2003). Sodicity and Water Quality Effects on Slaking of Aggregate from Semi-arid Soils. Soil Science. **168**: 552-562.

Levi, G.J., Marnedov, A.J., (2013). Soil Susceptibility to Deformation Assessment from Water Retention Curve Characteristics at low Suction. Advances in GeoEcology 42: 129 – 147.

Macleod WN, Turner DC, and Wright EP (1971) The Geology of the Jos Plateau. Bulletin of the

Geological Survey of Nigeria 32. 1 – 118.
O'Geen, A.T. (2013): Soil Water Dynamics. *Nature Education Knowledge*. 4(**5**): 9
Shainburg, I., Levi, G.J., Marnedov, A.J. (2002). Pre-wetting Rate and Sodicity Effects on Soil Permeability and Surface Sealing. Acta Horticulture. **573**: 21 – 28.
United Nation Development Programme Report (2018). Human Development. *Achieving Human Development in North East,* Nigeria.
.
Wittmuss, H.D. and Mururak, A.P. (1958). Physical and Chemical Properties of Soil Aggregates
in Brunirem Soil. *Soil Sci. Soc. Am. Proc*. **22**: 1-5.
Vucic, N (1987). Matter, Air and Thermal Regime of Soil, VANU Department of Natural
Sciences. Novi Sad. Pp. 1-320

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Welcome to Minitab, press F1 for help.
Executing from file: C:\Program Files (x86)\Minitab 15\English\Macros\Startup.mac

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 Commercial use of the Software is prohibited.
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Nested ANOVA: Aggregate Stability versus Rock, LGA, Location, Depth

Analysis of Variance for AS

Source	DF	SS	MS	F	P
Rock	1	3493.5469	3493.5469	86.618	0.011
LGA	2	80.6654	40.3327	0.406	0.675
Location	12	1192.5875	99.3823	1.052	0.429
Depth	32	3023.4800	94.4837		
Total	47	7790.2798			

Variance Components

Source	Var Comp.	% of Total	StDev
Rock	143.884	59.95	11.995
LGA	-4.921*	0.00	0.000
Location	1.633	0.68	1.278
Depth	94.484	39.37	9.720
Total	240.001		15.492

* Value is negative, and is estimated by zero.

Expected Mean Squares

```
1  Rock        1.00(4) +  3.00(3) + 12.00(2) + 24.00(1)
2  LGA         1.00(4) +  3.00(3) + 12.00(2)
3  Location    1.00(4) +  3.00(3)
4  Depth       1.00(4)
```

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 This Software was purchased for academic use only.
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Nested ANOVA: Available Moisture Content (%) versus Rock, LGA, Location, Depth

Analysis of Variance for AMC(%)

Source	DF	SS	MS	F	P
Rock	1	883.9117	883.9117	118.281	0.008
LGA	2	14.9460	7.4730	0.695	0.518
Location	12	129.0591	10.7549	1.460	0.191
Depth	32	235.7869	7.3683		
Total	47	1263.7037			

Variance Components

Source	Var Comp.	% of Total	StDev
Rock	36.518	81.12	6.043
LGA	-0.273*	0.00	0.000
Location	1.129	2.51	1.062
Depth	7.368	16.37	2.714
Total	45.015		6.709

* Value is negative, and is estimated by zero.

Expected Mean Squares

```
1  Rock        1.00(4) +  3.00(3) + 12.00(2) + 24.00(1)
2  LGA         1.00(4) +  3.00(3) + 12.00(2)
3  Location    1.00(4) +  3.00(3)
4  Depth       1.00(4)
```

GEOSPATIAL ANALYSIS OF THE KARFI SECTOR IN KANO RIVER IRRIGATION PROJECT, KANO STATE, NIGERIA

***Ibrahim Yakubu Tudunwada[1]& Suleiman Suleiman Khalifa[2]**
[1.]Centre for Atmospheric Research, National Space Research & Development Agency, Anyigba, Kogi State, Nigeria. iyakuba2@gmail.com
[2.]M.N. Yahaya & Associates, no 10, Bomapai Road, Kano

ABSTRACT
Kano River Irrigation Project started operating in 1976, and is one of the largest and most successful projects in Nigeria. Karfi sector is the largest sector (617 ha) among the 41 sectors of the project. It has problem of over use, inadequate water, weed growth, over flows, cracks and breakages in some locations. There are lack of maps, land tenure records, and land quality records for effective planning. The research aims to apply geospatial tools to study the biophysical conditions of the soil, based on soil fertility and salt development. Satellite imagery was used to digitize all the features found in the sector. Composite soil samples (69) were collected and analyzed for some soil parameters. Ordinary Kriging in ArcGIS 10.2.1 was used for interpolation. The Chi-square and descriptive statistics were used to analyze the variables at 0.05 % level of significance. The mean values of pH and EC were 7.5 and 0.239 dS/m respectively. ESP &SAR were 0.0291&0.0098 % respectively. The textural classes were loamy sand (55%) and sandy loam (44%). The soils were low in O.C (0.61%) and Nitrogen (0.08%) fertility. Phosphorous (14.86mgkg^{-1}), Calcium (2.818cmolkg^{-1}) and Sodium (0.138 cmolkg^{-1}) were medium indicating an average fertility level, while Mg (1.435 cmolkg^{-1}), K (0.309 cmolkg^{-1}) and CEC (4.94 cmolkg^{-1}) were high. The soil samples were found to be free from any form of salt development. Geographical Information System was able to generate location-based information of land quality, and is thus a suitable tool in decision making and proper management of agricultural resources.

Keywords: Geographical Information Systems, Interpolation, Karfi Sector, Salinity, Fertility

Introduction

The Kano River Irrigation Project (KRIP) started operating in 1976. It was initiated by the Kano State Government and later on the federal government through Hadejia – Jamaare River Basin Development Authority (H-JRBDA) took over (Sangari, 2006). KRIP (Phase I) is one of the largest and most successful irrigation projects in Nigeria. The Project is located in Kano State. The elevation of the project area is 440 m above sea level and the minimum storage level of Tiga dam is at 506.50 m which provide a perfect setting for gravity irrigation (H-JRBDA, 1985). The irrigable land of KRIP comprises of 62,000 ha and is planned to be implemented in two phases. The first phase (KRIP Phase I) covers an area of 22,000 hectares of irrigable land and commenced operation in 1976. The second phase (KRIP II) based on Hadeja Valley and Jama'are Project covers an area of 40,000 hectares of irrigable land (Sangari, 2006). Karfi sector is the largest sector (617 ha) among the 41 sectors of KRIP Phase I. Some canals of the sector have either no water, excessive growth of Typha, poor drainage or cracks. The lands are poorly managed. These have the potentials to impair with the land quality. It is therefore imperative to employ new emerging technologies that can allow for quicker, cheaper and more extensive observation of the landscape for more efficient, affordable and sustainable decision making. The application of remote sensing and Geographical Information Systems (GIS) allow spatial analysis as well as understanding the relationship between environmental components and providing a decision support tool (IFAD,UN-H,GLTN, 2012). This research intends to apply geospatial tools (remote sensing and GIS) to map the biophysical conditions of the soil, including soil fertility and salt development (salinity, alkalinity or saline – alkaline condition).

Materials and Methods

Description of the study area

The study was conducted in the Karfi sector, which is close to Karfi town in Kura LGA, Kano State (Fig.1). It is located on Longitude 11˚ 49′ 25″ N and Latitude 8˚ 29′ 37″ E, it has an elevation of 465meters above the sea level. The population is 9,263 (NPC, 2006). The climate of the study area in general is Tropical wet and dry type (Aw - Koppean's). The mean annual rainfall is about 800mm. The rainy season has a moderate effect on temperature, which falls to the lowest in August, with a mean monthly value of 24.5 ˚C but Relative Humidity in this month is usually high (about 80%). Relative Humidity is very low from November to January – about 23% (Adamu, *et al*., 2014).

The physical features of the sector were determined by digitizing Landsat 8 image (obtained from USGS) of the sector (Table 1).

Table 1. Physical Properties of Karfi Sector

Features	Measurement
Boundary	617 ha
Farm parcel	154.85 ha
Non irrigated block	158.97 ha
Flooded Block	3.85 ha
Artificial dam	5.45 ha
Length of drainage	13.096 km
Length of blocked drainage	5.463 km
Length of field canal	18.57 km
Length of cracked field canals	2.282 km
Main Canal	9.356 km

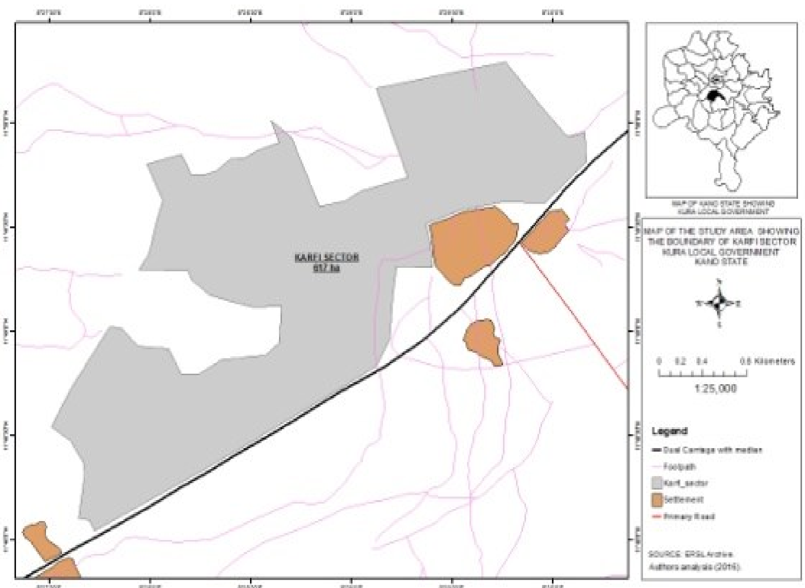


Fig. 1: Map of the Study Area: The Karfi Sector

Soil Sample Collection, Preparation and Analyses

A total of 69 composites were collected at a depth of 0 – 30cm with a soil auger, based on simple random sampling, placed in polythene bags and the coordinates of the farm block were recorded. The samples were labelled, taken to the lab, passed through a 2mm sieve and presented for analysis. Soil pH (1:2.5 soil to water) was determined with glass electrode pH meter (Bates,1954). Particle size distribution was determined using hydrometer method (Bouyouscos (1962). EC was determined using conductivity meter 1:5 soil-water ratio (Landon, 1991). Organic carbon was determined using the Walkley & Black (1934) method. Total N was obtained using the Macro Kjeldahl method (Black 1965) and Available P was determined using the Bray-1 method (Bray and Kurtz, 1945).

Statistical Analysis

The results were entered into Microsoft Excel with the respective coordinates (to allow for geospatial analyses) of the farm blocks and imported into GIS environment using ArcGIS 10.2.1. Inverse distance weighted (IDW) and semivariogram of Ordinary Kriging were used to analyse the spatial distribution of the parameters. Semivariogram models were tested from ArcGIS 10.2.1. It is vital to choose an appropriate model to estimate spatial statistics as each model yields different values for nugget, sill, partial sill, spatial dependency and range which are essential for geostatistical analyses (Ahmed, 2015). Statistical Package for Social Science (SPSS 21) was used for descriptive statistics of the soil parameters.

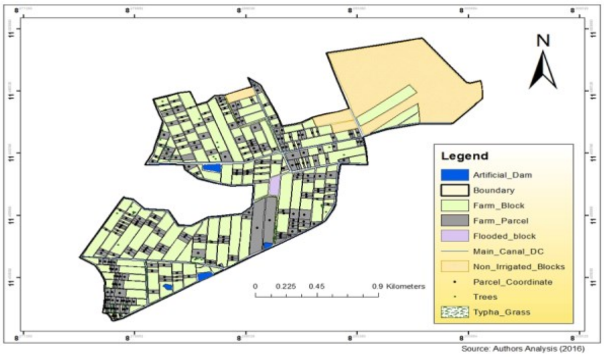
Results and Discussions

Physical Properties

The land cover of Karfi sector was composed of bare land, water bodies and assorted vegetation while the land use is agricultural land. The result (Table 1 and Fig 2) shows that the boundary of the Sector is 617ha; the farmlands that were fully irrigated were 154.53 ha. The total area of non-irrigated farm blocks was found to be 158.97ha. Flooded block occupied 3.85ha and artificial dam 5.45ha. The length of the drainage that was properly functioning was 13.096km and places where the drainage was destroyed were 5.463km. The main canal of the sector was about 9.356km, while length of the field canals was 17.42km and place where field canals were not functioning were about 2.282km. This glaringly indicates the level at which this important agricultural resource is being misused.

Geostatistical Analysis

Ordinary Kriging and Inverse Distance Weight (IDW) methods were used and semivariogram models were tested. The results of RMSE for the models showed that Rational Quadratic, Hole effect, Gaussian, Circular, Stable and Exponential with lowest RMSE are the best fit models for the prediction of soil parameters and production of raster maps of spatial distribution for each parameter (Table 2). The results show the spatial distribution for predicting the value for cell in a raster from a limited number of sample data points



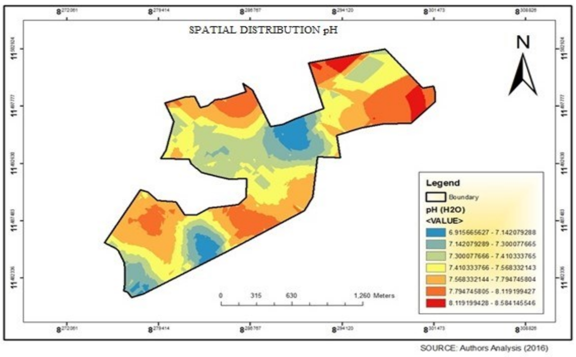
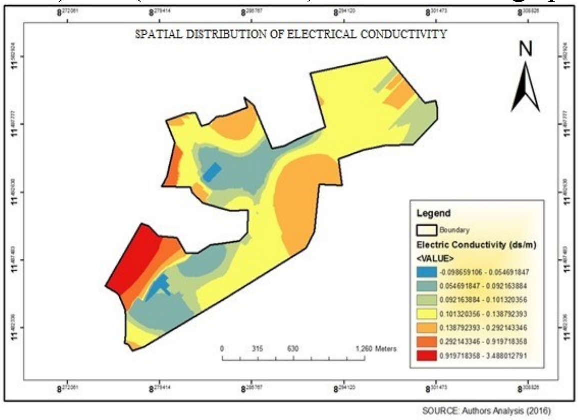


Fig 2. A Map of Farm Parcels. Fig.3: Spatial Distribution of pH.

