SOIL SCIENCE SOCIETY OF NIGERIA (SSSN)

PROCEEDINGS

of

The 47th Annual Conference

OF THE SOIL SCIENCE SOCIETY OF NIGERIA

Theme:

TROPICAL SOIL AND WATER RESOURCES MANAGEMENT:

Climate Change Mitigations for Functional Ecosystem Services and Food Security

19th to 23rd September, 2023

Princess Alexandra Auditorium, University of Nigeria, Nsukka

EDITED BY:

C. L. A. ASADU | C.V. AZUKA | C. M. JIDERE | M. A. N. ANIKWE

PROCEEDINGS of The 47th Annual Conference

SOIL SCIENCE SOCIETY OF NIGERIA

PUBLISHED BY THE SOIL SCIENCE SOCIETY OF NIGERIA

PROCEEDINGS OF THE 47TH ANNUAL CONFERENCE OF THE SOIL SCIENCE SOCIETY OF NIGERIA, (UNN 2023) 19TH – 23RD SEPTEMBER 2023

DEPARTMENT OF SOIL SCIENCE, FACULTY OF AGRICULTURE,
UNIVERSITY OF NIGERIA, NSUKKA

THEME:

TROPICAL SOIL AND WATER RESOURCES MANAGEMENT: CLIMATE CHANGE MITIGATIONS FOR FUNCTIONAL ECOSYSTEM SERVICES AND FOOD SECURITY

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CITATION

Asadu, C.L.A., Jidere C.M., Azuka C.V. and Anikwe M.A.N. (2023). Tropical Soil and Water Resources Management: Climate Change Mitigations for Functional Ecosystem Services and Food Security. Proceedings of the 47th Annual Conference of The Soil Science Society of Nigeria Held at Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka, 19th – 23rd September 2023.

Soil Science Society of Nigeria (SSSN)

Publishers of the Nigerian Journal of Soil Science

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FOREWARD

The Soil Science Society of Nigeria's 47th Annual Conference was held at the University of Nigeria, Nsukka from September 19 to 23, 2023. The hosting of the Conference at the University of Nigeria, Nsukka was approved during the AGM of the Society at Ahmadu Bello University, (ABU), Zaria in March 2022 after considering the request made by the Vice-Chancellor of UNN, Professor Charles Arinze Igwe. The conference date was postponed twice from March to August and finally to September 2023. The reasons for the postponement were due to the General elections in Nigeria and security situations in the Southeastern Nigeria respectively.

The theme of the Conference was **"Tropical Soil and Water Resources Management: Climate Change Mitigations for Functional Ecosystem and Food Security".**
The sub-themes included the following.
1. Nutrient management, integrated farming and food security
2. Climate smart agriculture, biological interactions and food security
3. Organic agriculture, soil and water resource management
4. Land use systems, farm practices and soil management
5. Land evaluation, GIS, Geo-statistics and spatial statistics
6. Tillage, irrigation and soil conservation practices
7. Socio-economic impact of climate change on ecosystem services and food security

The EXCO paid a courtesy call on the Vice-Chancellor at 9.30 am in his office on September 20. The Vice-Chancellor welcomed the EXCO and expressed his happiness that in spite of all that led to the postponement of the conference twice, the conference finally came to be. After a group photograph, the train moved to Princess Alexandria Auditorium (PAA), the venue for the opening ceremony.

The opening ceremony which was chaired by the Vice-Chancellor had many dignitaries in attendance in addition to those who joined virtually including the President and Chairman of Nigeria Institute of Soil Science (NISS) Council Prof. A. O. Ogunkule and the Registrar/CEO of NISS, Prof. V. O. Chude

The LOC Chairman, the President, SSSN, the UNN Vice-Chancellor, and the Permanent Secretary FMAFS presented their individual addresses. Then the Lead paper on "Climate Change Mitigation for Functional Ecosystem Services and Food Security- What should be our Focus?" by Professor J. K. Adesodun, Pioneer Rector, Ekiti State Polytechnic, Ekiti State, followed.

Professor W.O. Enwezor received his Award as the Pioneer Secretary of SSSN and his services in nurturing the Society. Special awards were given to OCP-Africa and Indorama for their contributions and support to SSSN. Professor Nafiu Abdu was conferred with the honour as a Fellow of SSSN. The SSSN Proceedings for SSSN Annual Conference at ABU, Zaria in 2022 was also launched during the Opening Ceremony.

The First break-out sessions also took place that day. Over 280 abstracts were received and acknowledged and accepted for oral or poster presentation. The papers covered various topics in tandem with the Theme and sub-themes of the Conference. The abstracts were successfully formatted and published in the Book of Abstracts and well captured in the program of events and according to break-out sessions. All the concurrent Sessions in the four venues at the UNN ICT Centre went well both physically and virtually. The presentations by Professor M.A.N. Anikwe on Master Class and that by Federal Ministry of Agriculture and Food Security on its activities were well appreciated by the conference participants

The field trip took place on September 21, 2023 at the University of Nigeria Teaching and Research Farm. Field Tour Manual was produced in a book form and each participant received a copy. The field trip was an outstanding field experience for the conference participants.

The Annual General Meeting (AGM) which took place at the Princess Alexandria Auditorium (PAA), on September 21, 2023 at 7.00 pm was well attended. The draft Communiqué was read and after some amendments, was approved. The EXCO expressed her satisfaction for the excellent organization of the conference and commended both the UNN Vice Chancellor and the LOC for a job well done.

The papers accepted for publication in this Book Proceedings were thoroughly reviewed and reflect the theme and subthemes of the Conference. They will be of immense benefits to Soil Scientists, Agriculturists, Extension Officers and other Stakeholders in land se and management in the Country.

Professor Charles L.A. Asadu

Chairman, LOC.

COMMUNIQUE

1.0 PREAMBLE

The Soil Science Society of Nigeria (SSSN) held its **47th** annual conference at the University of Nigeria, Nsukka (UNN) from Tuesday 19 to Saturday 23 September 2023. The theme of the Conference was **Tropical Soil and Water Resources Management: Climate Change Mitigations for Functional Ecosystem Services and Food Security.** This theme indicates the intimate relationship existing between soil, water and climate and that any mismanagement of one could be detrimental to others. The opening ceremony took place at the Princess Alexandra Auditorium of the UNN. The welcome address was presented by the Chief Host and Vice-Chancellor, UNN, Professor Charles A. Igwe, who doubles as a member and fellow of the Society. In his address, the Vice-Chancellor warmly welcomed all members of the Society and non-member participants to UNN, the lion's den. The Vice-Chancellor of UNN and Chief Host, Prof C. A. Igwe, declared the conference open while the opening remarks came from the LOC chairman, Prof. C. L. A. Asadu. The Conference featured, among other activities, presentation of keynote address and lead papers during the opening ceremony when awards were presented to some deserving members and corporate organizations. Also, research findings in over 250 papers were presented in the subsequent technical sessions.

1.0 PARTICIPANTS

The Conference was hybrid with physical and virtual participation; the participants comprised over 300 full and student members of the Society and their collaborators and sponsors. Many dignitaries were in attendance including the president-elect of International Union of Soil Sciences (IUSS), Prof. Victor O. Chude, the Permanent Secretary of Federal Ministry of Agriculture & Food Security; Dr. Ernest A. Umakhihe, ably represented by the Director of Agricultural Land & Climate Change Management Services (ALCCMS), Mr. O. O. Oshadiya; President of SSSN, Prof. Jibrin M. Jibrin; President & Chairman of Council, Nigeria Institute of Soil Science (NISS), Prof. Ayoade O. Ogunkunle; and the Pioneer Rector, Ekiti State Polytechnic, Prof. Johnson K. Adesodun. Other prominent dignitaries in attendance were former President of SSSN, Prof. Walter O. Enwezor and the immediate past President of SSSN, Prof. Bashiru A. Raji. Corporate bodies were also represented among which were Indorama and OCP.

2.0 HIGHLIGHTS

The Conference identified many soil-related problems affecting climate change, functional ecosystem services and food security in Nigeria. These included:

- a reduction in land area available for agriculture;
- seasonality of agricultural production due to the prevailing tropical climate;
- high degradation status of most Nigerian soils by high soil acidity;
- rapid decline in soil fertility due to accelerated erosion and excessive leaching;
- the highly weathered status of the soils compounded by poor levels of soil and water conservation and management;
- rising trend of less attention to field work in favour of modelling;
- reductions in crop yields and hence farm incomes due to climate change; and

- mass displacement and unabated migration of humans leading ultimately to mass unemployment.

3.0 RESOLUTIONS/RECOMMENDATIONS

The Conference recognized earlier interventions by the Government, corporate bodies and individuals in addressing the problems faced by the quest for functional ecosystem services and food security. Some of these interventions include creation of new departments saddled with the responsibility of understanding the peculiarity of our tropical soils and how best to manage them. These efforts notwithstanding the Conference rose to make the following recommendations:

1. The need to update the soil fertility map of the different agro-ecological zones of Nigeria based on field studies.
2. The need to promote farming practices that reduce emissions of greenhouse gases (GHGs), particularly carbon dioxide and methane into the atmosphere.
3. The need to promote ecosystem and human health through organic agriculture.
4. The need for capacity building and training of stakeholders in soil, water and climate management.
5. The need for a system of documentation of the negative impacts of our various activities on the environment and climate as well as the severity of such impacts.
6. There is an urgent need to resuscitate and equip existing soil laboratories and provide functional soil testing kits.
7. There is a need to revamp the existing dysfunctional irrigation schemes in the country and extend the scheme to all the geo-political zones of the country.
8. There is also a need for NISS to increase its efforts toward establishing zonal soil laboratories in the six geo-political zones of the country.
9. There is a need to establish demo-plots on feasible technologies for effective soil and water management across the country.

5.0 APPRECIATION

The Society hereby appreciates the warm reception accorded to participants at the Conference by the management of UNN ably led by the Vice-Chancellor, Prof. C.A. Igwe, the Faculty of Agriculture of UNN, and the Department of Soil Science which made the 47th Annual Conference of the Society a success.

Prof. Jibrin M. Jibrin, FSSSN **(President)** Dr. Jude C. Obi **(Secretary)**

Dated this 23rd day of September, 2023

Members of the Communiqué Drafting Committee
Prof. E. O. Onweremadu
Prof. S. E. Obalum
Dr. G. U. Nnaji

PRESIDENT'S ADDRESS

Permanent Secretary, Federal Ministry of Agriculture and Food Security,
Vice Chancellor and Principal Officers of the University of Nigeria,
Distinguished, Renowned Professors and Colleagues,
Distinguished Fellows and Members of the Soil Science Society of Nigeria,
Members of the Press,
Ladies and Gentlemen

It is with immense pleasure and a profound sense of purpose that we extend our warmest welcome to you all to the 47th Annual Conference of our great Society. The annual conference of the Soil Science Society of Nigeria (SSSN) represents a convergence of minds, hopes, dreams, and aspirations for better and more sustainable management of our soil resources. It is also a learning and networking opportunity that all soil scientists in Nigeria look forward to annually. Unfortunately, this year, the Conference had to be postponed twice due to uncertainties and security concerns associated with the 2023 general elections in Nigeria. We thank the Almighty for making it possible for us to be here today; we also commend the doggedness of the Local Organizing Committee. We are aware of the push, support, and encouragement of the Vice-Chancellor, our very own Professor Charles Igwe, toward making the conference a reality and a huge success.

The theme of this year's conference, *''Tropical Soil and Water Resources Management: Climate Change Mitigations for Functional Ecosystem Services and Food Security,'* is indeed very apt. As you all know, the tropical zones constitute about 40% of the earth's surface area and 36% of its landmass, stretching across four continents and several islands. The region is generally hot and wet; however, the annual precipitation can vary from as high as 3000 mm in the Congo Basins to less than 200 mm in parts of the Sahara Desert in North Africa. In tropical Africa, the soils vary greatly, with only about 16% of the land surface being of high potential for cultivation. As much as 55% of the land in tropical Africa is inherently low in fertility, chemically fragile, and easily degradable under continuous cultivation. These, coupled with the increasing population pressure on land and the impacts of climate change, imply that careful science-based management of our soil and water resources is imperative in our quest for food security. This year's conference theme also aligns perfectly with the current UN Decade for Ecosystem Restoration (2021 to 2030). It underscores the need to restore our planet's fragile ecosystems while, at the same time, addressing food security challenges.

Distinguished participants, the SSSN is a relatively small, but well-knitted and very close family of professionals. The last one year has been exceptionally emotionally challenging to the members of this great society because we lost several colleagues who have immensely contributed to the development of the society. They include:

1. Professor Yinka Okubena, the Vice President of SSSN
2. Professor Unamba Opara
3. Professor Joseph Tanimu
4. Dr. Frank Uzu

We pray for the repose of their souls and wish their families and loved ones the fortitude to bear the irreparable loss.

Distinguished participants, in the last one year, the Executive Committee has tried to introduce new activities to improve our membership experience, including the introduction of the *SoilTalk* lecture series. I want to use this medium to encourage senior colleagues to step forward and share their experience with members of the Society through this lecture series. The Society has also subscribed to a membership management App to ease communication between and among members. In the next couple of weeks, all registered members of the SSSN will be onboarded onto the platform. The Society's Newsletter is being resuscitated, we have filed to obtain an ISSN number and will henceforth publish it quarterly. It is heartening to report that, upon the nomination and recommendation of the SSSN, our past President and current Registrar of the Nigeria Institute of Soil Science (NISS), Professor V. O. Chude, was elected as the President-Elect of the International Union of Soil Science.

I must acknowledge the support from my colleagues in the executive committee, the contributions of the LOC under the chairmanship of Professor Charles Asadu, and the support and contributions of the Vice-Chancellor of UNN, Professor Charles Igwe. The contributions and support of the FMAFS through the Department of Agricultural Land Resources and climate change Management Services are well-appreciated.

At this conference one distinguished member of the Society and two corporate bodies would be conferred with the Fellow Award in recognition of his outstanding contributions to the society, science of soils and to the nation. One elder colleague and role model for most of us will also be honoured with the Award of excellence and Lifetime Achievement. The Honours and Award Committee is well appreciated in meticulous screening of potential awardee.

As we continue the journey towards sustainable management of our soil resources, mitigating the impacts of climate change, restoring our ecosystems, and ensuring food security, I extend my deepest gratitude to all participants who have played pivotal roles in making the 47th Annual Conference a reality. I anticipate lively engagements, enlightening discussions, and meaningful connections and networking among the conference participants. I am sure it is going to be an exciting and rewarding experience for all.

Once again, I welcome all the participants to the 47th Annual Conference of the Soil Science Society of Nigeria.

Professor Jibrin Mohammed Jibrin, RSS, FSSSN
President, Soil Science Society of Nigeria

ACKNOWLEDGEMENT

The editors happily express their profound gratitude and appreciation to the Vice-Chancellor, University of Nigeria, Nsukka, Prof. Charles Arinzechukwu Igwe for accepting to host the 47th Annual Conference of Soil Science Society of Nigeria. The Vice-Chancellor also graciously approved the use of Princess Alexandria Auditorium (PAA), the University's Presidential Lodge, and a host of other facilities which provided the participants an ambient and conducive environment for the successful hosting of the conference. The University Administration provided financial support, accommodation, and transportation for SSSN officials and guests, in addition to a sumptuous cocktail party. We are particularly grateful to Prof. V. O. Chude and the President of SSSN, Prof. J. M. Jibrin for their immense contribution in raising a greater part of funds for the Conference. We will not fail to acknowledge the Dean, Faculty of Agriculture, University of Nigeria for the great roles he played towards the successful hosting of the 47th Annual Conference of Soil Science Society of Nigeria.

We want to thank specially the entire Academic and Non-Academic Staff of the Department of Soil Science for their various contributions towards the success of this conference. Our appreciation also goes to the Chairmen and Members of the various sub-committees of the Local Organizing Committees (LOC) for their hard work, commitment, patience, dedication, and above all their meticulous planning and personal sacrifices that made the hosting of the conference possible and successful.

The Chairman acknowledges the immense donations and financial contributions from numerous individuals and corporate organizations already listed in this book, without which the hosting of this conference would have been very difficult if not doubtful.

We also thank immensely, the reviewers of the manuscripts for being meticulous and for a job well done

Finally, the Editors sincerely appreciate the unwavering and unflinching support of the National Executives of SSSN for their help in articulating the conference theme and sub-themes, and for the moral, logistics, and financial support. Thank you for the untiring support, selfless and persistent encouragement right from the day we got the hosting right to the end of the conference, and till the production of this Book of Proceedings is completed.

God bless you all

Editors

11th July, 2024

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CONFERENCE TECHNICAL PAPERS

SECTION ONE: SOIL GENESIS, SURVEY, CLASSIFICATION AND LAND EVALUATION

Characterization and Classification of Soils of Avyi Area in Wukari, Taraba State, Nigeria

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ABSTRACT

The study was carried out in Wukari Local Government Area of Taraba State, North East Nigeria with the view to characterize and classify soil of Wukari. Grid method of soil survey was employed in the field to investigate the morphological properties of the soils. Two soil units were identified in the study area. Soil samples were collected from different horizons, air dried, crushed and sieved (d<2 mm) for laboratory, physical and chemical analyses. The soils were deep (95 to 114 cm) and were well drained. The soils were sandy loam to loam, silty loam to silty clay and clay loam textured and moderately acidic to slightly alkaline in reaction (pH 6.80 to 7.61). The data generated were analyzed statistically using analysis of variance (ANOVA) in line with the generalized linear model of Statistic 9.1. The result indicated that, sand fraction of the particle size distribution generally dominated in all horizons followed by clay then silt. Organic carbon, total nitrogen, available phosphorus and exchangeable cations (total exchangeable base) were generally low (0.03 and 0.72%, 0.10 and 0.15%, 7.63 and 12.72 Mg/kg, 5.6 and 5.8 Cmol/kg in both units. The percentage bases were very high above 50%. The soils were classified according to USDA soil taxonomy and correlated with world reference base (WRB) as *Arenic Paleustalfs* (*Aeric Lixisols*) for unit 1 while that of unit 2 as *Arenic Kandiustalfs* (*Hypereutric Lixisols*). Farmers may avail themselves of the soil survey information in order to ensure appropriate land use management practices to protect the soils from either deterioration or degradation.

1.0 INTRODUCTION

Characterization and classification of soils are fundamental to all Soil studies and they help to document soil properties at research sites. They are essential for the successful transfer of research results to other locations (Buo *et al.,* 1997). Soil types and characteristics show great variations across the various regions of Nigeria (Ali *et al*, 2010). However, soil characterization provides the information for our understanding of the physical, chemical, mineralogical and microbiological properties of the soils. We depend on it to grow crops, sustain forests and grasslands as well as support home's and society structures (Ogunkunle, 2005).

A soil characterization study therefore, is a major building block for understanding the soil, classifying it and getting the best understanding of the environment (Esu, 2005). Usman *et al*., (2019) opine that classification is the product of differences in soil morphology, physical and chemical characteristics. Soil classification is seen as the systematic arrangement of soils into groups or categories on the basis of their characteristics (Esu, 2005). Hence, an increasing demand for information on soils as a means to produce food (Facina *et al*., 2007). According to Okusami (1987) lack of detailed information of soils and land characteristics had been one of the major factors limiting agricultural development in the Nigeria.

It is not long news that agriculture is the predominant economics activity in Nigeria, therefore soil characterization and classification has become necessary to know the prospects of the soils and also to unravel some unique soil problems in an ecosystem (Lekwa *et al*., 2004). There is little or no information about the Soils of Avyi in Wukari local government area of Taraba State. This study aims at producing information on characters and classes of the soils that may be useful in their management and sustainable use and may also serve as a baseline data for a similar research work here or elsewhere.

2.0 Material and method

2.1 Study Area

The study area is located in Avyi, Wukari Local Government Area of Taraba State North East, Nigeria. It lies between latitude 7^0 51' to 7^0 85' North and longitude 9^0 46' to 9^0 78' East. The entire area is a gently undulating plain, with a mean altitude of 200 m above the Sea level. The drainage systems drain northward and serve as tributaries network to the River Benue while Eastward discharge of rivulets and other smaller tributaries from Wukari town drains towards the Donga River, which is also a major tributary of River Benue. The mean annual rainfall value ranges from 1000-1500mm. The onset of the raining season is usually around April, while the offset period is October. The mean maximum temperature is being experienced around April at about 40^0C while the mean minimum temperature occurs between the period of December and February at about 20^0C (NIMET, 2015). The study area is situated over Cretaceous sandstone which is popularly called Bima-sand-stone. Wukari Local Government Area falls within the Southern Guinea Savannah Zone. Majority of the people living around the study area are Jukun and some minor tribe such as: Etulo, Fulani, Tiv, etc. The dominant land-use in the study area is residential and intensive agricultural activities such as farming, hunting etc.

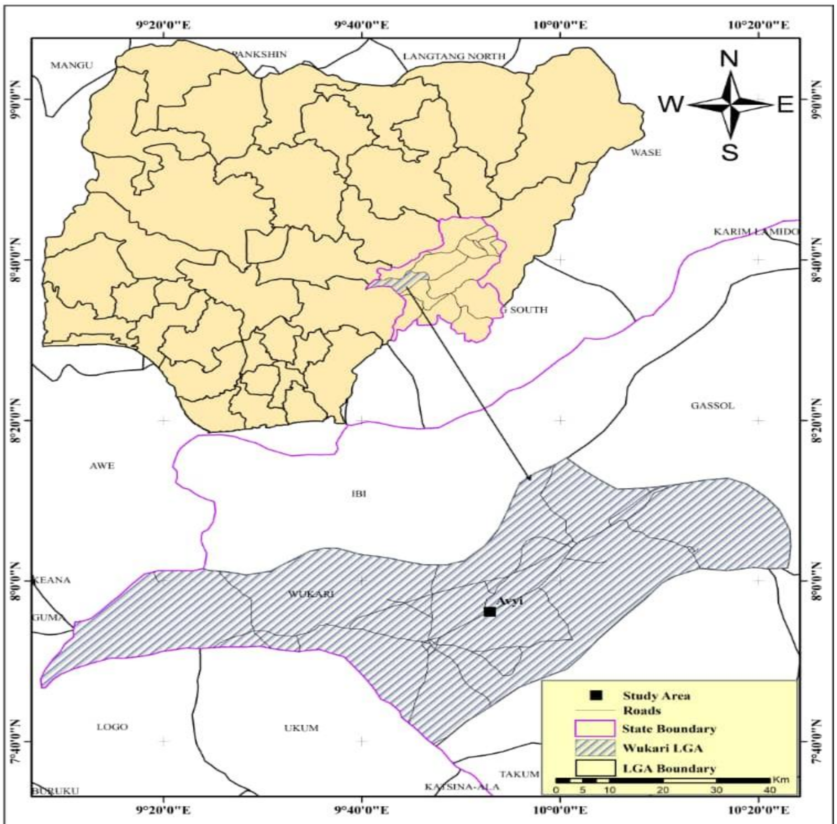

FIGURE 1: MAP OF WUKARI LGA SHOWING LOCATION OF STUDY AREA.