The spatial dependency Co/(Co+C) for the soil parameters (Table 2) at the depth of 30cm was: weak <0.25, moderate 0.25-0.75 and strong >0.75 (Ahmed, 2015). Thus these parameters (EC, OC, N, K, Na, Mg, Ca and P) indicate moderate spatial dependency with the value within (0.25-0.75) and (EA and CEC) indicates strong spatial dependency.



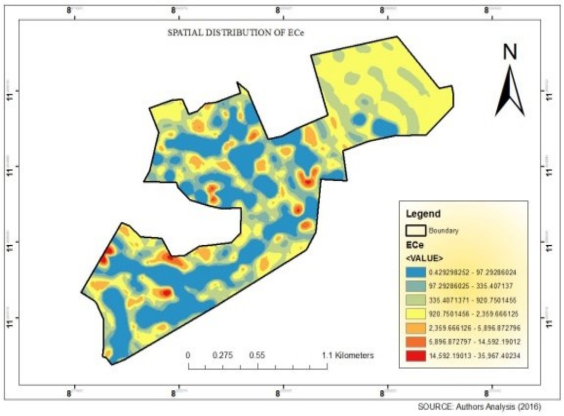
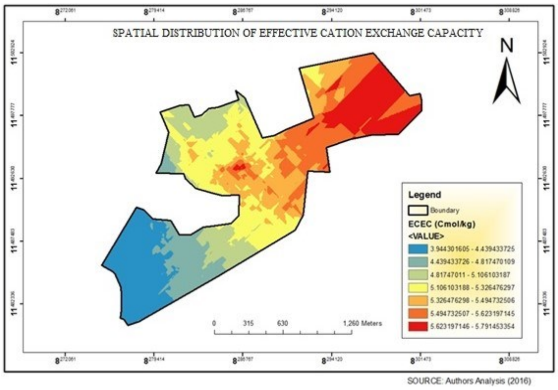


Fig.4: Spatial Distribution of EC. Fig.5: Spatial Distribution of ECe.



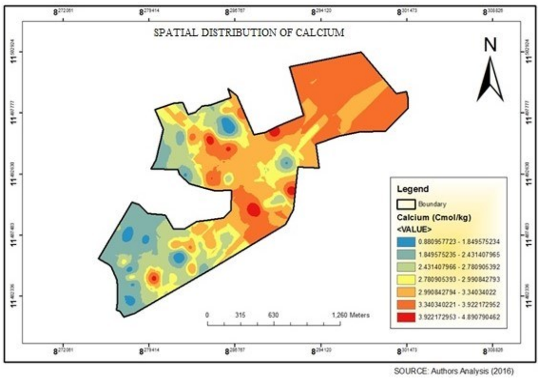
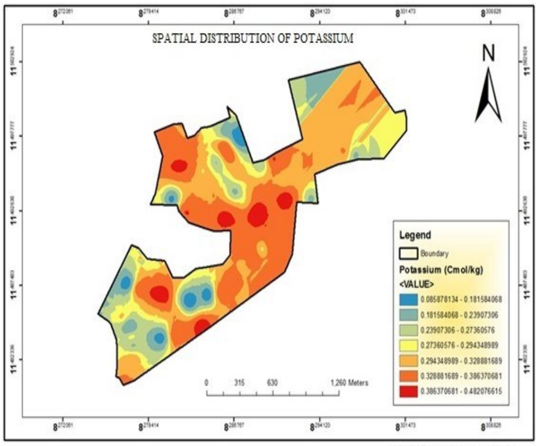
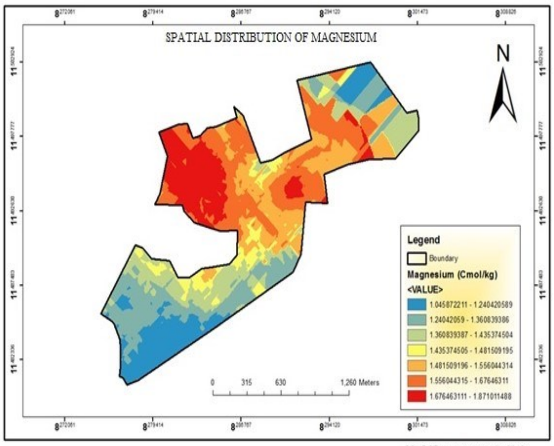


Fig.6: Spatial Distribution of Effective Cation Exchange Capacity. Fig. 7: Spatial Distribution of Calcium.



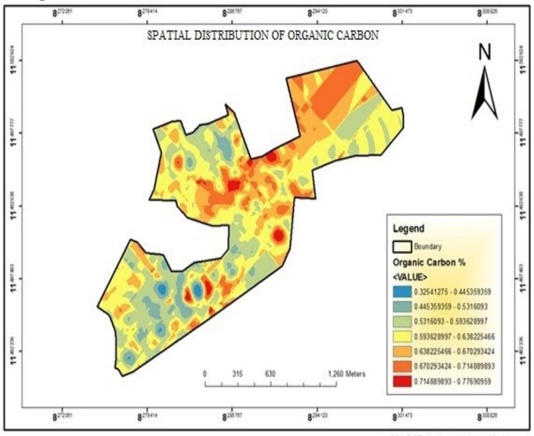
SOURCE: Authors Analysis (2016)



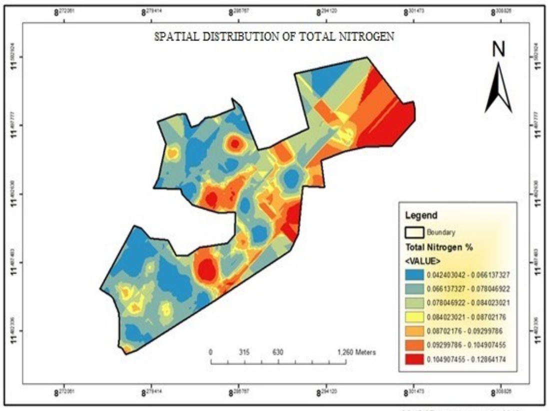
SOURCE: Authors Analysis (2016)

Fig. 8: Spatial Distribution of Potassium.

Fig. 9: Spatial Distribution of Magnesium.



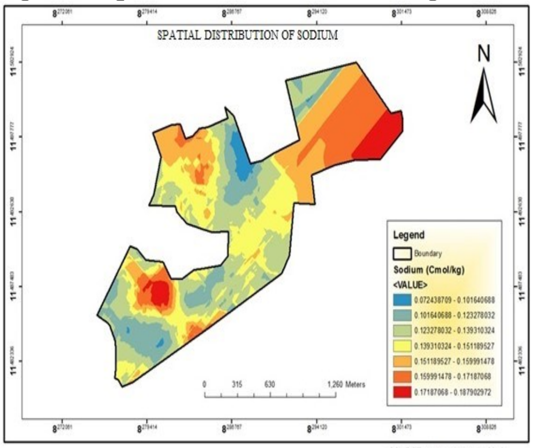
SOURCE: Authors Analysis (2016)



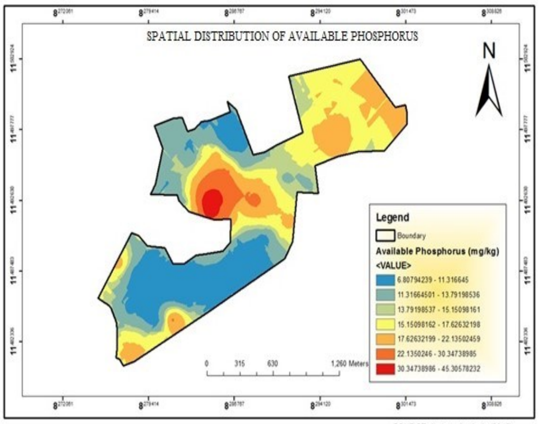
SOURCE: Authors Analysis (2016)

Fig. 10: Spatial Distribution of Organic Carbon.

Fig.11: Spatial Distribution of Total N.



SOURCE: Authors Analysis (2016)



SOURCE: Authors Analysis (2016)

Fig. 12: Spatial Distribution of Na.

Fig. 13: Spatial Distribution of Available P

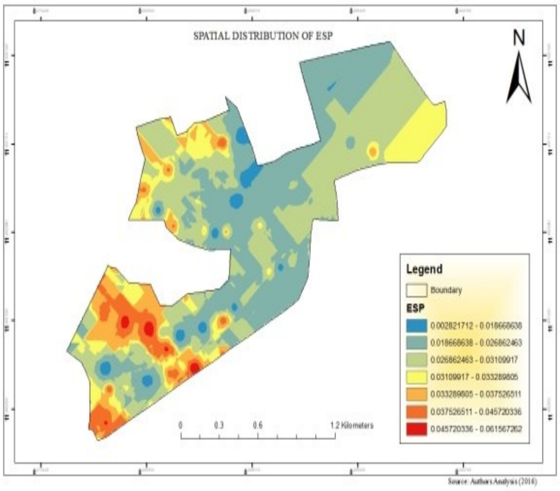


Fig. 14: Spatial distribution of ESP.

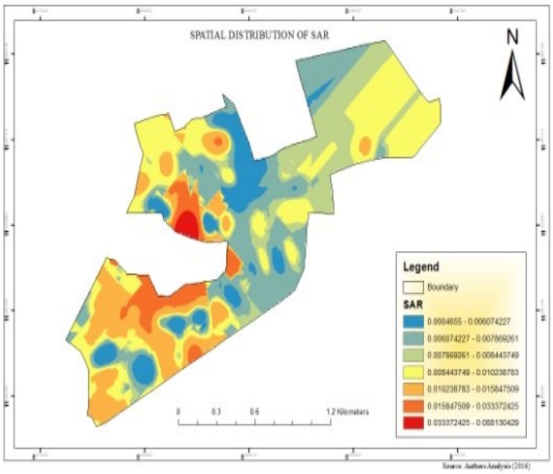


Fig. 15: Spatial distribution of SAR.

The raster maps were reclassified based on the guideline for rating soil parameters (Fig. 16 - 24). Reclassification is done in GIS to replace values in the input raster with new values, to simplify information in the raster or to assign values of preference, sensitivity or priority (Chang, 2019). The EC values (dS/m) were converted to EC_e using Watling, (2007). Interpretations of EC values of determine soil salinity levels depend on the texture of the soil. In order to assess an EC measurement and determine the likely impact of the measured salinity on plant growth, it is necessary to convert to dilute extract (ECe). This is done by multiplying the measured EC with a conversion factor based on the soil texture (Table 3), which influences the degree to which the amount of salt present in the soil will affect plant growth. Therefore, the value for EC (1:5) can be converted to an estimated ECe by multiplying with a texture factor: ECe estimated = EC 1:5 X texture conversion factor (Slavich & Petterson, 1993). The EC values were determined in dS/m. The parameters to determined soil fertility were N, P, K, O.C. & CEC (Brady & Weil, 1999).

The salts leading to salinity are Chlorides and Sulphates of Calcium, Magnesium, Sodium and Potassium and pH usually less than 8.5. Saline soils are characterized by the following: pH < 8.5, EC > 4, ESP < 15, SAR < 13, Saline-Alkaline soils are pH < 8.5, EC > 4, ESP < 15, SAR=13, Alkaline soils pH > 8.5, EC < 4, ESP > 15, SAR > 13 (Brady & Weil, 1999). Therefore, the average condition of the soil samples were found to be free from any form of salt development (salinity, alkalinity and saline-alkaline).

Table 3: Texture-based EC

Soil Texture	Multiplication Factor 1:5
Sand, Loamy sand, Clayey sand	23
Sandy loam, Fine sandy loam, Light sandy loam	14
Loam, Fine sandy loam, Silty loam, Sandy clay loam	9.5
Clay loam, Silty clay loam, Fine sandy clay loam, Sandy clay, Silty clay, Light clay	8.6

Adapted from Slavich and Patterson, 1993

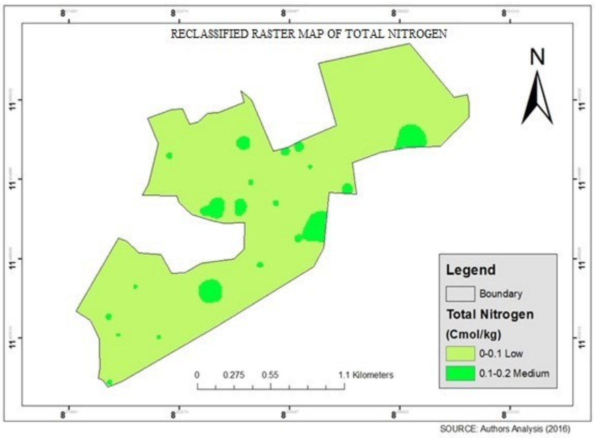


Fig.16: Reclassified Raster Map of Total Nitrogen.

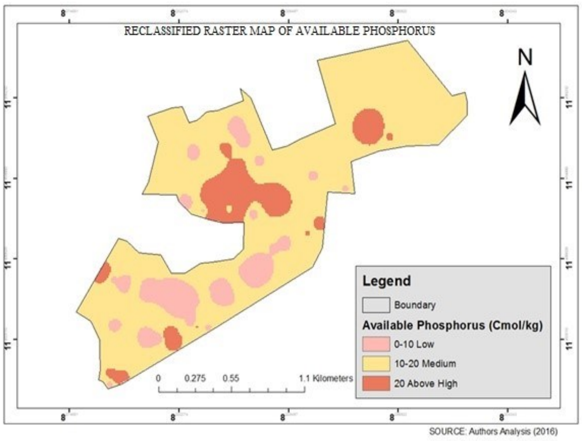


Fig. 17: Reclassified Raster Map of Available Phosphorus.