Field and Laboratory Studies

Soil profiles pits were dug at the most representative points of observation representing the various strata of the wetlands. The soil profiles were described according to the USDA Soil Survey Staff, (2016) guidelines. Soil samples were taken from the different horizons of the profile pits for routine physical and chemical analysis.

The soil samples collected from the field were air-dried, gently crushed and sieved with 2 mm mesh. The particle size distribution (PSD) was determined by Buoyoucos hydrometer method as described by Day (1965). Soil reaction (pH) was determined by the electrometric method in 1:1 soil: water ratio as described by Hesse (1971), and organic carbon was determined by the Walkley-Black method as described by Hesse (1971). The Macro Kjeldahl method was used to analyze the total N, while the Bray I method as described by IITA (2015) was used to analyze the available P. Exchangeable cations (Ca, Mg, K, Na) were determined from NH_4OAC filtrate. Exchange acidity was determined using the Barium chloride-triethanolamine method as described by Peech (1965). Effective cation exchange capacity (ECEC) was calculated by the summation of the exchangeable bases and exchangeable acidity while the percentage base saturation was equally calculated by dividing the sum of exchangeable bases over the effective cation exchange capacity and multiplying by 100.

4.0 RESULTS AND DISCUSSIONS

4.1 Morphological Properties of the Studied Area

The common soil morphological characteristics examined in the study include; soil colour, texture, structure, depth and consistence (Table 1). The soils were generally dark brown (2.5 YR 3/6 Moist) and reddish brown (2.5 YR 5/3) in their A and Ap horizons of all the units. This might be due to the presence of relatively high organic matter which is the main colouring agent on surface soils (Ufot, 2012). In the subsurface horizons of the units, the presence of reddish brown (2.5 Y 5/3) colour is an indication of complete organic matter decomposition. The soils were deep ranging from 95 to 114 cm. They are generally well drained with sandy loam surface textures while the sub-surfaces varied from sandy loam to loam, silty loam to silty clay loam. The textures of these soils reflected the parent rocks from which they are formed as well as the rate and the nature of some weathering processes (Ahukaemere *et al*., 2016; Idoga and Azagaku, 2005). The soil structures were well developed being moderate medium crumb to moderate medium subangular blocky at the surface while the subsurface was moderate to strong medium sub-angular blocky. The structures are functions of organic matter content of the soil (Akinyemi and Vivian, 2001). They were slightly sticky to sticky, plastic and very plastic wet, clear and diffuse smooth boundary with few and many fines, medium, coarse and common roots and iron concretion in the subsurface soil.

4.2 Physical Properties of the Studied Area

4.2.1 Particle size distribution

Table 2 shows the particle size distribution of the study area. Generally, the particle size distribution results obtained from this study showed that, the sand content dominated in all horizons followed by clay then silt. This is the trend in most soils of Southern Guinea Savannah, Nigeria (Akamigbo and Asadu, 1983). The high sand fraction is characteristics of most savannah soils and is mainly due to the nature of the parent materials, constant weathering of rocks and the downward movement of clay through the soil. Generally, the clay content ranged from 4.0 to 30.0% and had no regular pattern of distribution with depth in all the units. Though the clay content were higher in the lower horizons than the upper Ap and AB horizons. Variability in clay distribution down the profiles was low to moderate variation (4.0 to 30.8%). Low to moderate variation observed in the vertical distribution of clay showed homogeneity among the horizons and precludes the existence of well-developed argillic horizons. The trend of clay distribution down the profile observed in the study areas agrees with the reports by Idoga, (2002); Udoh *et al*., (2008); Chikezie *et al.*, (2009) who also reported higher clay content at the subsurface than surface horizons.

The textural class generally varied from sandy loam to loamy sand at the surface while the subsurface varied from loam to sandy loam, silty loam to silty clay loam and clay loam. Soil texture has an important role in the assessment of soil characteristics. The uptake capacity of soil, which is an indicator of soil fertility, depends on the textural composition of the soil. According to Loide (2004), as the percentage of clay particles and colloids contained in the soil increase, the content of plant nutrients bound by these particles and colloids increases as well. Thus, the soil's nutrient binding capacity dictates how easily the nutrients not bound by soil particles can be washed out of the soil. All the soils were well drained and may be attributed to their sandy texture (Table 2).

4.3 Chemical Properties of the soils of the Study Area

4.3.1 Soil pH

The soil chemical properties as indicated in Table 3 showed that the soil pH had values ranging between 6.80 and 7.61 indicating that the soils were neutral in reaction when compared with the range of 5.5 to 7.5 where most essential nutrients are optimally available to plants (Halving *et al*., 2005; Lake, 2000). This reaction may be associated with nature of parent materials as well as the climatic condition of the study area as pointed by Abua *et al*, (2010) and Osujieke *et al*, (2017). The soil pH content increased with depth in profile 1 which may be attributed to nutrient biocycling (Idoga and Azagaku, 2005; Ogunwale *et al*., 2002; Ugwu *et al*., 2001) and could also be accounted for by the direct deposition of crop and vegetation residues on the soil surface and subsequent decomposition to release basic cations to the soil (Ugwu *et al*., 2001). Whereas, reverse is the case with the remaining profiles. Soil pH plays a very important role in soil N's availability in soil bearing in mind its contribution to nitrogen fixation and the metabolism of urea (a nitrogen containing compound) and is important for seed germination (Brown *et al*., 2006). Soil N is also important for bacteria and fungi, which are both important for good plant growth.

Table 1: Morphological properties of the studied area

Horizon	Depth	Color moist	Mottle	Texture	Structure	Consistency	Inclusion	Drainage	Boundary
Unit 1 Profile 1: *Arenic Paleustalfs* (*Aeric Lixisols*)									
AP	0 – 17	2.5YR 3/6 (Dark Red)	-	Sandy Loam	2MSBK	Ssw	Medium Common Roots	Well Drained	cs
B	17 –30	2.5 YR3/6 (Dark Red)	-	Sandy Loam	2MSBK	Ssw	Few fine roots	Well Drained	cs
Bt 1	30 -42	5YR4/4 (Reddish, brown)	-	Loam	2MSBK	Ssw	Few fine roots	Well Drained	cs
Bt 2	42-60	2.5 YR 6/6 (Red)	-	Sandy Loam	2MSBK	Sw	Few fine roots	Well Drained	cs
Bt 3	88-105	2.5 YR 6/4(Light Reddish Brown)	-	Clay Loam	2MSBK	Sw	Few Fine roots/ hard coherent rock at 130cm	Well Drained	dw
Unit 1 Profile 2: *Arenic Paleustalfs* (*Aeric Lixisols*)									
AP	0 – 22	2.5YR 3/6(D ark Red)	-	Sandy Loam	2MSBK	Ssw	Many coarse roots	Well Drained	cs
AB	22 –40	2.5 YR3/6 (Dark Red)	-	Sandy Loam	2MSBK	Ssw	Many coarse roots	Well Drained	cs
Bt 1	40 -60	5YR4/4 (Reddish, Brown)	-	Sandy Loam	2MSBK	Ssw	Common medium roots	Well Drained	cs
Bt 2	60-85	2.5 YR 6/6 (Red)	-	Loam	2MSBK	Sw	Common medium roots	Well Drained	cs
Bt 3	85-114	2.5 YR 6/4 (Light Reddish Brown)	-	Loam	2MSBK	Sw	Few medium roots	Well Drained	dw
Unit II Profile 3: *Arenic Kandiustalfs* (*Hypereutric Lixisols*)									
AP	0-19	2.5YR 3/6 (Dark Red)	-	Sandy Loam	2MCR	Ssw	Many medium roots	Well Drained	cs
AB	19-33	2.5 YR5/3 (Reddish Brown)	-	Sandy Loam	2MSBK	Ssw	Common fine roots	Well Drained	cs
Bt 1	33-47	2.5YR6/4 (Light Reddish, Brown)	-	Silty Loam	2MSBK	Sw	Few fine roots	Well Drained	cs
Bt 2	47-67	2.5 YR5/6(Red)	-	Silty Clay Loam	2MSBK	Pw	Few fine roots	Well Drained	cs
Bt 3	67-95	5YR 7/6 (Reddish yellow)	-	Silty Loam	2MSBK	Vpw	Few fine roots	Well Drained	dw

Unit II Profile 4: *Arenic Kandiustalfs* (*Hypereutric Lixisols*)									
AP	0-25	2.5YR 3/6 (Dark Red)	-	Sandy Loam	2MSBK	Ssw	Many coarse roots	Well Drained	cs
AB	25-36	2.5 YR5/3 (Reddish Brown)	-	Sandy Loam	2MSBK	Ssw	Few fine roots	Well Drained	Cs
Bt $_1$	36-50	2.5YR6/4 (Light Reddish Brown)	-	Loam	2MSBK	Sw	Few fine roots	Well Drained	Cs
Bt $_2$	50-88	2.5 YR5/6 (Red)	-	Loam	2MSBK	Pw	Few fine roots	Well Drained	Cs
Bt $_3$	88-102	5YR 7/6 (Reddish Yellow)	-	Clay Loam	3MSBK	Vpw	-	Well Drained	Dw

Structure: 2ccr = moderate coarse crumb, 2mcr = moderate medium crumb, 2msbk = moderate medium sub angular blocky, fsbk = moderate fine subangular, 3csbk i strong coarse subangular blocky
Consistence: ssw= slightly sticky wet, vsw = very sticky wet, pw = plastic wet, vpw = very plastic wet, sw = sticky wet
boundary: ds = diffuse smooth, cs = clear smooth, ds = diffuse smooth

Table 2: Physical properties of the studied area

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	SCR (%)	TC
Unit 1 Profile 1: *Arenic Paleustalfs* (*Aeric Lixisols*)						
AP	0 – 17	65.6	26.4	8.0	3.3	SL
AB	17 –30	75.2	28.8	4.0	7.2	LS
Bt 1	30 -42	47.2	38.8	14.0	2.78	L
Bt 2	42-60	63.2	26.8	10.0	2.68	SL
Bt 3	88-105	59.2	30.8	10.0	3.08	CL
Uniy 1 Profile 2: *Arenic Paleustalfs* (*Aeric Lixisols*)						
AP	0 – 22	63.5	29.5	7.0	3.2	SL
AB	22 –40	73.0	30.8	4.2	7.1	SL
Bt 1	40 -60	60.0	29.8	10.2	2.8	SL
Bt 2	60-85	59.2	25.0	15.8	2.7	L
Bt 3	85-114	50.8	30.2	19.0	3.1	L
Unit II Profile 3: *Arenic Kandiustalfs* (*Hypereutric Lixisols*)						
AP	0-19	63.2	28.8	8	3.6	SL
AB	19-33	59.2	28.8	12	2.4	SL
Bt 1	33-47	55.6	33.8	10.56	3.2	SiL
Bt 2	47-67	27.2	42.8	30	1.43	SiCL
Bt 3	67-95	35.2	44.8	20	2.24	SiL
UnitII Profile 4: *Arenic Kandiustalfs* (*Hypereutric Lixisols*)						
AP	0-25	60.8	31.0	8.2	3.4	SL
AB	25-36	57.2	32.0	10.8	2.2	SL
Bt 1	36-50	51.2	33.6	15.2	3.0	L
Bt 2	50-88	42.2	32.8	25.0	1.4	L
Bt 3	88-102	40.2	29.8	30.0	2.2	CL

Key: SCR = Sand-Clay Ratio, TC = Textural Class, SL = Sandy Loam, L = Loam, SiL = Silty Loam, SiCL = Silty Clay Loam, CL = Clay Loam

Table 3: Chemical properties of the studied area

							Exchangeable cations								
Horizon 1	**Depth (cm)**	**pH (H_2O)**	**OC**	**OM (%)**	**TN**	**AVP (Mg/kg)**	**Ca (Cmol/kg)**	**Mg**	**K**	**Na**	**TEB**	**ECEC**	**TEA**	**BS (%)**	**Ca/Mg (Cmol/kg)**
Unit1 Profile 1: ***Arenic Paleustalfs*** **(*****Aeric Lixisols*****)**															
AP	0 – 17	6.80	0.21	0.36	0.13	9.18	4.5	0.79	0.29	0.22	5.8	6.0	0.2	96.6	5.69
AB	17 –30	7.01	0.03	0.05	0.12	8.04	4.6	0.8	0.27	0.22	5.9	6.1	0.2	96.7	5.75
Bt 1	30 -42	7.02	0.03	0.05	0.12	7.63	4.5	0.81	0.27	0.21	5.8	5.9	0.2	97.5	5.56
Bt 2	42-60	7.04	0.10	0.17	0.12	11.00	4.5	0.81	0.27	0.21	5.8	6.0	0.2	96.7	5.56
Bt 3	88-105	7.04	0.70	0.12	0.12	11.98	4.5	0.8	0.27	0.21	5.8	6.0	0.2	96.7	5.62
Unit 1 Profile 2: ***Arenic Paleustalfs*** **(*****Aeric Lixisols*****)**															
AP	0 – 22	7.00	0.20	0.34	0.15	9.18	4.4	0.80	0.27	0.24	5.7	5.8	0.3	95.5	5.65
AB	22 –40	6.90	0.04	0.07	0.10	8.04	4.3	0.80	0.30	0.23	5.6	6.0	0.2	95.6	5.77
Bt 1	40 -60	6.88	0.04	0.05	0.11	7.64	4.2	0.84	0.25	0.23	5.5	5.8	0.2	96.4	5.58
Bt 2	60-85	6.85	0.11	0.16	0.13	10.00	4.4	0.82	0.26	0.22	5.7	6.1	0.3	95.6	5.55
Bt 3	85-114	6.80	0.60	0.13	0.11	11.89	4.5	0.80	0.25	0.23	5.8	6.2	0.2	95.6	5.64
Unit II Profile 3: ***Arenic Kandiustalfs*** **(*****Hypereutric Lixisols*****)**															
AP	0-19	7.24	0.17	0.29	0.14	10.34	4.5	0.82	0.28	0.22	5.8	6.05	0.25	95.8	5.49
AB	19-33	7.61	0.07	0.12	0.13	9.09	4.5	0.81	0.27	0.22	5.8	6.00	0.2	96.7	5.55
Bt 1	33-47	7.61	0.10	0.17	0.12	12.62	4.5	0.81	0.27	0.21	5.8	6.05	0.25		5.55

														95.8	
Bt 2	47-67	7.42	0.06	3.55	0.12	9.59	4.5	0.81	0.27	0.2	5.8	6.00	0.2	96.7	5.55
Bt 3	67-95	7.35	0.72	1.24	0.12	12.46	4.5	0.81	0.26	0.21	5.8	6.00	0.2	96.7	5.55
Unit II Profile 4: *Arenic Kandiustalfs* (*Hypereutric Lixisols*)															
AP	0-25	7.23	0.18	0.30	0.13	10.33	4.4	0.83	0.27	0.23	5.7	6.10	0.25	95.5	5.50
AB	25-36	7.61	0.07	0.12	0.13	9.09	4.5	0.80	0.26	0.23	5.8	6.04	0.20	96.4	5.57
Bt 1	36-50	7.61	0.10	0.17	0.12	12.62	4.4	0.91	0.26	0.22	5.8	6.05	0.25	95.6	5.56
Bt 2	50-88	7.42	0.06	3.55	0.12	9.59	4.5	0.80	0.28	0.20	5.8	6.03	0.20	96.5	5.57
Bt 3	88-102	7.35	0.72	1.24	0.12	12.46	4.3	0.81	0.28	0.20	5.6	6.02	0.20	96.4	5.57

OC= organic carbon, OM = organic matter, TN = total nitrogen, CEC = cation exchange capacity, BS = Base saturation, AVP = Available phosphorus.

4.3.2 Organic carbon and total nitrogen

The organic carbon had an irregular pattern of distribution with depth in both units and was rated low. The low percentage organic carbon content of the soils might be associate with continual cultivation and bush burning which encourage organic matter decomposition (mineralization) (Kang, 1993), lack of incorporation of fertilizer and relatively higher temperature of the study area (Landon, 1991). Total nitrogen content generally ranged from 0.12 to 0.14% and was also rated low. The low content of total nitrogen in the soils could be attributed to low organic matter of these soils, since inorganic N is accounting for only a small portion of total N in soils (Almu and Audu, 2001). The low amount of total nitrogen reflects the amount of organic carbon in the soils. The low observed total nitrogen content may also be due to some pedogenic process of lessivage (kind of leaching from clay particles being carried down in suspension). Loss of N through denitrification and volatilization may also contribute to the low level of N in the area. It is obvious that climate, vegetation and human activities contribute to low level of total nitrogen. High temperatures and human activities of bush burning and cultivation both reduce soil organic matter (SOM) accumulation and consequently nitrogen content. This is in agreement with the view of Landon (1991), who observed that low organic carbon and low nitrogen content might be associated with continuous cultivation, lack of incorporation of fertilizer and relatively higher temperature of the areas.

4.3.3 Available phosphorus

Available phosphorus ranged between 7.63 and 12.62 mg/kg. The mean value obtained exceeded the critical limit of 8.0 mg/kg Bray 1-P established for crops in Nigeria (FPDD, 1989) and the critical level of 15 mg/kg Bray 1 extractable P recommended by Thomas and Peaslee, (1973) cited by Onyekwere *et al*. (2009). This indicates that the available phosphorus was high, which suggests that the available phosphorus have not being fixed in the soil.

4.3.4 Exchangeable bases

The exchangeable bases (Ca, Mg, K and Na) were low in all the soils. Calcium was the most prevalent cation on the exchange complex with values ranging from 4.2 to 4.6 $cmolkg^{-1}$. Next to calcium was magnesium which ranged from 0.79 to 0.84 $cmolkg^{-1}$. These values confirmed the predominance of calcium follow by magnesium over potassium and sodium as observed by Idoga, (1985) and Ogunkunle, (1989). The low exchangeable bases of these soils may be attributed to the underlying materials, intensity of weathering, leaching, low activity clay, very low organic matter content as well as the lateral translocation of bases (Krasilinikoff *et al*., (2002); Kang and Balasubramanian, (1990); Kang, (1993). Similar findings were reported by Idoga (2005) Fagbami and Akamigbo, (1986). According to Ahn, (1970); Ogunkunle, (1989); Idoga, (1985), the predominance of calcium over other cations in these soils may be due to the occurrence of exchange site in soils which shows specific affinity for calcium. This may be due to the fact that of all the exchangeable cations, calcium is the least easily leached from the exchange site (Brady, 1990).

4.3.5 Base saturation

Base saturation percentage can be regarded as the extent to which the adsorption complex of a soil is saturated with exchangeable cations other than hydrogen and aluminium. A high base saturation indicates that the exchange sites on a soil particle are dominated by non-acidic ions and vice versa. The results from observed profiles showed that percentage base saturation values for all the soils were high (95.8 to 97.5%). As the base saturation was above 50% in all cases, the soils have high fertility potential (which forms the separating index between fertile soils and less fertile soils as stated by Landon, 1984). The high base saturation is probably associated with the presence of weathered minerals which release nutrients into the soil and their alluvial nature.

4.4 Soil Classification

The soils in the study areas were classified using the USDA soil taxonomy (Soil Survey Staff, 2016). Based on the morphological characteristics of the units, physical and chemical properties of the soils and climate of the areas, the two units from the study areas were classified up to a subgroup level according to the criteria laid down by Soil Survey Staff, (2016). The clay distribution pattern coupled with the high base status (<50%) of the soils fit into *Alfisols*. Soils of unit 1 was well drained with Isohyperthermic soil temperature regime (>22^0c) and a limited soil moisture content but adequate for plant growth in the rainy season (*Ustic* moisture regime). These features fit into the suborder of *Ustalfs*. The soil had high clay content in subsurface than surface, coarse redox concentration. These properties placed the soils under the great group *Paleustalfs* and further classified as *Arenic Paleustalfs* as a result of their high sand fraction (27.2 to 75.2 %) throughout the horizons, extending from the mineral soil surface to the top of an argillic horizons at a depth of 50cm or more. These soils were correlated to World Reference Base as *Aeric Lixisols.* Soils of unit 2 also had *Ustic* moisture regime with *Kandic* horizon, higher clay content at the subsurface and irregular decrease of organic carbon with depth placed the soil in the great group *Kandiustalfs* and *ArenicKandiustalfs* at the subgroup level and were correlated to World Reference Base as *Hypereutric Lixisols.*

Summary of the Soil Classification

Soils of Unit 1

Order	*Afisols*
Sub-order	*Ustalfs*
Great group	*Paleustalfs*
Sub-group	*Arenic Paleustalfs* (*Aeric Lixisols*)

Soils of Unit II

Order	*Afisols*
Sub-order	*Ustalfs*
Great group	*Kandiustalfs*
Sub-group	*Arenic Kandiustalfs* (*Hypereutric Lixisols*)

Conclusion

Selected soils of Avyi ward in Wukari Local Government Area of Taraba State, North East Nigeria was studied with the aim to produce information that could be useful in the management and sustenance use of the soil of the study area which may also serve as a baseline data for similar research works here or elsewhere. Two major soil units were identified in the area.

The soils were deep, well drained and had sandy loam to loam to silty clay loam texture. They were generally neutral in reaction with pH values ranged between 6.80 and 7.61. This pH range is safe for any sustainable crop production. They also have high base saturation, high value of available P, low values of organic carbon, total nitrogen, and exchangeable cations. Based on the physical and chemical properties of the soils, they were classified as follows: pedon1 as *Arenic Paleustalfs* (*Aeric lixisols*) and pedon 2 as *Arenic Kandiustalfs* (*Hypereutric Lixisols*). Farmers may avail themselves of the soil survey information in order to ensure appropriate land use management practices to protect the soils from either deterioration or degradation.

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Classification and Land Capability Evaluation of Selected Soils of Okwulaga, Afaraukwu In Umuahia Area of Abia State, Nigeria

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ABSTRACT

The study was conducted on an 8.36 ha of land of Okwulaga community, Afaraukwu in Umuahia area of Abia State to classify and evaluate the land capability of the soils for sustainable crop production. The transect survey method, following judgmental sampling procedure was used to delineate the study site into three mapping units (IAC1, IAC2 and IAC3) and a modal soil profile pit established in each of the units. The profiles were described morphologically and soil samples collected from the identified horizons were analyzed for physical and chemical properties. The soils were classified using the USDA soil Taxonomy and World Reference Base systems of soil classification. Also, the USDA land capability classification (LCC) was used to assess the potentials of the soils for arable and non-arable crops production. Results revealed variations in morphological, physical and chemical properties of the soils. IAC1 and 2 were well drained and deep compared with the poorly drained soils of IAC3 whose depth was limited by high water table at the depth of 40 cm. Particle-size distribution revealed dominance of sand fraction in IAC1 and 3 (> 70 %) whereas, IAC2 was dominated by clay fraction (>50 %). The soils across the mapping units were strongly to moderately acidic (4.5 – 5.4). Organic carbon was high (>15.00g/kg) in IAC1 and 3 but low in IAC2. Exchangeable bases were high in IAC2 and 3 but low in IAC1. Two soil classes identified were Typic Kandiudalfs and Gleyic hamaquepts (USDA) correlated as Luvisols and Gleyic fluvisols (WRB) respectively. Three land capability classes II*sth*, III*seh* and V*dw* were identified with texture (t), acidity (h), depth (d), erosion (e) and wetness (w) as constraints. Generally, the soils differed in properties indicating their variation in productive potential and management requirements for specific agricultural use.