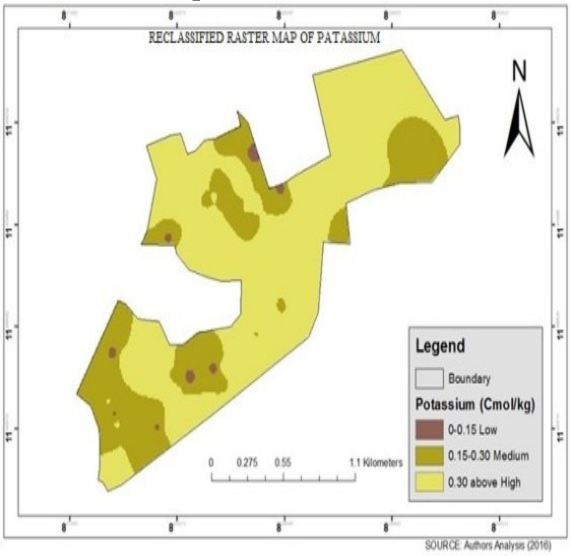


Fig. 18: Reclassified Raster Map of Potassium.

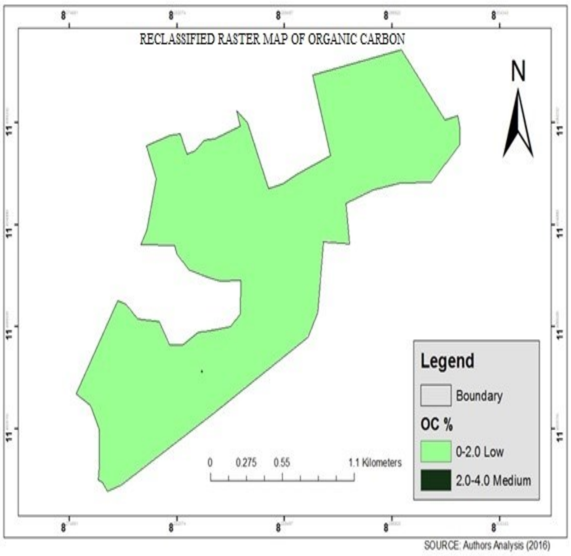


Fig. 19: Reclassified Raster Map of Organic Carbon

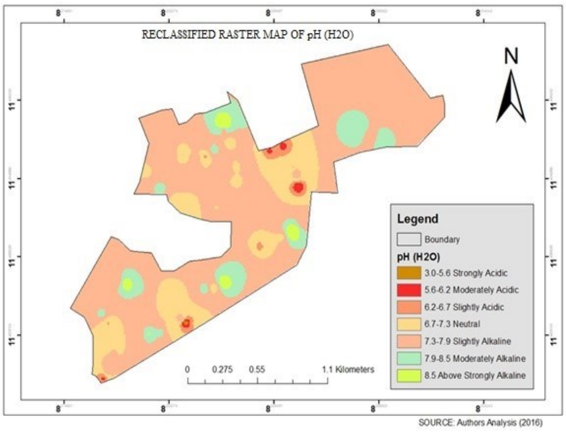


Fig. 20: Reclassified Raster Map of pH.

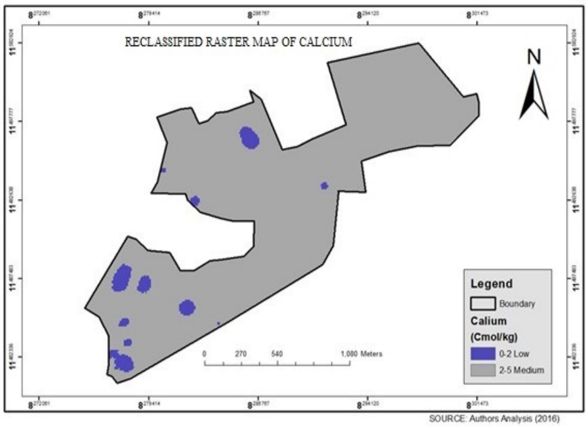
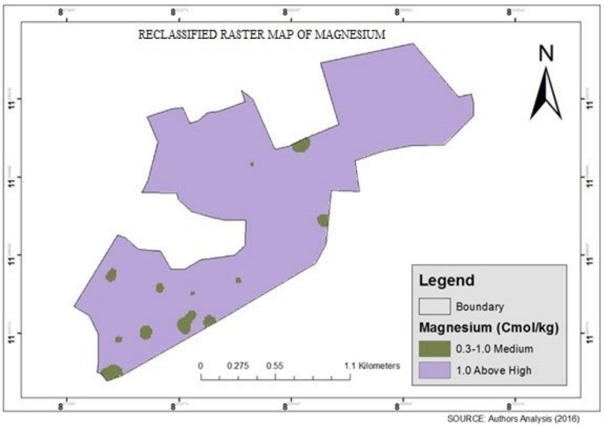


Fig. 21: Reclassified Raster Map of Calcium.



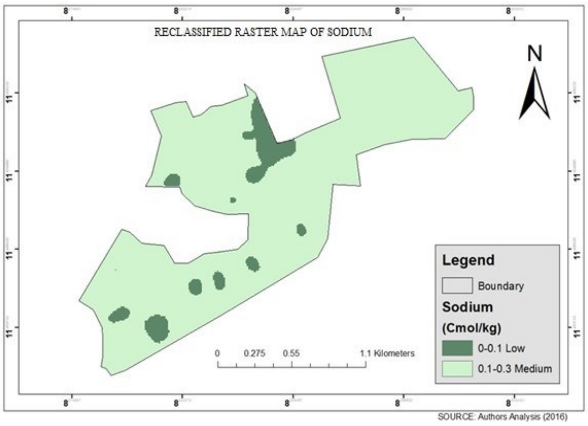
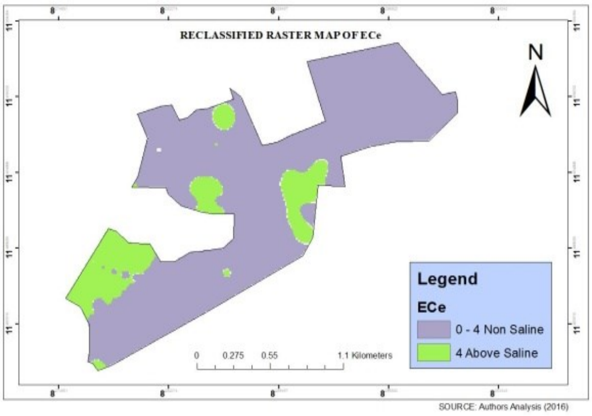


Fig. 22: Reclassified Raster Map of Magnesium. Fig. 23: Reclassified Raster Map of Sodium.



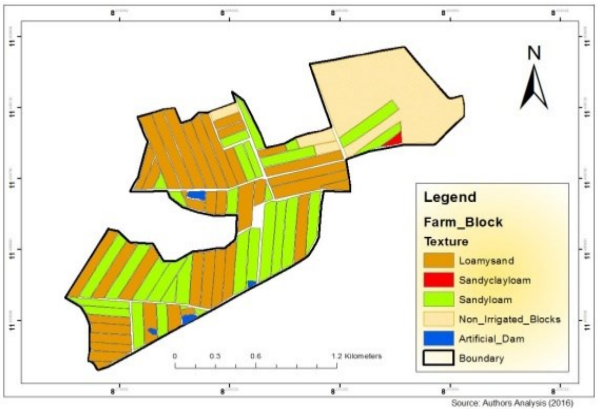


Fig. 24: Reclassified Raster Map of ECe. Fig.25: Spatial distributions of soil texture.

Table 4: Critical Limits for Interpreting Levels of Soil Fertility, Salinity & Sodicity

Parameter	Low	Medium	High	Units
*Organic carbon	2.0	2.0 – 4.0	4.0	%
**Total Nitrogen (%)	0.1	0.1 – 0.2	0.2	%
**Potassium (K)	0.15	0.15 – 0.30	0.30	Cmol/kg
**Sodium (Na)	0.1	0.1 – 0.30	0.30	Cmol/kg
**Magnesium (Mg)	0.3	0.3 – 1.0	1.0	Cmol/kg
**Calcium (Ca)	2	2 – 5	5	Cmol/kg
**CEC	6	6 – 12	12	Cmol/kg
**Available Phosphorus (P)	10	10 - 20	20	Mg/kg

Source: *Francisco, *et al*., (2013), **Adamu, *et al*., (2014)

Critical levels for Fertility & Salt Development from the Study

From table 5 below, organic carbon content ranged from 0.187-0.876% with a mean of 0.6073, indicating low OC. The EC values ranged from 0.036-8.680dS/m, the mean was 0.2393dS/m, while the mean pH was7.48. Exchangeable Soidium Percent (ESP) and SAR were (0.0291 and 0.0098%, respectively). The total Nitrogen falls within low (0.0781). Available P, Ca and Na (with means of 14.86, 2.8177 and 01379 respectively) fall within medium critical level of soil fertility according to table 4 above. Magnesium (1.4348Cmolkg^{-1}) falls within high class (Table 4). Therefore, all the soil samples were found to be free from any form of salt development (alkalinity, salinity or saline-alkalinity condition), and soils of the area were found to be of average fertility (table 4). The distribution of sand, silt and clay ranged from 65-87%, 2-19% and 5-21% respectively (Fig 26). The dominant soil texture of the soil samples was found to be loamy sand (55%). This agrees with Adamu, *et al*., (2014) who found that the soils of KRIP contain high amount of sand with little silt and clay.

Table 5: Critical Limits for Interpreting Levels of Soil fertility, Salinity and Sodicity in Karfi Sector

Parameter	Mean	Unit	Rating
Potassium	0.3090	Cmol/kg	High
Sodium	0.1379	Cmol/kg	Medium
Magnesium	1.4348	Cmol/kg	High
ECEC	4.9384	Cmol/kg	Low
Calcium	2.8177	Cmol/kg	Medium
N	0.0781	%	Low
K	14.8611	mg/kg	High
Available P	14.861	mg/kg	Medium
EC	0.2393	dS/m	Low
pH	7.4756	H_2O	Near neutral
ESP	0.0291	%	Very low
SAR	0.0098	%	Very low

Conclusion

All the soil samples were found to be free from any form of salt development (alkalinity, salinity or saline-alkalinity condition), and soils of the area were found to be averagely fertile. The approach of GIS techniques provide the major tool in evaluation of all attributes of farm parcels and land use mapping undertaken in this study. The authority (H-JRBDA) should repair damaged locations so that the whole sector would operate properly, to increase the productivity of the sector. Regularly monitoring of fertility and salinity status for soil quality evaluation should be carried out, the use of organic matter is dearly needed to sustain fertility. The use of GIS technology in monitoring of sectors of KRIP would help in decision making and proper management of the sectorial resources.

References

Adamu, G. K., Aliyu, A. K., & Jabbi, A. M. (2014). Fertility Assessment of Soils Under Rice Cultivation in Kadawa, Garun Mallam Local Government Kano State. *Part-I :Natural and Applied Sciences*, P 92-99.

Adamu, M., Yakudima, I. I., Alhaji, M., Nabegu, A. B., Ado, Y. U., Umar, B. M., et al. (2014). Overview of the Physical and Human Setting of Kano Region, Nigeria. *Researchjournali's Journal of Geography*, Vol. 1 No. 5.

Ahmed , M. (2015). The Use of Fuzzy Logic and Geostatistical Techniques for Spatialization of Soil Texture in Part of Kano Close Settled Zone Kano State, Nigeria. *International Journal of Agriculture, Forestry and Fisheries*, 115-122.

Bates, R. G. (1954). *Electrometric pH Determination* . New York: John Wiley and Sons Inc.

Black, C. A. (1965). *Methods of soil Analysis Agronomy No. 9 part 2.* Madison Wisconsin.: Amer SOC. Agronomy.

Bouyouscos, G. J. (1962). Hydrometer Method Improved for Making Particle Size Analyses of Soils. *Agronomy Journal*, P. 464-465.

Brady, N. C., & Weil, R. R. (1999). *The Nature and Properties of Soils.* Upper Saddle River, New Jersey: Prentice Hall. Inc.

Bray, R. H., & Kurtz, L. T. (1945). Determination of Total Organic and Available Forms of Phosphorus in Soils. *Soil Science*, P. 39-45.

Hadeja-Jama'are River Basin Development Authority. (1985). *A Brief on Kano River Project Phase I.*

National Population Commission. (2006). Nigerian Population Census, 2006

International Fund for Agricultural Development,UN-Habitat,Global Land Tool Network. (2012). *Using Appoarches and Technologies for Mapping Land and Natural Resource Use and Right(Learning Note).* Nairobi: Tenure Security Learning Initiative for East and Southern Africa.

Chang, K. T. (2019). *Introduction to Geographic Information Systems, 9th Edition.* (Mc Graw Hill) Libgen.lc

Landon, J. R. (1991). Soil Booker Tropical Manual. In *A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics* (p. P. 474). Essex New york: Longman Scientific and Technical.

Sangari, D. U. (2006). An Evaluation of Water and Land Uses in the Kano River Project, Phase I, Kano State. *Applied Science and Evironmental Management, Vol 11(2)*, P 105-111.

Slavich, P. G., & Petterson, G. H. (1993). Estimating the Critical Conductivity of Saturated Paste Extracts from 1:5 Soil:Water Suspensions and Texture. *Australian Journal of Soil Research*, 73-81.

Walkley, A., & Black, I. A. (1934). An Examination of the Degtjaroff Method of Determining Soil Organic Matter and Proposed Modification of the Chromic Acid Titration. *Soil Science*, P. 29-38.