Keywords: Soil properties, Classification, Land capability evaluation

1.0 INTRODUCTION

The persistent and widespread hunger and malnutrition across the country may be reduced to an appreciable level by 2030, if more lands are open for inclusive and sustainable food production. Therefore, characterization, classification, and land evaluation are fundamental to land potential for agricultural purposes and management decisions, planning, and utilization, providing a link between resource assessment and the decision-making process (Osinuga *et al*., 2020). Soil management and conservation may not be effective unless the soil is reliably characterized, classified and interpreted with regard to specific crop growth requirements. This is very expedient particularly, in this era of constant threats of misuse of soil resources that result in serious degradation, soil erosion and other environmental hazards (Akamigbo, 2010).

Ojanuga *et al*. (2003) observed that no two spots along a soil continuum are the same in the combination or interaction of factors responsible for their formation. So, variability of soils over a landscape needs proper inventory of its attributes for classification and optimal utilization. The study of soil resources in detail through characterization, classification and evaluation for various land utilization remains one of the strategies to achieve food security and a sustainable environment (Esu, 2004).

Land Capability Classification System was developed by the USDA to group soil mapping units based on their capability to produce commonly cultivated crops and pasture plants without deterioration over a long period (Akamigbo, 2010). Land capability classification systems aim at making use of all relevant data from both agricultural use and conservation measures for intensive and appropriate use of the land without undue dangers of soil degradation.

Okwulaga-Afaraukwu in Umuahia area of Southeast Nigeria is a rural agricultural-based community. However, the poor soil management practiced in the area due to dearth of soil information may have contributed to food insecurity experienced by the agrarian people of the community. This work was carried out to characterize, classify and evaluate the land capability evaluation coupled with the constraints that will need to be improved upon for sustainable production of both arable and non-arable crops in the area.

2.0 MATERIALS AND METHODS

2.1 Study area

The study was carried out in Okwulaga, Afaraukwu in Umuahia North Local Government Area of Abia State, Southeast Nigeria. The area, covering 8.36 ha is located in the rainforest zone of Nigeria and lies between latitudes $5^{o}29'$ –5^{o} 42' N and longitudes 7^{o} 29' –7^{o} 33' E. The area has an average annual rainfall of 2,238 mm distributed over seven months in the rainy season (NRCRI, 2019). Annual air temperatures range between 23^{o} C and 32^{o} C and a relative humidity of 60-80 % (NRCRI, 2021). The vegetation of the study area is typical of the forest belt of Nigeria. The native vegetation has been greatly replaced by secondary forest of wild oil palm trees of various densities, cocoa, rubber as well as woody shrubs and various grasses that form the under growth. Land use comprises mainly arable crops with varying fallow period. The fallow system is also used as a means of fertility orientation techniques.

The study area is underlain by one main geological formation, the coastal plain sands, comprising largely of unconsolidated sands (Lekwa, 2002). They are dominated by low activity clays, low organic matter content and are susceptible to accelerated erosion and soil degradation (Ogban and Ibia, 2006).

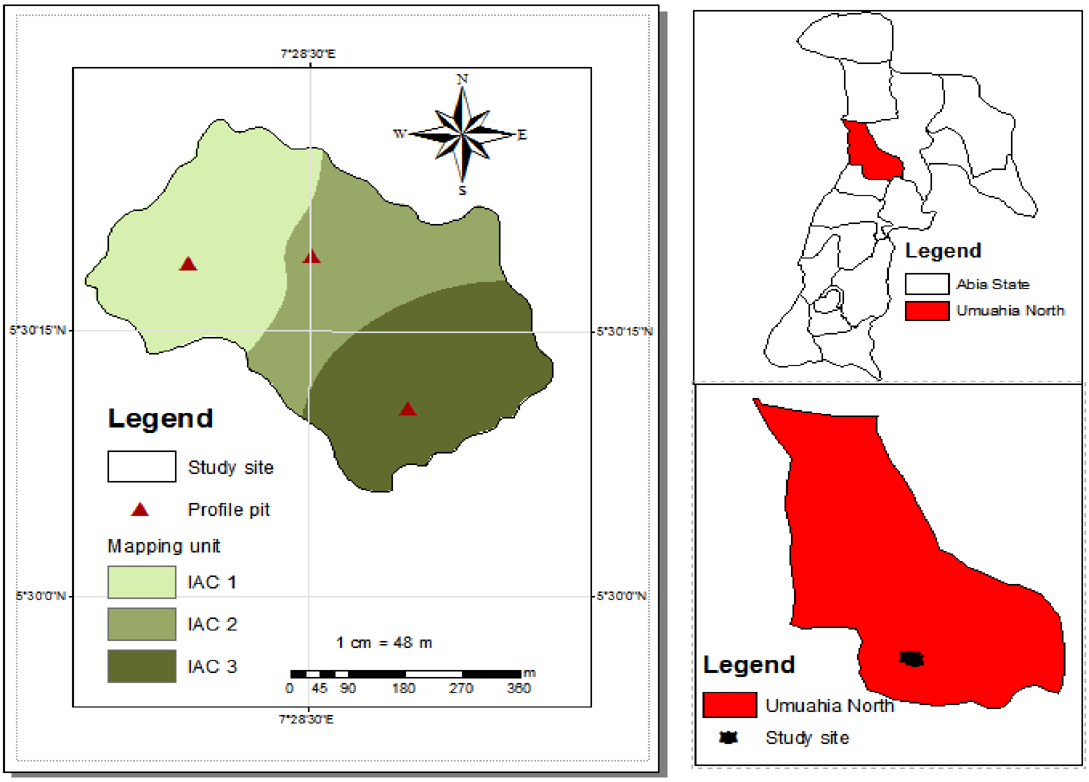

Figure 1: Map of the study area (Okwulaga Afaraukwu) showing profile pit location.

Field work and soil sample collection

The site (8.36 ha) was traversed using transect soil survey method and the boundary coordinates (latitudes and longitudes) and some notable elevation data of the land of the study site were recorded with a handheld Global Positioning System (GPS) receiver (*Garmin-etrex*). Auger investigations (0 - 15, 15 – 30, 30 – 50 cm) following differences in physiographic features formed the basis for delineating the landscape into three mapping units. Three representative profile pits (one in each of the units) were established. The soil profiles were examined, horizonated and described for their morphological attributes such as colour, texture, consistence and structure; following the procedure of FAO (2006). Eleven auger (disturbed) and eleven core soil samples were collected from identified horizons from the bottom of the profile upward (to avoid cross contamination of the soil samples) and analyzed in the laboratory for their physical and chemical properties.

Soil analysis and data interpretation

The disturbed soil samples collected from every identified horizon were air-dried, crushed gently and passed through 2 mm sieve to separate gravel content from other soil components. The less than 2 mm fractions were retained for physical and chemical sand analysis. The fine earth fractions (< 2 mm) were subjected to routine soil analyses. Following appropriate standard procedures described by Udo, *et al.* (2009), the following parameters were analyzed: Particle size distribution (Bouyocous method) using sodium hexametaphosphate as dispersant and selenium tablets as catalysts (Gee and Or 2002). Soil reaction (pH) was measured potentiometrically in a soil: water suspension (mixed at a ratio 1:2.5 soil: water) using a glass electrode pH meter (Thomas, 1996). Organic carbon was determined from the sieved soil samples (further passed through 0.5 mm sieves) by the dichromate wet oxidation method (Udo *et al*., 2009). Total nitrogen was determined on samples (also passed through 0.5 mm sieve) by the regular mico-Kjeldahl method as described by Bremner (1996). Available phosphorus was extracted with Bray number II solution of HF and HCl and the P in the extract determined spectrophotometrically. The exchangeable bases were extracted by saturating soil with neutral 1M NH_4OAc. Ca^{2+}, Mg^{2+}, Na^+, and K^+(TEB) displaced by NH_4^+ were measured by Atomic Absorption Spectrometer (AAS) (Udo, *et al.*,2009). Exchangeable acidity was extracted with 1N KCl and estimated in the extract by titration (Udo, *et al.*, 2009). Effective cation exchange capacity (ECEC) was determined by summation method of TEB and exchange acidity (Al^{3+} and H^+). Base saturation was obtained by expressing the sum of exchangeable Ca^{2+}, Mg^{2+} Na^+ and K^+ as percentages of the ECEC. Bulk density (*Bd*) (gcm^3) was determined by oven-drying at 105°C to a constant weight, the undisturbed soil core samples collected from the identified horizons.

$$Bd = \frac{Mass\ of\ oven-dried\ soil\ (g)}{Volume\ of\ the\ soil\ (cm3)} \quad \ldots\ldots\ldots.. 1$$

Total porosity (Pt) was determined from bulk density (*Bd*) value given that particle density (*Pd*) is 2.65 gcm^{-3} for mineral soils.

$$Pt = 1 - \left(\frac{Bd}{Pd}\right) \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

Data were interpreted based on Chude, *et al*. (2011) and Hazelton and Murphy (2016).

Soil classification

Based on the morphological (field data), physical and chemical (laboratory data) properties obtained, the soils were classified using the USDA Soil Taxonomy System (Soil Survey Staff, 2014) and correlated with World Reference Base for soil resources (WRB, 2015).

Land capability evaluation

The potential of the soil for land use was assessed using Land Capability Classification (LCC) as described by Akamigbo (2010) (Table 1). Classification was based on physical soil and land properties with organic matter as the only chemical property involved. Matching the characteristics (Tables 2 – 4) of the study site with the land capability requirements (Table 1) to produce the conversion table (Table 5), soil limitations in terms of these properties were used to place the soils into different classes with classes 1 - IV as arable and V - VIII as non- arable. The classification would depend more on the severity of the limitations than the number of limitations (FAO, 1984).

Table 1: Factors for the USDA Land Capability Classification System

	Class						
Parameter	**I**	**II**	**III**	**IV**	**V-VI**	**VII**	**VIII**
Slope (%)	0 - 2	2 - 4	4 - 10	11 - 32	> 33	> 33	> 33
Erosion	-	slight	moderate	moderate	High	high	very high
Surface stoniness (%)	0 - 5	6 - 14	15 - 39	40 – 79	> 80	> 80	> 80
Subsoil stoniness (%)	0 - 9	10 - 27	28 - 59	> 60	> 60	> 60	> 60
Soil depth (cm)	> 100	> 80	> 60	> 40	> 30	< 30	< 30
Soil drainage	good	moderate	poor	poor	very poor	very poor	very poor
Soil Texture	L, CL,SCL,SC	SL,LS SiCL	SiC, SC	S, C	Any	any	any
Rock outcrops	few	common	many	abundant	dominant	dominant	dominant
Available water capacity	>70	50 - 70	35 - 50	< 20	< 20	< 20	< 20
Organic matter (%)	>1	> 0.8	> 0.6	> 0.4	> 0.2	> 0.2	> 0.2

pH	6 - 8	6 - 8	5-6/8-9	5-6/8-9	<5/>9	<5/>9	<5/>9
Permeability of Surface soil	good	slow	very slow	very slow-rapid	Any	any	any
Permeability of subsoil	moderate	rapid-slow	rapid-slow	rapid-slow	Any	any	any
Wetness	-	-	slight	slight	moderate	moderate	severe

L=Loam, CL=Clay Loam, SCL=Sandy Clay Loam, SC=Sandy Clay, SL=Sandy Loam, LS=Loamy Sand, SiCL=Silty Clay Loam, SiC=Silty Clay, S=Sand, C=Clay.
Source: Akamigbo (2010)

3.0 RESULTS AND DISCUSSION

3.1 Soil properties of the study area

3.1.1 Mapping unit IAC 1

The mapping unit was 118 m above sea level and gently sloping (3 %). Land use comprised cassava farm with scattered oil palm of old age. The unit was well drained and deep (>160cm) with an udic soil moisture regime (Table 2). Colour matrix observed under moist condition showed dark reddish gray (5YR 4/2) epipedons, underlain by yellowish brown (5YR 3/3) and red (2.5 YR 4/6) sub surface horizons.