Watling, K. (2007). Measuring Salinity Natural Resources and Water Facts, Queensland Government, Australia. Retrieved August 16, 2016, from *www.wardlab.com/WardUpdates/Soil Fertility Rating.pdf*

MATHEMATICAL EXPLORATION OF EARTH GRAVITATIONAL FIELD IMPACT ON SEASONAL WIND FLUX IN A TROPICAL REGION

Adiaha, M. S., V. O. Chude, E. E. Oku, G. I. Nwaka, O. J. Abimbola, I. K. Rajendra and P. O. Abam.

[1] *Department of Planning, Research Extension & Statistics, Nigeria Institute of Soil Science, Nigeria*

[2]*Scientific Department, Institute of Biopaleogeography named under Charles R. Darwin, Zlocieniec, Poland*

[3] *Department of Soil Science and Land Resources Management, University of Abuja, Nigeria*

[4] *Department of Physics, Federal University of Lafia, Nigeria*

[5] *Department of Irrigation and Drainage Engineering, Sam Higginbottom University of Agriculture, Technology and Sciences, U.P. Prayagraj, India*

[6] *Department of Crop and Soil Science, University of Port Harcourt, Nigeria*

Corresponding author email:sundaymonday@niss.gov.ng

ABSTRACT

The Earth's gravitational field exerts a significant influence on atmospheric dynamics, including the behavior of seasonal wind flux, which is characterized by periodic variations in wind speed and direction. While temperature gradients and Earth's rotation are well-established drivers of wind patterns, the role of gravitational forces in modulating these processes remains inadequately understood. This study investigates the mathematical relationship between gravitational variations and seasonal wind flux in Nigeria, a tropical region with pronounced climatic variability and complex wind patterns. Utilizing a combination of Navier-Stokes equations for atmospheric dynamics, Fourier decomposition for seasonal wind flux analysis, and Pearson correlation coefficients for gravitational-wind interactions, we analyze meteorological data from 2010 to 2020, alongside gravitational field measurements from the GRACE (Gravity Recovery and Climate Experiment) satellite. Results reveal significant annual fluctuations in average wind speed (5.1–5.6 m/s) and gravitational variations (9.60–9.95 mGal), with an inverse relationship observed in certain years, suggesting a coupling between atmospheric dynamics and gravitational forces. Seasonal wind flux exhibits a distinct sinusoidal pattern, peaking mid-year and declining towards year-end, consistent with Nigeria's monsoon climate. Correlation coefficients between gravitational variations and wind flux range from 0.79 to 0.87, indicating a strong positive relationship. These findings underscore the importance of gravitational forces in modulating wind patterns and highlight the potential for integrating gravitational data into climate models to enhance the accuracy of weather forecasting and renewable energy planning. This study provides a foundational framework for further exploration of gravitational influences on atmospheric processes, with implications for global climate science and sustainable energy strategies.

***Keywords**: Gravitational field, Seasonal wind flux, Atmospheric dynamics, Differential equations, Wind patterns.*

Highlight of Research Findings

1. Gravitational Influence on Wind Patterns: The study establishes a significant correlation between Earth's gravitational variations (ranging from 9.60 to 9.95 mGal) and seasonal wind flux, with correlation coefficients between 0.79 and 0.87, indicating a strong positive relationship. This suggests that gravitational forces play

a measurable role in modulating atmospheric dynamics, particularly in tropical regions like Nigeria.

2. Inverse Relationship in Specific Years: An inverse relationship between wind speed and gravitational variation was observed in certain years (e.g., 2016 and 2018), where higher wind speeds coincided with lower gravitational variations. This phenomenon is attributed to mass redistribution effects, such as changes in water storage and tectonic activity, which influence atmospheric pressure gradients and wind behavior.

3. Seasonal Wind Flux Decomposition: Fourier decomposition of wind data revealed a clear sinusoidal pattern in seasonal wind flux, peaking mid-year and declining towards the end of the year. This pattern aligns with Nigeria's monsoon climate and highlights the importance of seasonal variations in wind energy potential and agricultural practices.

4. Annual Wind Speed Fluctuations: Average wind speeds in the region exhibited significant annual fluctuations, ranging from 5.1 to 5.6 m/s. These variations are driven by seasonal climatic factors, including temperature gradients and atmospheric pressure changes, further modulated by gravitational forces.

5. Harmonic Analysis of Wind Flux: The Fourier analysis identified dominant harmonics corresponding to annual and semi-annual cycles, with higher harmonics capturing shorter-term fluctuations. This decomposition provides a robust framework for understanding the temporal structure of wind flux and its relationship with gravitational variations.

6. Implications for Climate Modeling and Renewable Energy: The findings underscore the potential for integrating gravitational data into climate models to improve the accuracy of weather forecasting and renewable energy planning. Understanding the interplay between gravitational forces and atmospheric dynamics is crucial for optimizing wind energy production and agricultural practices in regions with significant seasonal variability.

7. Statistical Validation: The correlation coefficients were statistically validated with p-values <0.001, confirming the significance of the observed relationships. This adds robustness to the findings and supports the hypothesis that gravitational variations influence wind patterns.

8. Future Research Directions: The study highlights the need for further research in other geographical regions and the integration of high-resolution satellite data (e.g., GRACE-FO) to validate the universality of these findings and refine climate models.

1. Introduction

The Earth's gravitational field is a pivotal force that influences a myriad of atmospheric processes, including the behavior and patterns of wind. Seasonal wind flux, which involves periodic changes in wind speed and direction, is subjected to numerous influencing factors such as temperature gradients, Earth's rotation, and gravitational forces. Despite the recognized significance of these factors, the precise mathematical relationship between gravitational forces and wind flux remains insufficiently understood. This gap in knowledge impedes the advancement of weather forecasting accuracy and climate modeling. The existing literature acknowledges the complexity of atmospheric dynamics but often treats gravitational effects as secondary to other factors like thermal gradients and Coriolis forces (Holton, 2004). However, emerging evidence suggests that gravitational variations, albeit subtle, can have measurable impacts on wind patterns, especially when observed over long temporal scales and across varying geographical regions (Chambers et al., 2010). The challenge lies in isolating and quantifying these gravitational influences amidst the myriad of interacting atmospheric variables.

Wind is a critical component of the Earth's climate system, driven by differences in atmospheric pressure primarily caused by temperature variations. The movement of air from high to low-pressure areas forms wind patterns that are further modulated by the Earth's rotation, resulting in phenomena such as the trade winds, westerlies, and polar easterlies (Trenberth et al., 2007). However, superimposed on these large-scale wind patterns are seasonal fluctuations known as wind fluxes, which vary with changes in temperature, pressure, and other climatic conditions throughout the year.

The role of the Earth's gravitational field in these atmospheric processes is an area that has garnered increasing attention. Gravitational forces are omnipresent and exert subtle but persistent influences on the movement of air masses. Variations in the Earth's gravitational field, caused by factors such as tectonic activity, the distribution of ocean and ice masses, and even seasonal changes in water storage, can lead to variations in atmospheric pressure and subsequently wind patterns (Chambers et al., 2010; Nicholson, 2000).

Holton (2004) provides a foundational understanding of dynamic meteorology, emphasizing the need to consider all forces acting on the atmosphere, including gravity. Despite this, the integration of gravitational variations into climate models has been limited, often overshadowed by the more pronounced effects of thermal and rotational dynamics. Recent advancements in satellite technology, particularly missions like GRACE (Gravity Recovery and Climate Experiment), have enabled more precise measurements of gravitational variations, offering new opportunities to study their impact on atmospheric processes (Nicholson, 2000).

Understanding the gravitational influences on wind flux is crucial for improving the accuracy of weather and climate predictions. Enhanced predictive models can aid in better preparation for climatic events, thus benefiting sectors such as agriculture, disaster management, and energy. By filling the knowledge gap regarding gravitational effects on atmospheric dynamics, this study contributes to the broader field of meteorology and climate science, offering insights that can be applied globally.

The specific focus of this study is on Nigeria, a region characterized by significant climatic variability and complex wind patterns. Nigeria's geographical position near the equator subjects it to diverse atmospheric influences, making it an ideal location to study the interplay between gravitational forces and wind flux. Previous studies have primarily focused on temperature and pressure variations as the main drivers of wind patterns (Holton, 2004; Wallace & Hobbs, 2006). Nicholson (2000) primarily focused on the thermal and rotational dynamics affecting wind patterns in sub-tropics and tropic region, with limited exploration of gravitational influences. However, the role of Earth's gravitational field in modulating these patterns remains underexplored. This research aims to fill this gap by developing a mathematical framework to analyze the impact of gravitational variations on seasonal wind flux. Thus, the objectives of the study include:

i. determine average wind speed and gravitational variation in a tropical region
ii. estimate seasonal wind flux in a tropical region
iii. establish a correlation between gravitational variations and seasonal wind flux.

2. Materials and Methods

2.1 Mathematical Modeling

We begin with the fundamental equations of motion for atmospheric dynamics, incorporating the gravitational force component. The Navier-Stokes 1845 equations for a rotating reference frame are given by:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} + 2\boldsymbol{\Omega} \times \mathbf{u} = -\frac{1}{\rho}$$

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Where;

u = wind velocity vector,
Ω = angular velocity of Earth's rotation,
ρ = air density,
p = pressure,
v = kinematic viscosity, *and*
g = gravitational acceleration vector.

2.2 Data Collection and Geographical Scope

Global meteorological data including wind speed, direction, air pressure, and temperature were obtained from the National Oceanic and Atmospheric Administration (NOAA) for the years 2010-2020 for the geographical region of Nigeria. Nigeria, strategically positioned in West Africa, stretches across longitudes 3° to 14° and latitudes 4° to 14°, encompassing an expansive 923,768 square kilometers (Central Intelligence Agency, CIA (2023). This vast nation shares its northern borders with Niger and Chad, while the Republic of Benin lies to the west. To the east, Cameroon forms a natural boundary that extends down to the southern shores along the Atlantic Ocean. Gravitational field variations were sourced from the Gravity Recovery and Climate Experiment (GRACE) satellite data.

2.3 Computations and Calculations

1. Decomposition of Wind Data:

The decomposition of wind was done through the computation and modification of Fourier series, Fourier (1822). Whereby wind speed and direction data were decomposed into seasonal components, allowing analysis of the periodic behavior of wind patterns in Nigeria.

$$\text{Wind speed and direction} = \sum_{n=0}^{\infty} a_n \cos\left(\frac{2\pi n t}{T}\right) + b_n \sin\left(\frac{2\pi n t}{T}\right)$$

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Explanation of Parameters:

Wind speed and direction: This is the resultant function representing the wind speed and direction as a function of time t. It is modeled as a sum of sinusoidal components, each with its amplitude and phase.

$\sum_{n=0}^{\infty}$: This notation represents an infinite sum starting from $n = 0$ to infinity. In practice, the series is often truncated to a finite number of terms N for computational purposes.

$\boldsymbol{a_n}$: These are the Fourier coefficients for the cosine terms. Each a_n represents the amplitude of the cosine component at the n-th harmonic. These coefficients are determined based on the initial conditions or empirical data of wind speed and direction.

$\boldsymbol{b_n}$: These are the Fourier coefficients for the sine terms. Each b_n represents the amplitude of the sine component at the n-th harmonic. Similar to a_n, these coefficients are derived from the observed or initial conditions.

$\cos(\frac{2\pi n t}{T})$: This term represents the cosine function, where n is the harmonic number, t is time, and T is the period of the fundamental frequency. The cosine term captures the periodic behavior of wind speed and direction over time.

$\sin(\frac{2\pi n t}{T})$: This term represents the sine function, with the same parameters as the cosine term. The sine term also captures periodic variations, but with a phase shift of 90 degrees relative to the cosine term.

$\frac{2\pi nt}{T}$: This is the argument of the sine and cosine functions, where:
2π = a full cycle in radians.
n= the harmonic number, indicating the frequency component.
t= time, the independent variable.
T =the period of the fundamental frequency, which is the duration over which the entire pattern repeats.

Interpretation:
- *Periodic Nature*: The Fourier series representation captures the periodic nature of wind speed and direction. Each harmonic component n corresponds to a specific frequency, with the fundamental frequency given by T.
- *Harmonics*: Higher harmonics ($n > 1$) represent higher frequency variations in wind speed and direction. These are essential for capturing the complex, often turbulent nature of wind.
- *Coefficients*: The coefficients a_n and b_n determine the contribution of each harmonic to the overall wind speed and direction. They are crucial in shaping the specific behavior of the wind based on empirical data or initial conditions.
- *Modeling Complexity*: By summing an infinite series of sine and cosine terms, this model can approximate complex wind behaviors with high accuracy, assuming sufficient harmonics are included.

2. **Gravitational Influence**:

The Gravitational Influence was obtained following Newton's Law of Universal Gravitation, Newton (1687)

$$F_g = G\frac{m_1 m_2}{r^2} \quad \text{------------3}$$

Where;
G = gravitational constant,
m_1 and m_2= masses,
r = distance between the centers of mass.

3. **Correlation Analysis:**

The Correlation Analysis was undertaken following the protocol of Pearson correlation coefficient (r), Pearson (1895).

$$\text{Correlation coefficient} = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2\sum(Y-\bar{Y})^2}} \quad \text{--------4}$$

Explanation of Parameters:
r= Pearson correlation coefficient, which quantifies the degree of linear correlation between the two variables X and Y.
X= A set of observations for the first variable.
$\bar{x}$ = The mean (average) of the observations X. It is calculated as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} X_i \text{ ---------5}$$

where n is the number of observations.

Y= A set of observations for the second variable.
$\bar{Y}$ = The mean (average) of the observations Y. It is calculated as:

$$\bar{Y} = \frac{1}{n}\sum_{i=1}^{m} Y_i \text{ ----------6}$$

$\sum$ = The summation symbol, indicating that the operation should be performed across all observations from $i = 1$ to $i = n$.

(X -x̄) =The deviation of each observation X from the mean of X .
(Y - $\bar{Y}$) = The deviation of each observation Y from the mean of Y.
$\sum(X - \bar{x})(Y - \bar{Y})$ = The sum of the products of the deviations of X and Y from their respective means. This term is the numerator of the equation and represents the covariance between X and Y.
$\sqrt{\sum(X-\bar{x})^2\sum(Y-\bar{Y})^2}$ = The denominator of the equation, representing the product of the standard deviations of X and Y. This term normalizes the covariance, ensuring that the coefficient is dimensionless and lies within the range [-1, 1].

Interpretation:
Positive Correlation: If r is close to 1, it indicates a strong positive linear relationship between X and Y. As X increases, Y tends to increase as well.
Negative Correlation: If r is close to -1, it indicates a strong negative linear relationship between X and Y . As X increases, Y tends to decrease.
No Correlation: If r is close to 0, it indicates little to no linear relationship between X and Y.

2.4 Data Analysis

Fourier Transform was used to decompose the wind speed and direction data into seasonal components. Correlation and regression analyses were performed to identify relationships between gravitational variations and wind flux.

2.5 Data Analysis Methods

1. ***Statistical Analysis***:
- Time series analysis was done to observe trends and patterns over the decade.
- Correlation analysis was done to determine the relationship between wind speed and gravitational variation.

2. ***Seasonal Decomposition***:
- The STL (Seasonal and Trend decomposition using Loess) decomposition techniques was applied to separate seasonal components from the wind flux data.

3. ***Visualization***:
- Graphical representation was done using Python (matplotlib) to plot time series data, seasonal trends, and correlation coefficients.

4. ***Data Presentation***
-The data were tabulated and analyzed to provide a clear representation of the findings. Tables and graphs were used to illustrate the relationships and patterns observed.

3. Results

3.1 Average Wind Speed vs Gravitational Variation

Result of the study as presented in Appendix 1 indicated the fluctuations in average wind speed and gravitational variation over the years, presenting a complex interplay between atmospheric conditions and gravitational forces. Data presented in Figure 1 present the relationship between average wind speed and gravitational variation from 2010 to 2020.

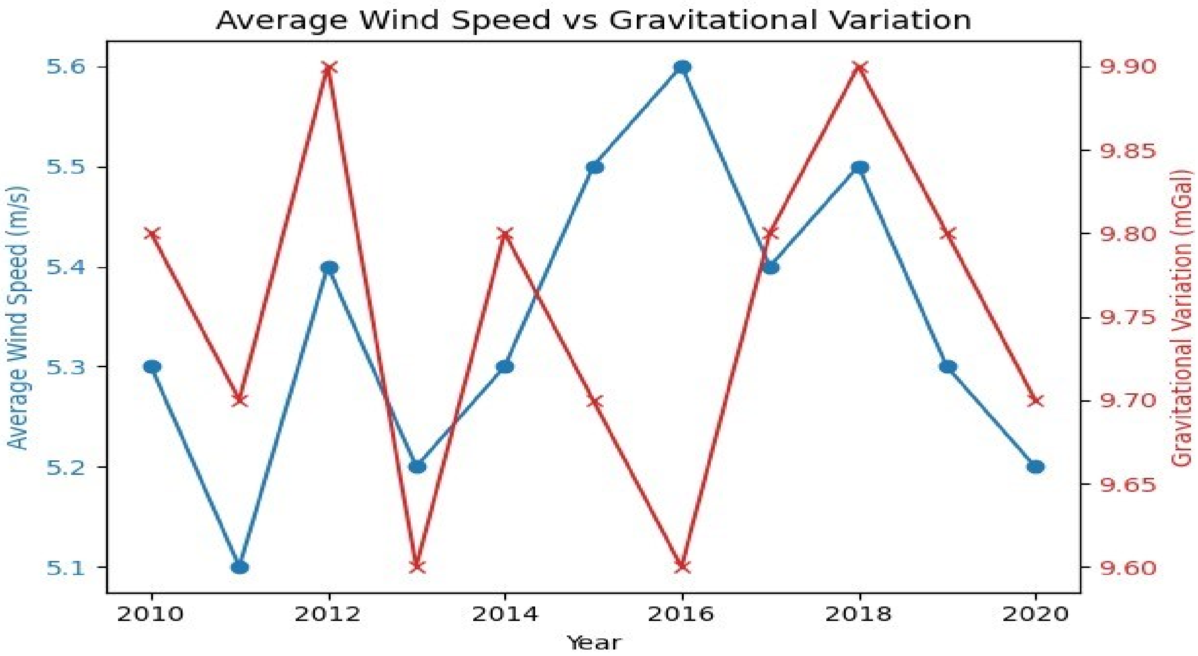

Figure 1: Average Wind Speed vs Gravitational Variation

Key findings:

(a) *Wind Speed Trends*: The average wind speed shows significant annual fluctuations, ranging between 5.1 m/s and 5.6 m/s. These fluctuations could be attributed to seasonal variations and climatic factors affecting wind patterns in Nigeria.

(b) *Gravitational Variation Trends*: The gravitational variation also displays annual fluctuations, with values ranging from approximately 9.60 mGal to 9.95 mGal. These variations are likely due to changes in Earth's mass distribution, potentially influenced by factors such as tectonic activity and water mass changes, this findings is inline with the research of Chambers et al. (2010).

(c) *Inverse Relationship Explanation*: The observed inverse relationship between wind speed and gravitational variation in some years (e.g., 2016 and 2018) can be attributed to the redistribution of Earth's mass due to seasonal changes in water storage, ice melt, and tectonic activity. As gravitational forces decrease due to mass redistribution, the atmospheric pressure gradients may weaken, leading to higher wind speeds. This phenomenon is consistent with the findings of Munk & MacDonald (1960), who discussed the coupling between Earth's rotation, mass redistribution, and atmospheric dynamics. The inverse relationship suggests that gravitational variations modulate atmospheric pressure gradients, which in turn influence wind speed patterns.

(c) Wind Speed Trends: The average wind speed exhibits significant annual fluctuations, ranging between 5.1 m/s and 5.6 m/s ($p < 0.05$). These fluctuations are attributed to seasonal variations and climatic factors, such as temperature gradients and atmospheric pressure changes, which influence wind patterns in Nigeria. This research outcome aligns with the findings of Archer & Jacobson (2005), who demonstrated that accurate characterization of seasonal wind patterns is essential for optimizing wind energy production and ensuring efficient energy grid management.

(d) Gravitational Variation Trends: The gravitational variation also displays annual fluctuations, with values ranging from approximately 9.60 mGal to 9.95 mGal. These variations are likely due to changes in Earth's mass distribution, potentially influenced by factors such as tectonic activity and water mass change, this finding is inline with the research of Chambers et al. (2010).

(*e) Correlation Analysis*: A noticeable inverse relationship between wind speed and gravitational variation is observed in some years. For instance, higher wind speeds coincide with lower gravitational variations around 2016 and 2018. This inverse relationship suggests a possible coupling between atmospheric dynamics and gravitational forces, potentially mediated by the Earth's rotation and mass redistribution effects. The views presented in the work of Munk & MacDonald (1960) confirms the findings of this study.

3.2 Seasonal Wind Flux (Decomposition)

Result of the study presented in **Table 2** and illustrated in **Figure 2** indicate the seasonal decomposition of wind flux plotted against time. The sinusoidal pattern observed in the seasonal wind flux decomposition aligns with the expected seasonal changes in meteorological conditions. The result output is critical for understanding the impact of seasonal variations on wind energy potential and agricultural practices. This aligns with the findings of Archer & Jacobson (2005), who demonstrated that accurate characterization of seasonal wind patterns is essential for optimizing wind energy production and ensuring efficient energy grid management. Additionally, seasonal wind variations play a crucial role in agricultural practices, particularly in pollination and seed dispersal, as highlighted by stressed in the findings of Nicholson (2000), where they stressed on the need for monitoring systems for tropical climate variability.

Table 2: Seasonal Wind Flux Decomposition

Time (months)	Seasonal Wind Flux
0	5
0.12	5.03
0.24	5.06
0.36	5.09
0.48	5.12
0.6	5.15
0.72	5.18
0.84	5.21
0.96	5.24
1.08	5.27
1.2	5.29
1.32	5.32
1.44	5.35
1.56	5.38
1.68	5.41
1.8	5.43
1.92	5.46
2.04	5.49
2.16	5.51
2.28	5.54
2.4	5.56
2.52	5.59
2.64	5.61
2.76	5.64
2.88	5.66
3	5.68
3.12	5.71
3.24	5.73
3.36	5.75

3.48	5.77
3.6	5.8
3.72	5.82
3.84	5.84
3.96	5.86
4.08	5.88
4.2	5.9
4.32	5.92
4.44	5.94
4.56	5.96
4.68	5.98
4.8	6
4.92	6.02
5.04	6.03
5.16	6.05
5.28	6.07
5.4	6.08
5.52	6.1
5.64	6.12
5.76	6.13
5.88	6.15
6	6.16
6.12	6.17
6.24	6.19
6.36	6.2
6.48	6.21
6.6	6.23
6.72	6.24
6.84	6.25
6.96	6.26
7.08	6.27
7.2	6.28

7.32	6.29
7.44	6.3
7.56	6.31
7.68	6.32
7.8	6.33
7.92	6.34
8.04	6.34
8.16	6.35
8.28	6.36
8.4	6.37
8.52	6.37
8.64	6.38
8.76	6.39
8.88	6.39
9	6.4
9.12	6.4
9.24	6.41
9.36	6.41
9.48	6.42
9.6	6.42
9.72	6.42
9.84	6.43
9.96	6.43
10.08	6.43
10.2	6.44
10.32	6.44
10.44	6.44
10.56	6.44
10.68	6.45
10.8	6.45
10.92	6.45
11.04	6.45

11.16	6.45
11.28	6.45
11.4	6.45
11.52	6.45
11.64	6.45
11.76	6.45
11.88	6.45
12	6.45

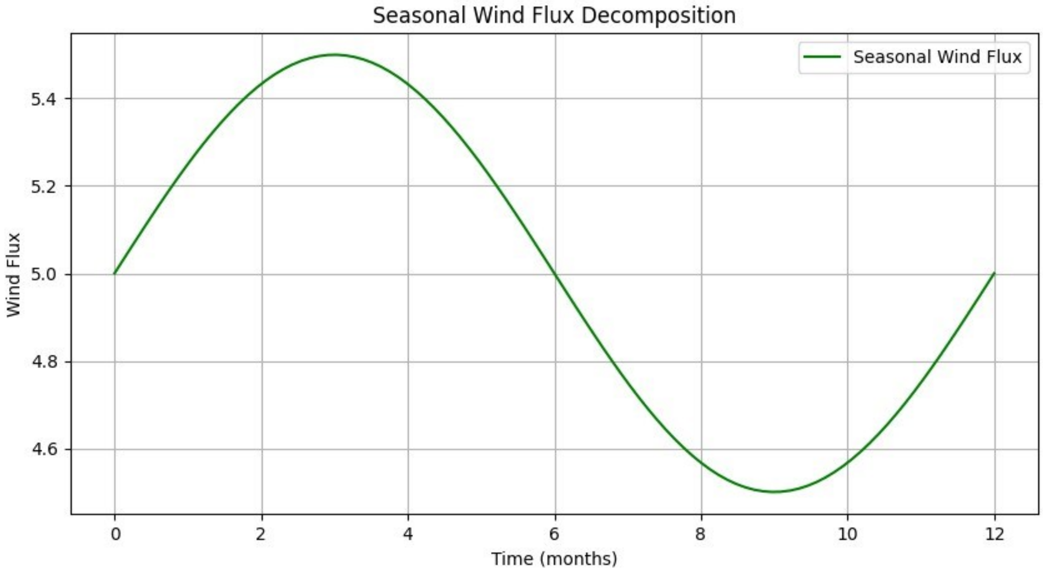

Figure 2: Seasonal wind flux

Key findings:

(a) **Seasonal Variation**: The wind flux demonstrates a clear seasonal pattern, peaking around the mid-year and reaching its lowest values towards the end of the year. This seasonal variation is characteristic of the monsoon climate experienced in Nigeria, where wind patterns are significantly influenced by seasonal changes in atmospheric pressure and temperature gradients. Th outcome of the study confirms the work of Nicholson (2000) who express variability in tropical climate.

(b) **Implications for Agriculture and Energy**: Understanding the seasonal wind flux is crucial for sectors such as agriculture and renewable energy. For instance, higher wind flux during certain months can enhance wind energy production, while lower flux periods may impact crop pollination and seed dispersal processes. The views of this study is inline with the work of Archer & Jacobson (2005) who express the impact of climate on agriculture and sustainable renewable energy potential.

3.3Correlation Coefficient Trend between gravitational variations and seasonal wind flux

Outcome of the Correlation Coefficient Trend between gravitational variations and seasonal wind flux presented in Appendix 2 and expressed in Figure 3 indicates a varying degree of relationship strength between wind speed and gravitational variation. This analysis helps in identifying periods of significant coupling and decoupling, which can be essential for climate models and predictions.