The epipedons indicated crumb structural types and friable (moist) soil consistence overlying sub-angular structure and firm consistence respectively. The crumb structure and friable consistence of the surface soils will enhance good tillage operation and easy penetration of plant roots. Ogba and Ibia (2006) reported that a friable soil often has the optimum conditions for tillage operations, resulting in better seedbed preparation with good drainage, gaseous exchange and heat conductance.

Soil texture ranged from sandy loam topsoil to sandy clay loam and clay subsoil (Table 3). There were no concretions and roots concentrated in the topsoil with few to no roots at the subsoil. Sand fractions were high in the surface horizons but decreased sharply with depth (78.60 – 42.60 %). Contrarily, there was a progressive increase in clay fractions with depth (10.20 – 54.20 %). Schaetzi and Anderson (2005) attributed the increase of clay down the profile to pedogenic processes involving eluviation (washing down or translocation of finer soil separates from the topsoil) and illuviation (deposition of translocated materials) of clay particles in subsoil horizons. Also, low clay content of topsoil could be due to sorting of soil material by biological and/ or agricultural activities, clay migration or surface erosion by runoff or a combination of these (Malgwi *et al*. (2000). The low silt fractions (5.2-11.2 %) may be in tandem with the report of Madueke *et al*. (2012), that low silt content is as a result of the high degree and extent of weathering and leaching the soils have undergone. Bulk density ranged from (1.31-1.61 mgm^{-3}). Ufot (2012) reported that a normal range of bulk density for clay is 1.0-1.6 mgm^{-3} and 1.2-1.8 mgm^{-3} for sand with potential root restriction occurring at > 1.4 mgm^{-3} for clay and > 1.6 mgm-3 for sand. This corroborated Esu (2010) who reported that values less than 1.6mg m^{-3} is an indication that air and water movement in the soil is optimum for plant growth. The bulk density increased regularly with the soil depth. The lower bulk density recorded in the topsoil was as a result of the influence of organic matter on soil bulk density causing less soil compaction (Ahukaemere, 2012; Esu and Ojanuga, 1986).

The unit was moderately acidic surface (5.7) to strongly acid (5.2) subsoil (Enwezor, *et al*., 1989; Chude *et al*., 2011). The high acidic nature of the soils may be as a result of high intensity rainfall in the area which leaches cations down the profile. Organic carbon content of the pedon's surface horizons was medium (1.98 %) but decreased with soil depth. The surface soil organic carbon is considered moderate based on soil nutrient interpretation of Chude, *et al.* (2011) that soil organic carbon between 1.5 and 2.0 % is moderate for crop production. The subsurface horizons were generally lower in organic carbon than the surface horizons. The reasons for this may be adduced to the fact that the surface horizons are the points where decomposition and humification of organic materials take place.

Generally, the exchangeable bases were low which suggest that leaching is a marked pedogenic process, resulting from the area's high sand proportion (Amusan *et al*., 2006). The cations exchange capacity (CEC) was generally low with values ranging from 7.34 - 14.80 cmolkg-^{1}. The low CEC could be attributed, as observed by Nnaji *et al*. (2002) that, low CEC of soil is because of clay type content, high rainfall intensity and previous land use. Base saturation was high and reflected the concentration of basic cations at the exchange complex site (Atofarati *et al*., 2012).

3.1.2 Mapping unit IAC 2

The mapping unit occurred on an elevation of 112 m above sea level under vegetative cover of cassava and bush re-growth. The soils were imperfectly drained at the depth of 120 cm with an Udic moisture regime (Table 3.1). Colour matrix observed under moist condition ranged from light reddish brown (5YR 6/4) topsoil underlain by reddish yellow (5YR 7/6) and light brownish gray (10YR 6/2) subsoil. Mottles of light gray (5YR 7/1) and strong brown (7.5YR 5/8) from depths 75-120cm were observed. The mottles are evidence of redoximorphic features (Soil Science Division Staff 2017). Chukwu *et al.*, (2013a) reported similar observation in the morphological characteristics of a Lithosequence in south-eastern, Nigeria. Soil consistence was firm (moist), sticky and plastic (wet) across the horizons. The structural aggregates were sub-angular blocky throughout the profile. The pressure on soil matrix due to integrated translocation of clay, micro swelling and shrinkage probably, explained the sub-angular blocky structures (Chukwu *et al*. (2013b). Concretions occurred at the depth of 50 cm down the profile and roots concentrated in the surface horizons.

Contrary to the mapping unit IAC 1, particle size distribution (Table 3) showed dominance of clay fraction. The values increased insignificantly down the horizons (50.2 - 66.2 %). This may be attributed as an indication of weak pedogenic processes (Udoh *et al*. 2008; Chikezie *et al*. 2010; Schaetzi and Anderson, 2005). Bulk density ranged from 1.42- 1.62 mgm^{-3}. The increase in bulk density down the profile could be attributed to less organic content leading to more soil compaction.

The pH (H_2O) values ranged from strongly acid (5.10) surface to very strongly acid (4.80) sub-surface soil (Table 3.3). The acid nature of the soil can be adduced to high amount of rainfall in the area. Based on the established optimum pH range (5.5-70) of Lawal *et al*. (2013), Enwezor *et al.* (1989) and Chude *et al.* (2011) for overall satisfactory availability of plant nutrients, this mapping unit is below the critical level for plant nutrient availability. Organic carbon was low compared to IAC 1. Exchangeable cations (Na^+, K^+, Ca^{+2} and Mg^{+2}) and base saturation were relatively higher than IAC 1. This may be adduced to high clay fractions resulting to higher colloidal properties for cations adsorption.

3.1.3 Mapping unit IAC 3

Soils of this mapping unit occurred on a nearly level plain with an elevation of 95 m above sea level under vegetative cover of scattered rubber plantation. The unit was shallow and very poorly drained as ground water was encountered at the depth of 40 cm thus had aquic moisture regime (Table 2). Colour matrix observed under moist condition ranged from dark yellowish brown (10YR 4/4) epipedon underlain by light gray (10YR 7/1) and gray (10YR 5/1) endopedon. Mottles of reddish yellow (5YR 6/8) and red (2.5 YR 5/6) were observed from the depth 15 cm. The epipedons indicated crumb structural types and friable (moist) soil consistence underlain by sub-angular structure and firm consistence.

Soil texture ranged from sandy loam topsoil to sandy loam and sandy clay loam subsoil. There were no concretions and roots concentrated at the topsoil with few to no roots at the subsoil. Sand fractions were high in the surface horizons but decreased sharply with depth (72.6 - 62.6 %) whereas, there was a gradual increase in clay and silt fractions down the depth with values of 12.2-21.2% and 13.2 - 19.2 % respectively.

Bulk density values (0.91-1.49 mgm^{-3}) were higher in subsoil than in the topsoil. These bulk values are rated low and will not impair crop production. The soils were moderately acidic (5.90) surface to very strongly acidic (4.70) subsoil. Organic carbon content was very high (3.44%) compared to the other two mapping units. Similarly, exchangeable cations (Na^+, K^+, Ca^{+2} and Mg^{+2}), available P and base saturation values were high compared to those observed in IAC 1.

Table 2: Morphological properties of the soils of the study area

Horizon	Depth (cm)	Colour (Moist)	Mottles	Drainage	Slope (%)	Structure	Consistence Moist	Consistence Wet	Concretion	Root	Boundary
			Mapping unit IAC 1								
Ap	0.20	5YR 4/2,DRG	-	Well drained	3	2CCr	vfr	ns-np	-	cm	as
Bt1	20-38	5YR 3/3,DRB	-			2CCr	Fr	ss-np	-	cf	gw
Bt2	38-60	2.5YR 4/6,RB	-			2MSbk	Fr	ss-sp	-	ff	as
	60-162	2.5YR 4/8,RB				2MSbk	Fm	ss-sp	-	vff	-
			Mapping unit IAC 2								
Ap	0 – 20	5YR 6/4,LRB	-	Moderate	5	2MSbk	Fm	Sp	-	cm	cg
AB	20-65	5YR 6/4,LRB	-			2MSbk	Fm	Sp	-	cf	sh
Bg	65-75	5YR 7/6,RY	5YR 7/1,LG			2MSbk	Fm	Sp	-	ff	as
BCg	75-120	10YR 6/2,LBG	7.5YR 5/8,SB			2MSbk	Fm	Sp	-	-	-
			Mapping unit IAC 3								
Ap	0-5	10YR 4/4,DYB	-	Very Poor	2	1CCr	Fr	ns-np	-	cf	cs
ABg	5-15	10YR 7/1,LG	5YR 6/8,RY			2MSbk	Fr	ns-np	-	ff	cs
BCg	15-40	10YR 5/1,G	5YR 6/8,RY			2MSbk	fm	sp	-	-	-

Key: ***Colour***: DRG=Dark reddish gray, DRB=Dark reddish brown, DR=Dusty red, R=Red, LRB=Light reddish brown, LBG=Light brownish gray, RY=Reddish yellow, G=Gray, DG=Dark gray, SB=Strong brown, LG=Light gray. ***Structure***: 1=Weak, 2=Moderate, 3=Strong. M=Medium, C=Coarse. Cr=Crumb, Sbk=Sub-angular blocky. ***Root***: ff=fine few, fvf=fine very few, fc=fine common, cf=coarse few, mf=medium few, cm=common medium. Boundary: a=abrupt c=clear, g=gradual, w=wavy, s=smooth. ***Consistence***: fr = friable, fm = firm, vfm = very firm, ns-np = non-sticky-non plastic, ss-sp = slightly sticky-slightly plastic.

Table 3: Physical properties of the soils of the study area

Horizon	Depth (cm)	Sand	Silt	Clay	Textural Class	Silt/Clay	BD mgkg^{-3}	TP (%)
			%					
			Mapping unit IAC 1					
Ap	0.20	78.60	11.10	10.30	Sandy loam	1.08	1.31	50.56
Bt1	20-38	64.30	10.50	25.20	Sandy clay loam	0.42	1.46	44.90
Bt2	38-60	50.20	5.60	44.20	Sandy clay	0.13	1.59	40.00
BC	60-162	42.60	7.00	50.40	Clay	0.14	1.61	39.24
			Mapping unit IAC 2					
Ap	0–20	58.20	11.40	30.40	Sandy clay loam	0.38	1.42	46.41
AB	20-65	46.50	10.30	43.20	Sandy clay	0.24	1.38	47.92
Bg	65-75	36.60	13.00	50.40	Clay	0.26	1.44	45.66
BCg	75-120	30.60	9.20	60.20	Clay	0.15	1.62	39.86
			Mapping unit IAC 3					
Ap	0-5	68.00	19.80	12.20	Sandy loam	1.62	0.91	65.66
ABg	5-15	72.60	13.20	14.20	Sandy loam	0.93	1.49	43.77
BCg	15-40	62.10	16.50	21.40	Sandy clay loam	0.77	1.24	53.20