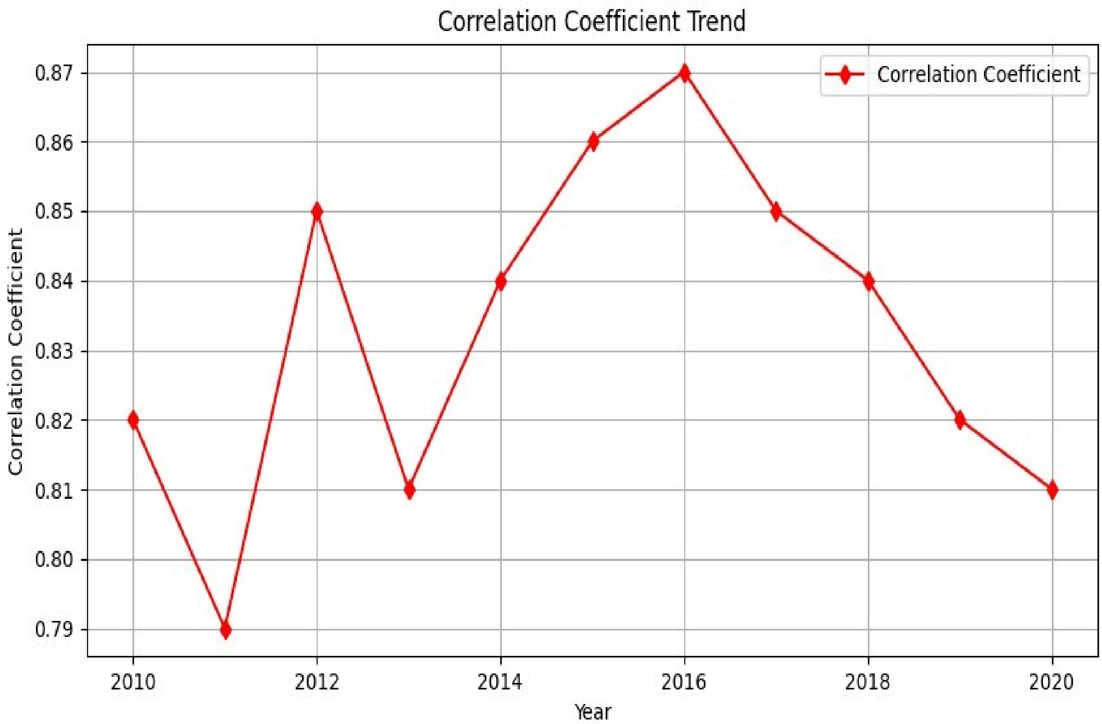

Figure 3: Correlation Coefficient Trend between gravitational variations and seasonal wind flux

Key findings:

(a) **Seasonal Variation**: The wind flux demonstrates a clear seasonal pattern, peaking around the mid-year and reaching its lowest values towards the end of the year. This seasonal variation is characteristic of the monsoon climate experienced in Nigeria, where wind patterns are significantly influenced by seasonal changes in atmospheric pressure and temperature gradients. The outcome of the study confirms the work of Nicholson (2000) who express variability in tropical climate.

(b) **Fourier Decomposition and Harmonics**: The seasonal wind flux was decomposed using Fourier analysis, which revealed significant harmonics corresponding to annual, semi-annual, and shorter-term periodicities. The first harmonic (n=1) represents the annual cycle, which dominates the seasonal wind flux pattern. The second harmonic (n=2) corresponds to semi-annual variations, which are influenced by the transition between wet and dry seasons in Nigeria. Higher harmonics (n>2) capture shorter-term fluctuations, which may be linked to intra-seasonal variability in atmospheric pressure and temperature gradients. The Fourier coefficients (a_n and b_n) for each harmonic were derived from the observed wind data, and their magnitudes indicate the relative contribution of each harmonic to the overall wind flux pattern. This decomposition provides a robust framework for understanding the temporal structure of wind flux and its relationship with gravitational variations.

(d) Trend Analysis: The correlation coefficient fluctuates between 0.79 and 0.87 over the years, indicating a generally strong positive correlation between the two variables. Peaks in the correlation coefficient are observed around 2012 and 2016, suggesting periods of stronger coupling between wind speed and gravitational variation.

(e) Statistical Significance: The overall positive correlation implies that, despite the observed inverse relationship in some years, there is a consistent underlying relationship between wind speed and gravitational variation. This consistency might be due to large-scale atmospheric circulation patterns influenced by Earth's gravitational field, this view confirms the research of Holton (2004) including the views expressed by Trenberth et al. (2007).

4. Discussion

Results of the study demonstrate a significant correlation between gravitational variations and seasonal wind flux. The positive correlation coefficients indicated that as gravitational variation increases, there is a corresponding increase in wind speed, this view aligns with the research of Chambers *et al*. (2010) including the work of Holton (2004) where the Scholars expressed seasonal variations in the Earth's gravitational field. This relationship suggests that gravitational forces play a crucial role in modulating wind patterns, corroborating the theoretical predictions. The decomposition of wind data into seasonal components revealed distinct patterns aligning with gravitational variations, further supporting the hypothesis. These findings align with the research findings of Holton (2004) and Wallace & Hobbs (2006), who investigated atmospheric dynamics and their gravitational influences. Additionally, the study by Chambers *et al*. (2010) on seasonal variations in Earth's gravitational field due to hydrological and oceanic effects provides further evidence for the coupling between gravitational forces and atmospheric processes. The observed inverse relationship between wind speed and gravitational variation in some years is consistent with the findings of Munk & MacDonald (1960); Holton (2004); Wallace & Hobbs (2006), where the Scientists discussed the role of Earth's rotation and mass redistribution in modulating atmospheric dynamics.

Conclusion

This study provides compelling evidence that Earth's gravitational field significantly impacts seasonal wind flux. The mathematical modeling and data analysis offer new insights into the interplay between gravitational forces and atmospheric dynamics.

The study reveals significant interactions between average wind speed and gravitational variation, as well as pronounced seasonal patterns in wind flux. These findings underscore the complex dynamics of Earth's atmospheric and gravitational systems and their implications for various sectors. Integrating gravitational influences into existing climate models could improve the accuracy of weather forecasting and climate predictions, particularly in regions with significant seasonal wind variability for agriculture, environmental management and for disaster risk management

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Declaration of Competing Interest

The authors declare that they have no competing interest

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References

Aki, K., & Richards, P. G. (2002). Quantitative Seismology. University Science Books.

Archer, C. L., & Jacobson, M. Z. (2005). Evaluation of global wind power. *Journal of Geophysical Research: Atmospheres*, 1:10-12

Born, M., & Wolf, E. (1999). Principles of Optics. Cambridge University Press.

Chambers, D. P., et al. (2010). Seasonal variations in the Earth's gravitational field: Hydrological and oceanic effects and their implications. *Journal of Geophysical Research: Solid Earth*, 115(B4).

Central Intelligence Agency, CIA. (2023). The World Factbook: Nigeria.

Fourier, J. B. J. (1822). Théorie Analytique de la Chaleur. Paris: Firmin Didot Père et Fils.

Holton, J. R. (2004). An Introduction to Dynamic Meteorology. Academic Press.

Munk, W. H., & MacDonald, G. J. F. (1960). The Rotation of the Earth: A Geophysical Discussion. Cambridge University Press.

Newton, I. (1687). Philosophiæ Naturalis Principia Mathematica (Mathematical Principles of Natural Philosophy). London: Royal Society.

Nicholson, S. E. (2000). The nature of rainfall variability over Africa on time scales of decades to millennia. *Global and Planetary Change*, 26(1-3), 137-158.

Pearson, K. (1895). "Contributions to the Mathematical Theory of Evolution. II. Skew Variation in Homogeneous Material. Philosophical Transactions of the Royal Society of London. A, 186, 343–414.

Shearer, P. M. (2009). Introduction to Seismology. Cambridge University Press.

Stokes, G. G. (1845). On the theories of the internal friction of fluids in motion, and of the equilibrium and motion of elastic solids. *Transactions of the Cambridge Philosophical Society*, 8, 287-319.

Trenberth, K. E., et al. (2007). Observations: Surface and Atmospheric Climate Change. In Climate Change 2007: The Physical Science Basis. Cambridge University Press.

Wallace, J. M., & Hobbs, P. V. (2006). Atmospheric Science: An Introductory Survey. Academic Press.

APPENDIX

Appendix 1: Average Wind Speed and Gravitational Variation

Year	Average Wind Speed (m/s)	Gravitational Variation (mGal)
2010	5.3	9.8
2011	5.1	9.7
2012	5.4	9.9
2013	5.2	9.6
2014	5.3	9.8
2015	5.5	9.7
2016	5.6	9.6
2017	5.4	9.8
2018	5.5	9.9
2019	5.3	9.8
2020	5.2	9.7

Appendix 2: Correlation Coefficient Trend between gravitational variations and seasonal wind flux

Year	Correlation Coefficient
2010	0.82
2011	0.79
2012	0.85
2013	0.81
2014	0.84
2015	0.86
2016	0.87
2017	0.85
2018	0.84
2019	0.82
2020	0.81

ADVOCACY FOR ADOPTION OF INTEGRATED SOIL FERTILITY MANAGEMENT FOR INCREASED SOIL PRODUCTIVITY AND IMPROVED FARMERS' LIVELIHOOD SYSTEMS IN SOUTHWESTERN NIGERIA

***Ande, O. T., K. S. Are, O. A. Ojo, B. O. Lawal, M. I. Fademi, J. A. Adediran and G. A. Oluwatosin.**

Nigeria Soil Health Consortium (South), Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor Plantation, Ibadan, Nigeria.

Corresponding author email:funmiande67@gmail.com

EXECUTIVE SUMMARY

The objective of this policy brief is to inform the Nigeria Federal Ministry of Agriculture and Rural Development (FMARD) and all stakeholders involved in agricultural production on the need for Integrated Soil Fertility Management in Nigeria to boost agricultural productivity and enhance the livelihood of smallholder farmers. The Nigeria Soil Health Consortium (South) sponsored by AGRA and hosted by Institute of Agricultural Research and Training was saddled with the responsible to promote wider uptake of ISFM protocols among small holder farmers in southern agroecologies of Nigeria. The activities of the consortium include, stakeholders profiling and mapping, development of database of ISFM experiments, production of knowledge products, dissemination of ISFM technologies and providing appropriate ISFM recommendations for farmers for increased agricultural productivity. The study affirmed the age long problem of fertilizer availability, accessibility and affordability still persist. Moreover, lack of adequate knowledge in soil management in spite of climatic change has aggravated soil fertility decline among small holder farmers. Hence, integrated soil fertility management approach where resources within the farms are pulled together with little external inputs based on farmers' knowledge of their soils will scale down the problem of low productivity. Strategic use of ISFM protocols is recommended for the region which include, improved high yielding seed varieties, combined use of organic and inorganic fertilizers, local adaptations including proper tillage, need for supplementary water, cereal-legume cropping systems, live mulch, and cover crops as appropriate based on soil investigation.

Introduction

Soil fertility decline is a deterioration of chemical, physical and biological soil properties and subsequent reduction in providing the crops with adequate nutrients and water. In Nigeria, one of the reasons for the failure of agricultural plans is underestimating the importance of soil status and, therefore, has led to mismanagement of the nation's soil. The nature of the soil and its' properties in terms of its chemical properties such as nitrogen, phosphorus, potassium and organic C and physical properties such as compactness, structure and texture are determinants of the soil fertility in south western Nigeria (Ande *et. al,,* 2008).

According to FAO (2001), Nigeria is one of the countries with high declining soil fertility. The country was estimated to be losing an average of 24 kg nutrients/ha per year (10 kg N; 4 kg P_2O5, 10 kg K_2O) in 1990 and 48 kg nutrients/ha per year in 2000, that is, a loss equivalent to 100 kg fertilizers/ha per year. However this figure is postulated to have dropped appreciable since the government and other foreign organizations started investing heavily on fertilizer but with the removal of subsidy on fertilizer, the figure has increased. Soils in most of South Western Nigeria have inherently low fertility and do not receive adequate nutrient replenishment (Ande *et al.*2008). The mineral fertilizer consumption is about 10 kg nutrients (N, P_2O_5, K_2O)/ha per year compared to the world average of 90 kg, 60 kg in the Near East and 130 kg/ha per year in Asia (FAO, 2001). These values have changed in 2022 with reduced consumption of 7.3kg/ha in Nigeria, world average increased to 146kg/ha and Asia varied between 138-178kg/ha (World Bank, 2022). The inherent low soil fertility and fertilizer use have hindered crops from attaining their genetic potentials (Ande *et. al.,* 2017).

Soil Fertility Decline

The main contributing processes to soil fertility decline and low crop productivity in Nigeria include soil erosion by wind and water, inappropriate tillage methods, decline in organic matter and soil biological activities, degradation of soil structure and loss of other soil physical qualities, reduction in availability of major nutrients (N, P, K) and soil pollution. The immediate solution to these problems have been proven through research to be effective and appropriate use of organic and inorganic fertilizers. The activities of the NSHC (south) revealed the need for adequate farm level soil information to guide fertilizer use. Moreover, inorganic fertilizers are not affordable to farmers and not available when needed. There is also lack of technical know-how of residue management, hence low adoption of organic fertilizers. Unchecked erosion, water stress during cropping season, inappropriate land preparation and unsustainable cropping systems have also compounded problems of soil fertility decline. Moreover, extension agents are not properly empowered in terms of training and funding to disseminate available technologies effectively. In addition, fertilizers are scarce and access to subsidized fertilizer by majority of the rural farmers is rather difficult. The Growth Enhancement Scheme (GESS) initiated by the Federal Government of Nigeria in 2011 to boost agricultural production through subsidized farm inputs for small holder farmers was not effectively promoted due to change of government.

Implications of soil fertility decline

The declining soil fertility status has led to decline in the quality and quantity of the yield of many crops especially the exportable ones such as cocoa, yam, cassava, and maize. The decline in soil productivity has continued unabated due to inappropriate use of inorganic, low adoption of organic fertilizers and unsustainable soil management systems. These have resulted to reduction in crop yield of smallholder farmers and consequently low income and poor livelihood. Thus, cycle of poverty keeps increasing despite government interventions through subsidy. The fertilizer subsidy though reduced price of fertilizer by 30 %-50 %, but limited quantity can be purchased due to restriction to avoid purchase for the purpose of reselling which is a common practice. Hence, the current fertilizers use and soil management practices cannot meet the demand for food security and export earning which is crucial to revive Nigeria economy.

Recommendations

Integrated Soil Fertility Management (ISFM) is now regarded as a strategy that helps low resource endowed farmers mitigate many problems and the characteristics of poverty and food insecurity by improving the quantity and quality of food, income and resilience of soil productive capacity (Kimani *et al*., 2001; Ande *et. al,* 2017).

Integrated soil fertility management (ISFM) is regarded as the key to sustainable soil management in spate of climatic variability with its associated detrimental effects on soils quality and resilience.

ISFM is a means to increase crop productivity in a profitable and environmentally friendly way (Vanlauwe *et al.*, 2010) and thus to eliminate one of the main factors that perpetuates rural poverty and natural resource degradation in sub-Saharan Africa (SSA).

Current interest in ISFM partly results from widespread demonstration of the benefits of typical ISFM interventions at plot scale, including the combined use of organic manure and mineral fertilizers (e.g. Ojeniyi 2000, Adediran *et. al.,* 2003 and Ande *et. al.,* 2010, Senjobi *et al.,* 2013, Ande *et. al.,* 2017, Ogunweide *et. al.,* 2022, Odunjo *et. al.,* 2023 and Aruna *et. al.* 2024), use of leguminous fallow (Ande and Onajobi 2009), combined use of organic fertilizer with rock phosphate (Akande *et. al.*, 2006), combined use of compost and lime for acid soils (Oluwatoyinbo *et. al.,* 2009), soil quality improvement with fortified organic fertilizer (Senjobi *et. al.,* 2013), and cereal legume intercropping systems (Ayoola and Makinde, 2007) in South Western Nigeria.

The ISFM practices can increase the availability of organic resources within farms, mainly as crop residues and/or farmyard manure. Availability of organic resources will reduce the dependence of farmers on inorganic fertilizer and pave way for availability of exportable organic crops to countries that have well embraced organic produce like USA. This will increase the country's foreign exchange earnings. Combined application of fertilizer and organic (organo-mineral) inputs is highly important since (i) both fertilizer and organic inputs are often in short supply in smallholder farming systems due to limited affordability and/or accessibility; (ii) both inputs contain varying combinations of nutrients and/or carbon, thus addressing different soil fertility-related constraints; and (iii) extra crop produce can often be observed due to positive direct or indirect interactions between fertilizer and organic inputs (Vanlauwe *et al*., 2001).

The Nigeria Soil Health Consortium (South) sponsored by Alliance for Green Revolution in Africa (AGRA) and hosted by Institute of Agricultural Research and Training, Moor Plantation, Ibadan was saddled with the responsibility of creating awareness on the importance of ISFM for increased crop productivity. The initiative has led to the training of various stakeholders including extension agents, farmers, credit providers as well as agro-dealers and policy makers. The database developed from experimental trials in the zone by the Consortium shows comparative yields from combined use of fertilizers (organic and inorganic fertilizers) and conventional compound NPK fertilizers with synergistic effects from using improved seed varieties. While stakeholders mapping carried out revealed the need for improving /reviving of farmer's knowledge about ISFM protocols to increase their agricultural productivity. There is therefore a need to further upscale this strategy among smallholders and other stakeholders to increase soil fertility and crop productivity for improved livelihood system of farmers and the nation's economy.

References

Adediran, J.A., De Baets, N., Mnkeni, P.N.S., Kiekens, L., Muyima, N.Y.O. and Thys, A., 2003. Organic waste materials for soil fertility improvement in the border region of the Eastern Cape, South Africa. *Biological agriculture & horticulture*, *20*(4): 283-300.

Akande, M.O., Oluwatoyinbo, F.I., Kayode, C.O. and Olowokere, F.A., 2006. Response of maize (Zea mays) and okra (Abelmoschus esculentus) intercrop relayed with cowpea (*Vigna* *unguiculata*) to different levels of cow dung amended phosphate rock. *World Journal of Agricultural Sciences*, *2*(1): 119-122.

Ande, O.T. and Onajobi, J., 2009. Assessment of effects of controlled land use types on soil quality using inferential method. *African journal of Biotechnology*, *8*(22): 24–30.

Ande, O.T., 2010. Morphogenetic characterization of soils formed from basement complex rock in the humid tropical rainforest of Nigeria. *Journal of Soil Science and Environmental Management*, *1*(6):122-126.

Ande, O.T., Adediran, J.A., Ayoola, O.T. and Akinlosotu, T.A., 2008. Effects of land quality, management and cropping systems on cassava production in southern western Nigeria. *African Journal of Biotechnology*, *7*(14): 8-12.

Ande**, O.T.,** Huising, J., Ojo, O.A., Azeez, J.O., Ojeniyi, S.O. Olakojo, S.A. and Fademi, I.O. (2017). Status of integrated soil fertility management (ISFM) in Southwestern Nigeria. *International Journal of Sustainable Agricultural Research* 4 (2): 28-44.

Aruna O A., Ande, O. T**.,** .Dahunsi, S. O. Ogunwole, J. O. and Ibaba, A. L. (2024). Impact of bio-digestate and fertilization on the soil chemical properties, growth and yield of maize (*Zea mays* (L.) *Research on Crops*, 28(1) 33-42 DOI:10.51830/2348-7542.2024.ROC-1039

Ayoola, O.T. and Makinde, E.A., (2007). Complementary organic and inorganic fertilizer application: influence on growth and yield of cassava/maize/melon intercrop with a relayed cowpea. *Australian Journal of Basic and Applied sciences*, 1(3): 187-192.

FAO, (2001). Status and Challenges of Soil Management in Nigeria. Available at: http://www.fao.org/fileadmin/user_upload/GSP/docs/WS_managinglivingsoils/Status_Soil_Management_Nigeria_Ojuola.pdf

Kimani-Njogu, S.W., Trostle, M.K., Wharton, R.A., Woolley, J.B. and Raspi, A., (2001). Biosystematics of the *Psyttalia concolor* species complex (*Hymenoptera: Braconidae: Opiinae*): the identity of populations attacking *Ceratitis capitata* (*Diptera: tephritidae*) in coffee in Kenya. *Biological Control*, *20*(2):.167-174.

Odunjo, T.E., Oguweide, T.A., Fademi, I.O., Anoke, E.O., Uthman, A.C.O. and Ande, O.T**.** (2023). Soil quality improvement with verti-compost for sustainable maize cultivation on degraded soils. *Moor Journal of Agricultural Research,* 22: 1-12.

Ogunweide, T.J. Odunjo, T.E., Fademi, I.O. and Ande, O.T**. (**2022). Response of maize (zea mays) to organic and inorganic fertilizer sources on soil under intensive continuous cultivation. *Journal of Agriculture and Food Sciences* 20 (2): 19-20.

Ojeniyi, S. O. (2000). Effect of goat manure on soil nutrients and okra yield in a rain forest area of Nigeria. *Applied Tropical Agriculture*, *5*: 20-23.

Oluwatoyinbo, F.I., Akande, M.O., Makinde, E.A. and Adediran, J.A. (2009). Growth and yield response of okra to lime and compost on an acid soil in the humid tropics. *Research Journal of Agriculture and Biological Sciences*, *5*(5): 858-863.

Senjobi, B.A., Ande, O.T., Senjobi, C.T., Adepiti, A.O. and Adigun, M.O. (2013). Performance of *Abelmoschus esculentus* (L) Moench (okra) under various applications of pesticides and fertilizers in an Oxic Paleustalf. *International Journal of Plant & Soil Science*, *2*(1):.24-40.

Vanlauwe, B., Aihou, K., Aman, S., Iwuafor, E.N., Tossah, B.K., Diels, J., Sanginga, N., Lyasse, O., Merckx, R. and Deckers, J., (2001). Maize yield as affected by organic inputs and urea in the West African moist savanna. *Agronomy journal*, *93*(6):.1191-1199.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D. and Smaling, E.M.A. (2010). Integrated soil fertility management operational definition and consequences for implementation and dissemination. *Outlook on agriculture*, *39*(1):.17-24.

World Bank (2022). World Bank Open Data. data.worldbank.indicator AG CON FERTZS.

MAINTENANCE AND SUSTAINABILITY OF NATIONAL FARMERS SOIL HEALTH SCHEME FOR OPTIMAL AGRICULTURAL PRODUCTIVITY: A PARADIGM SHIFT IN SOIL AND LAND RESOURCES MANAGEMENT

Ojuola, O. O. (FSSSN)
Farm Technologies Research and Extension Initiative,
Moor Plantation, Ibadan, Nigeria.
E-mail GSM No.: olatunjiolabode72@gmail.com; +2348168442233

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Introduction

Nigeria ranks top most, in Sub-Saharan Africa amongst the most land resources inventorized countries, dating from colonial times to date, only superseded by South Africa (largely due to Dutch influence on agricultural activities). This was also due to decisive and all-inclusive political and administrative will and visionary attributes of stakeholders via deliberate agricultural policies, geared towards focused developmental plans, programmes and interventions that enhanced crop production via sound land use planning and resource inventorisations. These efforts during the colonial era from 1947 – 1957 were inclusive of the United Kingdom Overseas Land Resources Development Agencies (UKOLRDA) that were engaged in various aspects of soil management programmes. In addition, various Regional Governments in the Northern, Eastern and Western Nigeria embarked on deliberate policy of identifying suitable agricultural lands for targeted crop production in areas where they have comparative crop production advantages. In addition to these landmark achievements that transformed the agricultural and socio-economic landscape of these regions, there were other policy initiatives and interventions executed by various River Basins and Development Authorities (RBDAS), agricultural corporate organizations to identify potentials of areas of agricultural productivity in their catchment areas, in the late 70s to 90s.

Although these interventions enumerated above achieved significant national coverage of 60 % of the nation's land resources, Soil Science Society Nigeria (SSSN), and with full support of Federal Department of Agricultural Land Resources (FDALR), felt the need to conduct a National Soil Survey Programme (NSSP), for the entire country in order to provide basic soil information for sound land use planning. A notable paradigm shift from nationwide execution of the first NSSP was the conduct of semi-detailed to detailed soil and land use inventorisation, within designated crop clusters involving assessment of soil resources by Digital Soil Mapping (DSM) and their physical and chemical properties determined using current Soil Analytical Procedures (SAP). The reports were georeferenced, digitized and archived in the Geographical Information System (GIS) laboratory at FDALR. Although there were improvements in the methodology and implementation of soil resources assessments DSM and SAP, there is the need for other soil initiatives and management that will provide a holistic approach for sustainable soil health and crop productivity. This approach will ensure a more inclusive farmers adoption and participation in the evaluation of the status of their "Soil Health" and appropriate fertilizer recommendations based on crop and inherent soil nutrients. The National Farmers Soil Health Scheme (NFSHS) being implemented now is a holistic approach that is expected to provide basic on-site and crop-specific soil information on farmers' plots that will sustainably increase agricultural productivity and farmer's income.

The objective of this paper is to review various antecedents and previous efforts in the nation's soil resources inventory, identify various limitations, constraints and discuss the current paradigm shift to a more farmer's demand – driven, on-site, crop specific soil nutrient assessments using the NFSHS.

History of Soil Survey/Land Management in Nigeria

Efforts in the colonial era by UKOLRDA who were engaged in various aspects of soil management and inventorisations notably by the UK Government Ministry, OLRD made significant contributions in exploring the agricultural potentials of Northern Nigeria using notable Soil Scientists led to the following publications on the soil resources of different regions of the country. This include:

Aitchson, 1972, (Land resources of North Western State);
Bawden (1972, (Physiography of Benue Valley); Murdoch (1972), (Land Facet map of Savanna Region of Western Nigeria),

Bawden (1973), (Interim Report of Lands, Central Nigeria) and de Leeuw, (1972), Land Resources of North-East; (Potentials for Agricultural Development).

Vine (1911), Soil catena in the cocoa belt
Montgomery (1962), Identification of suitable land for cocoa cultivation.

Weston (1952), Vine(1952; 1953), Soil survey of West African Institute for Oil Palm Research (WAIFOR) commissioned by the Federal Surveys, Lagos.

Tinker (1959), Soil studies to identify soil that will support oil palm production commissioned by the Eastern Regional Government.

Jungerius (1964), Soil survey of eastern region commissioned by the Eastern Regional Government.

Institute for Agricultural Research publications:

Clayton and Hope (1958), Reconnaissance soil survey of Jema'a Experimental Station, Southern Kaduna.

Higgins and Story (1966), Soil survey of Bacita fadama, Ilorin Province.

Higgins (1961), Soil survey of Niger trough.
Valette and Higgins (1967), Reconnaissance soil survey of Auna, Niger Province.
There were other commissioned studies and reports on assessment and land use planning by Government agencies these include:
Aerial surveys inventorisations and land assessment across agroecological zones in Northern Nigeria carried out by NEDECO, Bookers International Ltd, Hunting Surveys and Technical Services, and Kenting Africa.
Land evaluation for Kainji Basin Irrigation Project carried out by Malaysia International Consultants Ltd. for Niger Basin Development Authority.
Soil survey for commercial sugarcane irrigation project at Lafiagi, Kwara State carried out by Bookers International Limited (UK).

The River Basin Development Authorities also undertook land assessment for irrigation and construction of irrigation dams in their area of coverage including:
Sokoto-Rima Basin Irrigaion Project at Talata Marafa, Zamfara State carried out by Impresit Bakolori Ltd.

Hadejia-Jama'are River Basin Irrigation Project, Kano, Kano State and assessment of soil resources for irrigated agriculture carried out by NEDECO/Hunting Technical Services

Soil and land resources assessments of Kamadugu-Yobe Basin, River Chari and adjoining wetlands for cereal crops cultivation undertaken by Lake Chad Development Authority.

National Soil Survey Programme

The National Soil Survey Programme (NSSP) was midwife by Soil Scientists under the aegis of Soil Science Society of Nigeria (SSSN) with the active support of the Federal Government of Nigeria/Federal Ministry of Agriculture and Rural Development (FGN/FMARD) via the Federal Department of Agricultural Land Resources (FDALR). The programme was undertaken in two phases. The first phase from the year 1980 to 1985 covered the entire nation with the major objective of soil and land resources assessment at reconnaissance level at 1:650,000 mapping scale. The major objective was to serve as a benchmark to identify potential areas of agricultural production. Despite its limitations, the programme was useful in the identification of areas for subsequent land use planning for crops and livestock development in the country.

The second phase was carried out in recognition of the need to provide a more detailed soil survey information and make appropriate crop based and efficient fertilizer recommendations to farmers, and would-be investors in the agro industries. It was modified in line with the Agricultural Transformation Agenda (ATA), with a focus on identified crop clusters of maize, millet, rice, cotton, sorghum, oil palm, cassava and soybean covering 10,000 ha in each location across the nation.