Table 4: Some chemical properties of the soils

Horizon	Depth (cm)	pH (H_2O)	pH (KCl)	OC g/kg	Total N %	Av.P ($mgkg^{-1}$)	Exchangeable bases Ca^{2+} ($cmolkg^{-1}$)	Mg^{2+}	K^+	Na^+	EA	CEC	BS (%)
	Mapping unit IAC 1												
Ap	0.20	6.0	4.9	19.8	0.224	22.7	8.4	4.6	0.309	0.290	1.28	10.88	87.36
Bt1	20-38	5.4	4.5	9.50	0.114	20.3	5.0	2.8	0.206	0.186	1.36	9.55	85.75
Bt2	38-60	5.0	4.1	5.00	0.088	15.1	5.2	2.0	0.209	0.164	1.48	9.10	83.73
BC	60-162	5.2	4.1	3.09	0.040	15.2	4.2	1.2	0.174	0.164	1.60	7.34	78.20
	Mapping unit IAC 2												
Ap	0-20	5.3 5.1	4.3	12.2	0.129	23.6	8.8	4.8	0.392	0.334	1.22	15.55	92.15
AB	20-65	4.7	3.9	6.04	0.108	19.8	5.6	3.2	0.311	0.286	1.42	10.82	86.87
Bg	65-75	4.7	3.6	8.80	0.071	14.8	4.1	1.6	0.201	0.182	1.68	7.76	78.35
BCg	75-120	4.8	3.6	5.90	0.042	14.4	4.4	1.6	0.180	0.16	1.68	8.02	79.05
	Mapping unit IAC 3												
Ap	0-5	5.8	5.0	34.40	0.484	36.8	12.8	7.1	0.589	0.470	0.88	21.84	95.97
ABg	5-15	5.5	4.6	25.60	0.278	25.2	8.8	4.8	0.476	0.408	0.72	15.21	95.26
BCg	15-40	4.7	4.0	18.60	0.166	20.6	6.8	3.4	0.410	0.368	1.24	12.22	89.85

Key: OC = organic carbon; N = nitrogen; Av. P = available phosphorus; CEC = cation exchange capacity; BS = base saturation

3.2 Classification of soils of the study area

The increase in clay content with depth indicates clay migration or probably shows the presence of active eluviation-illuviation pedogenic processes. Clay translocation and enrichment fulfilled requirements for the argic subsurface horizon development. Schaetzi and Anderson (2005) attributed the increase of clay down the profile to pedogenic processes involving eluviation (washing down or translocation of finer soil separates from the topsoil) and illuviation (deposition of translocated materials) of clay particles in subsoil horizons. Soils of mapping units IAC 1 and 2 were characterized by presence of argillic horizons with base saturation greater than 50 % thus, were classified as order Alfisol. The udic moisture regime (soils, moist for more than 90 cumulative days) observed in the unit placed soils into the sub-order udalfs. They had low activity clay (CEC< 16 cmol/kg) thus, further classified as great group Kandiudalfs and Typic Kandiudalfs at sub group level. This correlates as Luvisol using World Reference Base (2015).

Clay movement or accumulation was weakly demonstrated in mapping unit IAC 3 by the particle size data (Table 3). This signifies the weak indication of argillic horizons in the unit though clay content slightly increased with depth (Soil Survey Staff, 2014). This evidence of weakly developed horizon (cambic horizon) classified the soils into the order Inceptisols. They were poorly drained with aquic moisture regime thus, classified into sub-order Aquept and great group Hamaquept because they had high organic carbon within horizon greater than 20 cm thick and the unit was saturated with water more than 30 days. The unit was later classified into sub-group Gleyic hamaquept because of the reduced condition caused by underground water. The soils were correlated as Gleyic Fluvisol in the World Reference Base system of soil classification.

3.3 Land capability classification (LCC) of soils of the study area

Table 5 shows the indices of land capability assessment used in the study. The results showed that mapping unit IAC 1 was deep and well drained, devoid of rock outcrops. However, the soils had fairly good texture (sandy loam), gentle slope and moderately acidic thus, classified into land capability classification (LCC) unit II. The mapping unit is moderate for arable cropping. The mapping unit would need to be limed adequately to reduce acidity and make nutrients more available to crops. Contrarily, mapping unit 2 was classified into land capability classification (LCC) unit III. In spite of the fact that the region was devoid of rock outcrops and had effective soil depth, evidence of erosion due to slope terrain and acid level limit the full potentials of the unit to classify into LCC I or II. The sustainable use of this unit for arable cropping would be consequent upon the effective management limitations. Mapping unit 3 had high organic carbon and without rock outcrops but its shallowness (water limitation) and poorly drained conditions classified it into LCC unit V, indicating not fit for arable cropping. This unit could be devoted to lowland rice cultivation or fish farming.

Table 5: Land capability indices of the study area

	Mapping Unit		
Limitations	IAC 1	IAC 2	IAC 3
Slope angle(*s*) (degree)	II	III	I
Erosion (e)	I	III	I
Surface stoniness (%)	I	I	I
Subsoil Stoniness (%)	I	I	I
Effective soil depth (*d*) (cm)	I	I	V
Soil drainage (*w*)	I	II	V
Soil texture (t)	II	I	II
Rock outcrops (*r*)	I	I	I
pH (*h*)	II	III	III
Organic carbon (*c*) (%)	I	I	I
LCC unit	II*sth*	III*seh*	V*dw*

II, III = Suitable for arable, V = Not suitable for arable

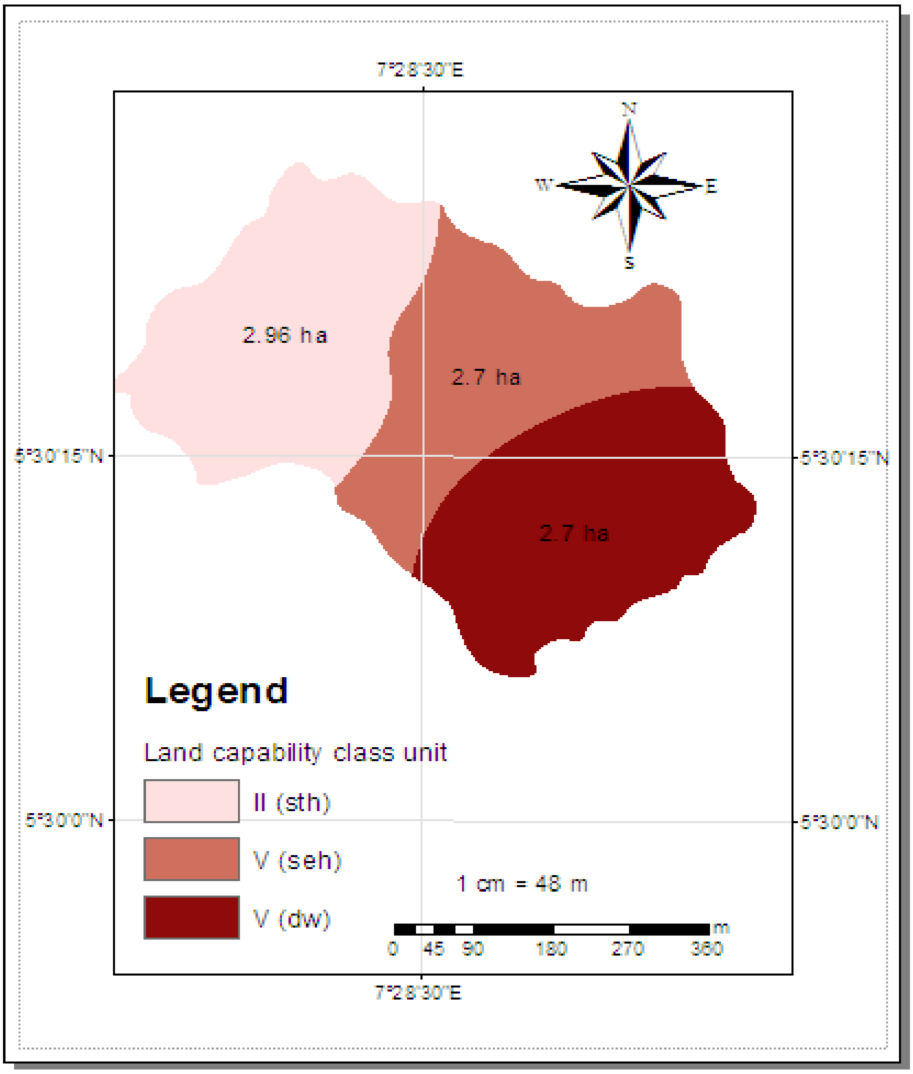

Fig. 2: Land capability class of the study site

4.1 CONCLUSION AND RECOMMEDATION

The results obtained revealed variability in soil properties across mapping units. Mapping unit IAC 1 was well drained and deep while IAC 2 was moderately drained compared to the poorly drained soils of IAC 3 whose depth was limited by high water table. The study area was classified as Typic Kandiudalfs (IAC 1 and 2) and Gleyic hamaquepts (IAC 3). The land use potential of the study area for crop production revealed three land capability classes II, III and V with soil texture, effective depth and poor drainage as constraints.

Maintenance of high organic matter level in the soil and proper drainage to improve the structure of soils are equally essential for a sustained crop production in the study area.

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Use of Satellite Data and Gis for Soil Mapping and Capability Assessment of Kwara State University Teaching and Research Farm, Malete

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ABSTRACT

A field study on the use of satellite data and Geographic Information System (GIS) for soil mapping and capability assessment of Teaching and Research Farm, Malete was carried out on a 100-ha land. This study aims to use the satellite data and GIS to produce the soil map and use the spatial analysis technique to assess the soil capability of the study area. The farm was divided into four (4) blocks: Block 2, Block 3, Block 4, Operation feed yourself 1 based on Land use and a total of sampling point was 170 from four (4) blocks. The analysis such as CaCO3 content, textural class, soil depth, salinity, alkalinity, CEC and drainage condition were linked with the different landforms of the studied area. The thematic layers of these data were created in Arc-GIS 9.2 software using the spatial analysis function, and then these layers were matched together to assess the soil capability. The obtained results reveal the main physiographic units in the studied area as Dried lake Bed, High terraces, sand dune, and sand sheet. The land capability ranged from II-IV), the highly capable soils (class II) represent 10.25% of the total area. The produced semi-detailed map highlights the relationship between landforms and soil qualities, which can be used in extrapolation of soil characteristics in the different landforms. The main limitations are soil depth, low ECEC, acidic condition, soil texture etc. Therefore, this study suggested that Nutrient deficiencies can be corrected with appropriate organic and inorganic fertilizers.

KEYWORDS: satellite data, soil mapping, soil capability, spatial analysis technique, nutrient deficiency, organic fertilizer

1.0 INTRODUCTION

Many scholars have recognized a fundamental issue impeding the growth of agriculture in various regions of Nigeria as a lack of understanding of soil (Chukwu *et al*., 2013). In much of Africa, similar findings have previously been recorded (Ololade *et al*., 2010).

The compilation of soil maps for the majority of rural communities and Local Government Areas (LGAs), where food and fiber production take place, is hampered by the lack of soil survey reports, which is one of the causes of this scenario. Additionally, the sizes of the bulk of national soil surveys are so small (at the reconnaissance level) that information on the landforms, pedology, and nutrients reserves in rural areas, where the majority of agricultural output is produced, is essentially non-existent (Lawal *et al.*, 2010).

Today there is great demand for accurate soil information over large areas from environmental modelers and land use planners (both urban and rural) as well as more traditional agricultural users of soil resource inventories. All these users want interpreted information; that is, soil properties or behavior directly relevant to their application. The soil information so generated was interpreted for various purposes like land capability classification, land irrigability assessment, crop suitability studies, management of watersheds, prioritization of watersheds etc. (Rossiter, 2005).

Due to developments in remote sensing and geographic information technology, thematic mapping has experienced a revolution in recent years. For soil mapping, historical data is frequently sufficient and inexpensive. According to Green (1992), integrating remote sensing into a GIS database can save costs, shorten survey times, and enhance the amount of comprehensive data collected. Determining landscape attributes that are used in the characterization of land forms, in particular, requires the use of Digital Elevation Models (DEMs) (Brough, 1986; Dobos et al., 2000).