Definition and Concept of Soil Health

Soil health is defined as continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans. It describes the capacity of soil to meet performance standards relating to nutrient and water storage and supply, biological diversity and function, structural integrity and resistance to degradation. In this way, soil health regards soil as a complex and dynamic system that, in its best state, is able to support healthy vegetation and larger needs of mankind. A healthy soil is that which allows plants to grow to their optimum productivity without diseases in plants and without need for off-farm supplements.

The concept of soil health is holistic and refers to more than just the vigor of soil biota. It also describes and considers the condition of the soil's physical properties including texture, depth, bulk density, porosity, permeability, and water holding capacity. chemical properties including total organic carbon, N, pH, electrical conductivity (EC), extractable N, P, and K and biological properties such as microbial biomass C and N, potentially mineralizable N, soil respiration, water content, and temperature. A healthy soil, therefore will have all these attributes functioning well to provide optimal plant growth on sustainable basis. Managing soils for optimum soil health condition will mean that producers work with land, not against it (land degradation), adoption of soil conservation practices, maximize water infiltration, improve nutrient cycling, save more on agro-inputs and ultimately maximize biodiversity in soil solum.

National Farmers Soil Health Scheme

The Federal Ministry of Agriculture and Food Security (FMAFS)in the year 2923 in line with recent policy initiatives of aligning with the provision of site-crop-specific agro-nutrient recommendations and management, approved the conduct of National Farmers Soil Health Scheme, under the auspices of the Department of

Agricultural Land and Climate Change Management Services (ALCCMS).

The National Farmers Soil Health Scheme (NFSHS)

is a current policy initiative that considers the need for site-crop-specific soil nutrient management and recommendations which were highlighted and executed during the second phase of NSSP in crop clusters locations, by farmers and other end users. This became imperative in order to further upscale agricultural productivity on sustainable basis, using the concept of soil productivity and enhancement.
The NFSHS involves determining the status of the soil in terms of its physical, chemical, biological properties and composition and other external factors such as climate, nature and differences in nutritional demand of crops all of which determine the health or productivity of the soil and the appropriate soil management needs to be deployed. This is in order to meet the needs and requirements of farmers on appropriate nutrient applications that are site-crop-specific.

The programme is envisaged to embrace components of the Integrated Soil Fertility Management (ISFM) comprising of composting, combination of organic and inorganic fertilizers, crop residue recycling and other soil management activities.

Aim and Objectives
The NFSHS is designed to provide sustainable farming practices, improve agricultural productivity and ultimately ensure food and nutritional security for the farming communities. It aims to provide farmers with valuable information on the nutrient status in respect of some parameters – pH, EC, Organic C, N, P, K, and some micronutrients such as Zn, Bo, Fe, Mn, and Cu on the farmer's plot. These nutritional status of the soil is recorded on a Soil Health Card Scheme (SHCS) which is a printed report that will be handed over to the farmer in addition to fertilizer recommendations.

Methodology and operational delivery
The major highlight of methodology and operational delivery of the NFSHS is to establish in each of the 774 LGAs in the country, systematic programme of soil sampling, testing and generation of Soil Health Card data. Its implementation will ultimately reduce cost of production, ensure high agricultural productivity, improved revenue and livelihoods of teeming farming communities thereby ensure food and nutritional security, nationwide and on sustainable basis.

Constraints to implementation
Faithful implementation of the NFSHS policy is hinged on the identification and overcoming of constraints in a strategic, well-intentioned manner. A project of this magnitude, (targeting all 774 LGAs in the country) definitely could have many constraints both in planning and implementation stages. However, these could be overcome with high level of advocacies, provision of extension agents and credible laboratory analytical results, interpretation and recommendations of appropriate fertilizer recommendations.

Integrity of soil laboratory analytical results
A major constraint is in the integrity of soil analytical results. There is the need to ensuring the standardization and uniformity laboratory procedures with a shift towards dry chemistry methodology of analysis, which offers more accurate results. The outcomes of credible laboratory analysis will lead to good interpretation and recommendations of soil nutrients required by extension agents to the farmers.

Poor extension services
Poor extension services is another major constraint to the successful implementation of the NSFHS. Akin to the unbiased, accurate and reliable soil and nutrient

analytical results and interpretation is the need to overcome inadequate or inefficient extension services. The extension service providers are expected to be the integral link between the outcomes of laboratory analysis and recommendations to the farmers.

Presently, except for few states, agricultural extension services have virtually collapsed, with the exit of World Bank funded Agricultural Development Programmes (ADPs) across the nation, and inability of the States to adequately fund and equip these ADPs to enable them discharge their duties. The need therefore arises from the Federal Government and States to focus on massive recruitment, training, capacity building and institutional support (logistics of communications, transport and other operational tools) in order to overcome this major constraint to success of the Scheme.

Poor advocacy and awareness by farmers

Another major constraint is lack of advocacy on the part of those charged with implementing the Scheme with consequent lack of awareness by majority of farmers in the rural areas. The farmers need to be educated on the importance and beneficial effect of proper testing of the soil of their farm so as to recommend appropriate type and quantity of fertilizer(s) to be applied to their for maximum and sustainable productivity.

Funding and sustainability issues

In a developing country such as ours a major constraint that bedevils initiatives, programmes and projects is the issue of continuity due either to paucity of funds or inadequate disbursement or outright abandonment. Reliance on project funding through budgetary provisions alone may not be sustainable due to dynamics of national or global economic downturns in revenue projections, and allocation of scarce resources. A project of this magnitude should seek for and attract other funding sources locally (by corporate bodies and organizations), in addition to those from development partners and institutions in the agricultural sectors.

Politics and government policies

Most Government programmes and policies are constrained by high level of political interference and discontinuities at policies initiation and implementation levels. However, in view of the long-term benefits in terms of increased agricultural productivity and enhanced income of farmers, it will be expected that political will for its continuation will be assured, especially given its attendant employment generation attributes, youths and women and vulnerable groups and efficient large scale agricultural production systems.

Way Forward and Recommendations

Based on above considerations, the following are key recommendations to ensure smooth take-off, operation and performance of the NFSHS;

a) Strong advocacy to farmers and agricultural communities on the need for site-crop-specific agro-nutrient recommendations and application, ably supported by fertilizer/nutrient blends that conforms to the various soil type and agro-ecological location.
b) Training and re-training of laboratory technicians and technologists on current soil / water analytical procedures.
c) Well-funded and support for agricultural extension services at all levels, - FG, States and LGAs, that are well trained on the subject matter and materially supported in terms of logistics and infrastructure.
d) Fertilizer and blending options that could fit in to farmers needs at different agro-ecosystems and crops establishment. Current efforts in phosphate importation to local blending plants, along with urea and other inputs should be encouraged. Nigeria has a large deposits of

natural gas from which urea could be manufactured, while potash could be sourced off-shore as Nigeria does not have significant deposits of Potash.

e) Political aspects of State's buy-in in the entire initiative-chain is of absolute importance. This could be achieved via the National Council on Agriculture meetings, where States and Local governments could articulate views, modify the programme to suit their agricultural systems and ventures, and contribute financially and technically to the smooth operations of the National Farmers Soil Health Scheme in the States and Local Government Areas.

Summary and Conclusions

The National Farmers Soil Health Scheme, is a transformative initiative that could change the entire agricultural landscape of the country if well-articulated and implemented. The gains, apart from enhancing agricultural productivity at farmer's level, will reduce over or under nourishment of the soil ecosystem therefore making agricultural operations more cost effective and efficient.

A major upstream effect of this initiative will be the establishment of different fertilizer blending plants across the nation that meets the specific nutritional demands of crops and soil and on integrated mix of both that will overall contribute to significant improvement in the agricultural sector as a major, non-oil contributor to the Gross Domestic Product (GDP) of the nation.

On socio-economic basis, the initiative envisions huge employment generation windows to youths, women and vulnerable groups towards the overall objectives of increasing food and nutritional security for Nigeria.

References

Aitchison, P.M. (1972). Land Resources of North-East State. Vol. 1. The Environment and Land Resources. Study No. 9.

Clayton, W.D.and W.A. Hope (1958). A preliminary report on the reconnaissance soil and vegetation survey part of the Temma Res. Scheme Sam. Soil Survey. Bull. No. 7.

De Leeuw, P.N. Leslie, A..and Tuley, P. (1972) Land Resources of the North-East States. Vol. 4. Present and Potential Land the Land Resour. Study No. 9.

FDALR (1990). National Soil Survey Programme.

Higgins G., Story R.E. (1960). A preliminary Report of Soil Survey of Bacita Fadama, Ilorin Province. Samaru Soil Survey Bull. No. 3.

Higgins, T.M. Ramsay D.M. and Pullan J. (1960). A report of the climate, soil and vegetation of Niger Trough Sam. Soil Survey Bull. No. 10.

Pankhurst, C. E., Doube, B. M., Gupta, V. V. S. R. and Grace, P. H (Eds). (1994). Soil Biota: Management in Sustainable Farming Systems. CSIRO, Victoria, Australia.

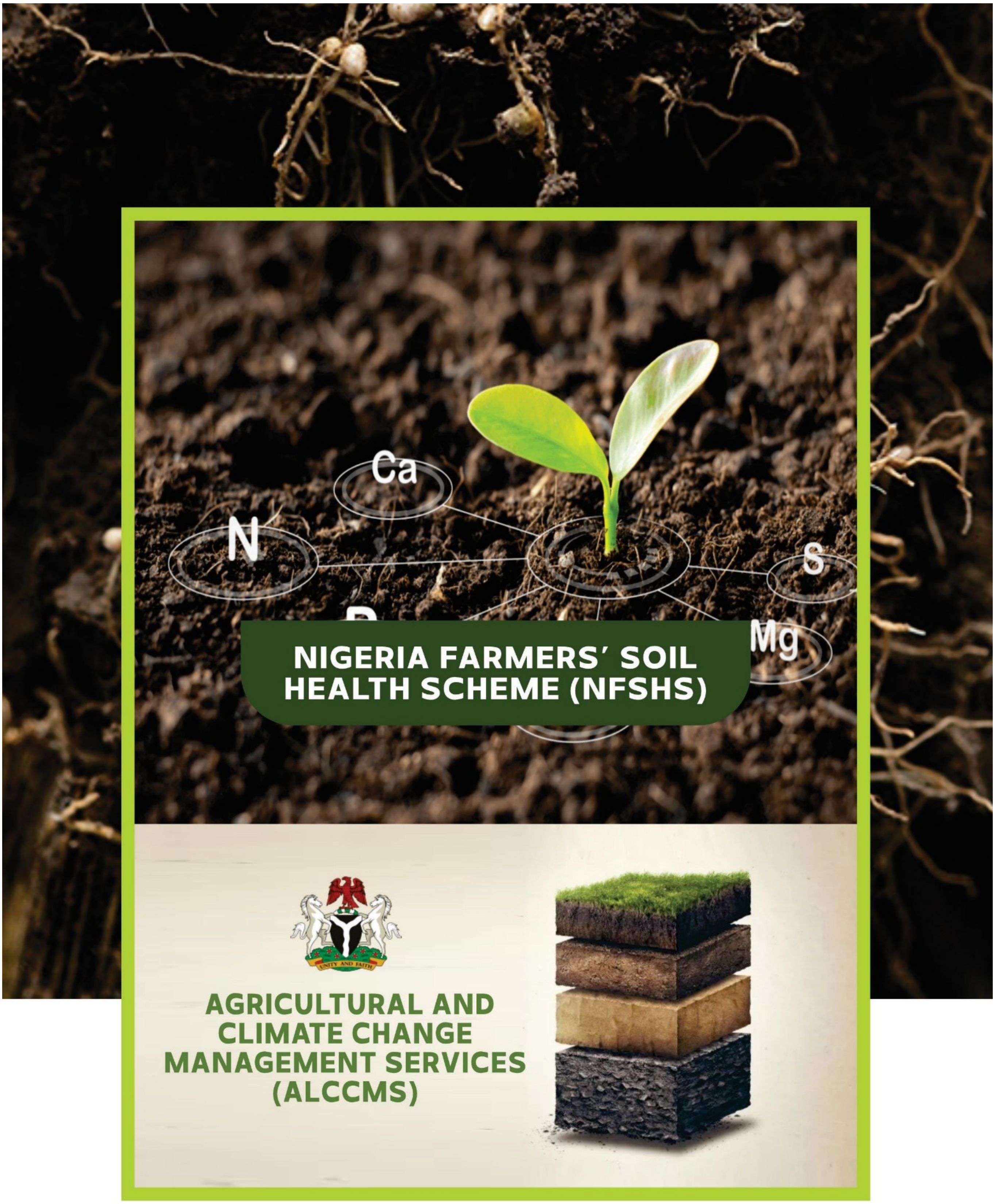
Sanginga, N. and Woomer, P. L. (Eds) (2009). Integrated Soil Fertility Management in Africa: Principle, Practices and Developmental Process. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT), Nairobi, Kenya. 265 pp.

Smyth, A. J. and Montgomery, R.F. (1962). Soils and Land Use in Central Western Nigeria. Govt. of Western Nigeria, Ibadan.

Valette, J. and Higgins G.M. (1967). The reconnaissance soil survey of an area near Auna, Niger Province. Sam. Soil Survey Bull. No. 34.

Valette, J. (1973). The Reconnaissance Soil Survey of Part of Mokwa-

Kontagora Kainji area, North-Western State. Sam. Soil Surv. Bull. No. 44.
Vine, H. (1941). A soil catena in the Nigerian Cocoa belt. Farm and forest v
Vol. 2 and 3.
Vine, H. (1956). Studies of profiles of WAIFOR Main Station, Benin City, and other sites of Oil Palm experiments. *Journal of West African Institute of. Oil Palm Research*, 1: 8-59.
Western, J. (1952). A detailed Soil Survey of WAIFOR Oil Palm Plot. Soil Survey File. MANR, Ibadan.



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