A DEM is an electronic model of the Earth’s surface that can be stored and manipulated in a computer (Brough, 1986). It provides greater functionalities than the qualitative and nominal characterization of topography. A DEM can be manipulated to provide many kinds of data that can assist the soil surveyor in mapping and giving a quantitative description of landforms and of soil variability. By itself the DEM can yield maps of slopes, aspects, rate of change of slope, drainage network on catchments areas (Brough, 1986 and Brabyn, 1997).

Information derived from a DEM, such as elevation, slope and aspect maps can also be used with the images to improve their capabilities for soil mapping (Lee, *et al*, 1988).

The spatial analysis used in this study can be defined as the analytical techniques associated with the study of locations of geographic phenomena together with their spatial dimensions and their associated attributes (ESRI, 2001). The use of this techniques in evaluating the soil capability, allow producing multi-thematic maps and outlining the limiting factors, accordingly suitable suggestions could be attained to understanding how to deal with these soils for sustainable agricultural use.

The main goal of this research was to use digital elevation model (DEM) and Landsat TM imagery for a detailed soil mapping and capability assessment of the studied area.

2.0MATERIALS AND METHODS

2.1 Experimental Site

The experimental site was at Teaching and Research Farm in Moro Local Government Area of Kwara State University, Malete, Kwara State, Nigeria (Figure 1). It lies between latitude 8°71’ N and longitude 4°44’ E at 365 above sea level. The Kwara State University Teaching and Research Farm, Malete consists of approximately 100 hectares. It consists of the farm centre and area for the teaching and research activities of the Department of crop production, Agricultural Economics and Extension Services, Animal production, Fisheries and Aquaculture.

Figure 1: Study Area Map

2.2 Field Survey and Sampling Technique

The farm was divided into four (4) blocks (Block 2, Block 3, Block 4, Operation feed yourself 1) based on Land use and a total of sampling point was 170 from four (4) blocks, was collected from the top soil layers (0-30cm) which was stored inside different polyethylene bags. To avoid mix up, the samples from each sampling point was stored in polythene bags, labeled accordingly and taken to the laboratory where they were air dried at room temperature, crushed and passed through a 2mm sieve for the determination of selected chemical properties.

2.3 Data Acquisition

Due to the requirement for high spatial resolution images for the identification of landform units from satellite data, the spatial resolution of the employed Landsat ETM+ was increased through the data merging procedure. Using panchromatic data with higher spatial resolution or single band, this procedure is frequently used to improve the spatial resolution of multi-spectral datasets use panchromatic band 8.In this study, data were combined using panchromatic band 8 of the ETM+ satellite image, which has a high spatial resolution of 14.25 m, and multi-spectral bands, which have a poor spatial resolution of 28.50 m. (14.25 m). Using the ERDAS Imagine software, the landforms map was created using enhanced Landsat ETM+ and SRTM (30 m) images. The image texture, parceling, pattern, shape, size, color, location, and circumstance all affect the data that can be recovered from an ETM+ image. In order to better visualize the terrain, the SRTM data has been combined with controlled ETM+; in this case, topographic parameters (such as surface elevation, slope, aspect, shaded relief, and convexity) were retrieved using ArcGIS 10.8 software.

In order to extract the various landforms of the examined area, the Shuttle Radar Topographic Mission (SRTM) image and the Landsat ETM+ image (path 190 row 54) from the year 2022 were combined and processed with Digital Elevation Model in the ERDAS Imagine software. A preliminary geomorphologic map is produced by the extracted data and was verified and finished by field observation. In order to obtain more precise information on the soil patterns, soil nutrients, and characteristics inside the farm, a semi-detailed survey was conducted throughout the researched area. Four soil profiles were chosen to represent various mapping units, and they were morphologically described in the laboratory in accordance with FAO, 2006.

Soil samples collected were air dried at room temperature, sieved with 2 mm sieve and subjected to laboratory methods. Particle size analysis was determined using the hydrometer method modified by Gee and Or, 2002. Soil pH wasdetermined electrometrically in 1:1 soil water suspension. Organic carbon is determined by Walkey-Black method while Total Nitrogen was determined by the Micro-Kjeldahl method (Bremner and Mulvaney, 1982) and extractable P was determined by Bray and Kurtz, 1945). Exchangeable Ca, Mg, Na and K were extracted with 1M ammonium acetate (1M NH4OAc) solution buffered at pH 7.0, as described by Anderson and Ingram (1998). The exchangeable sodium (Na^+) and potassium (K^+) content of the filtrates were determined by Flame photometer while the exchangeable calcium (Ca^+) magnesium (Mg^+) were determined by EDTA titration method and were read with atomic absorption spectrophotometer (AAS). The varied soil types in the examined area were categorized at the group level using the American Soil taxonomy. The relationship between physiographic and taxonomy units was then discovered. The collected information was integrated into a GIS database, which used the digital geomorphologic map as its basis map. The theme layers of Ca and Ma content, soil texture, nitrogen concentration, salinity, alkalinity, CEC, and drainage condition were created using the interpolation tool in Arc-GIS 10.8's spatial analysis function. The dirt was created by overlapping the thematic layers.

3.0 RESULTS AND DISCUSSION

3.1. Physical and chemical properties of the study area

ThePhysical and chemical properties of the soils of study area is presented in Table 1. The soil reaction in water (pH (H_2O)) ranges from 6.0-7.1 which indicate slightly acidic to neutral soil. The pH (KCL) ranged from 4.75 to 5.30, indicating strongly acidic properties. The total organic carbon ranges from 0.14-1.54% indicating that it is very low. The total nitrogen ranges from 0.41-0.73% indicating that it is very low. The textural classes of the soil in this study area are Loamy sand, sandy loam and sand. The cation exchange capacity ranged from 1.76-3.06 % indicating very low. The total nitrogen ranged from 0.041-0.073 which also indication very low content.

Table 1: Physical and Chemical properties of soil in the study area

PARAMETERS	SAMPLE CM - OFY2	SAMPLE CM -2A	SAMPLE CM -3A	SAMPLE CM -4A
pH (H_2O)	7.10	6.85	6.15	6.00
pH (Kcl)	5.30	4.80	5.10	4.75
Electrical Conductivity (µS/cm)	29.2	12.47	34.30	13.07
Organic Carbon (%)	1.54	0.14	0.34	0.34
Organic Matter (%)	2.65	0.24	0.59	0.59
Sand (%)	88	90	90	80
Silt (%)	4	2	2	6
Clay (%)	8	8	8	14
Textural Class	Loamy sand	Sand	Sand	Sandy loam
Nitrogen (%)	0.041	0.060	0.073	0.049
Available Phosphorus (ppm)	11.08	11.76	9.95	9.04
Exchangeable Potassium (cmol/Kg)	0.20	0.25	0.33	0.28
Exchangeable Magnesium (cmol/Kg)	0.03	0.09	0.05	0.06
Exchangeable Calcium (cmol/Kg)	0.08	0.10	0.13	0.11
Exchangeable Sodium (cmol/Kg)	0.27	0.27	0.56	0.27
Exchangeable Acidity (cmol/Kg)	2.48	1.44	1.28	1.04
Cation Exchange Capacity (cmol/Kg)	3.06	2.15	2.35	1.76
Base Saturation (%)	18.95	33.02	45.53	40.91

3.2 Landforms of the studied area

Based on the Landsat ETM+ images, the Digital Elevation Model (DEM) (Figure 3) and the field check, the physiography of the studied area was identified. The obtained results reveal that, the main physiographic unites in the studied area are; Dried lake Bed, High terraces, sand dune, and sand sheet (Figure 4). The sand sheet is the main landform in this area. This landform dominated the Block 2A, 2B, 3A and 3B parts of the farm. The sand dunes and dried lake beds dominated crop Museum while the dried lake bed dominated block 4 and dried lake bed and high terraces dominated Operation feed yourself field. Surface sample (0-30 cm) was taken from each land form and analytical data result is shown in Table 1.

3.3 Soil Classification of the Study Area

The soil types identified in study area were loamy sand, Sandy and sandy loam. Due to sandy nature of the soils of this area with Plinthite occupying half volume of the soil is classified as Typic Plinthustalf (Alabi *et al*., 2017).

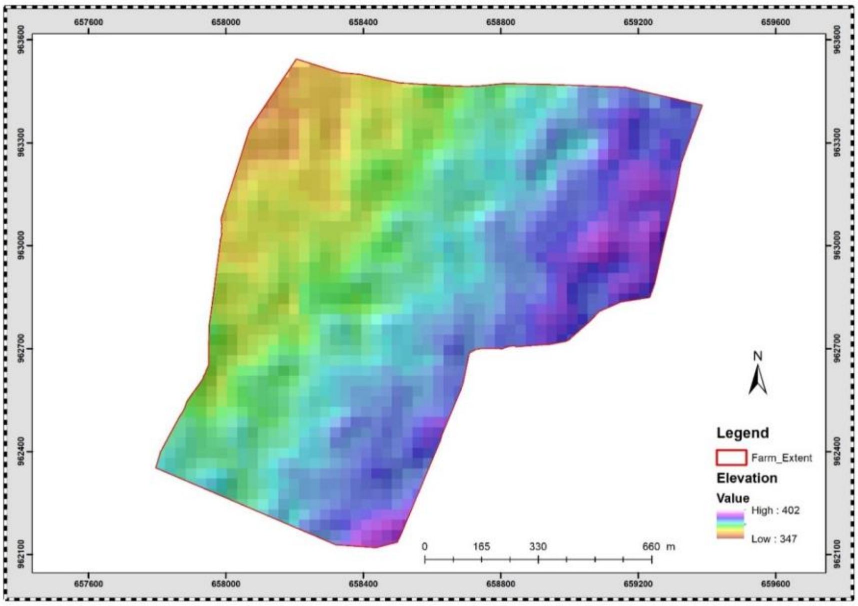

Figure 2: Topographical map of the farm.

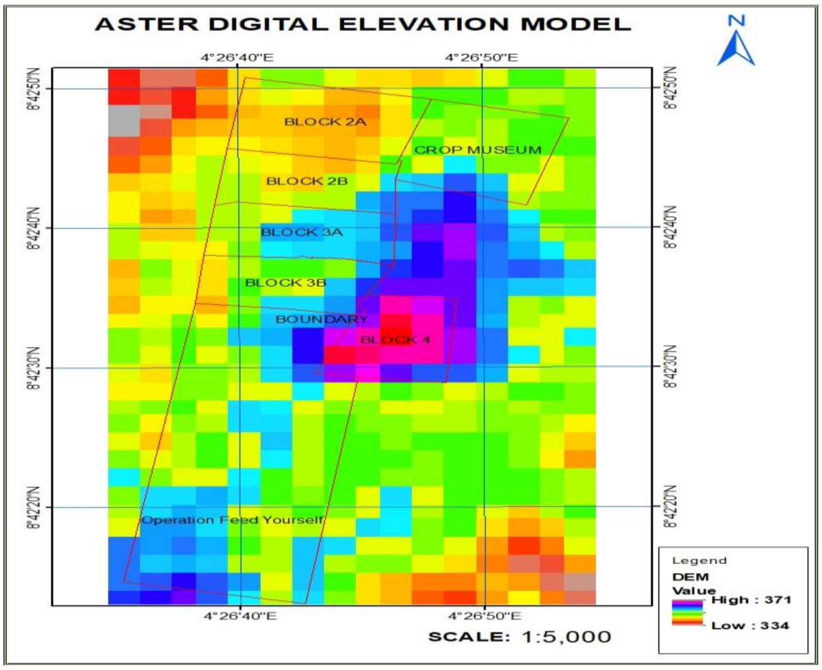

Figure 3: Aster Digital Elevation Model (DEM)

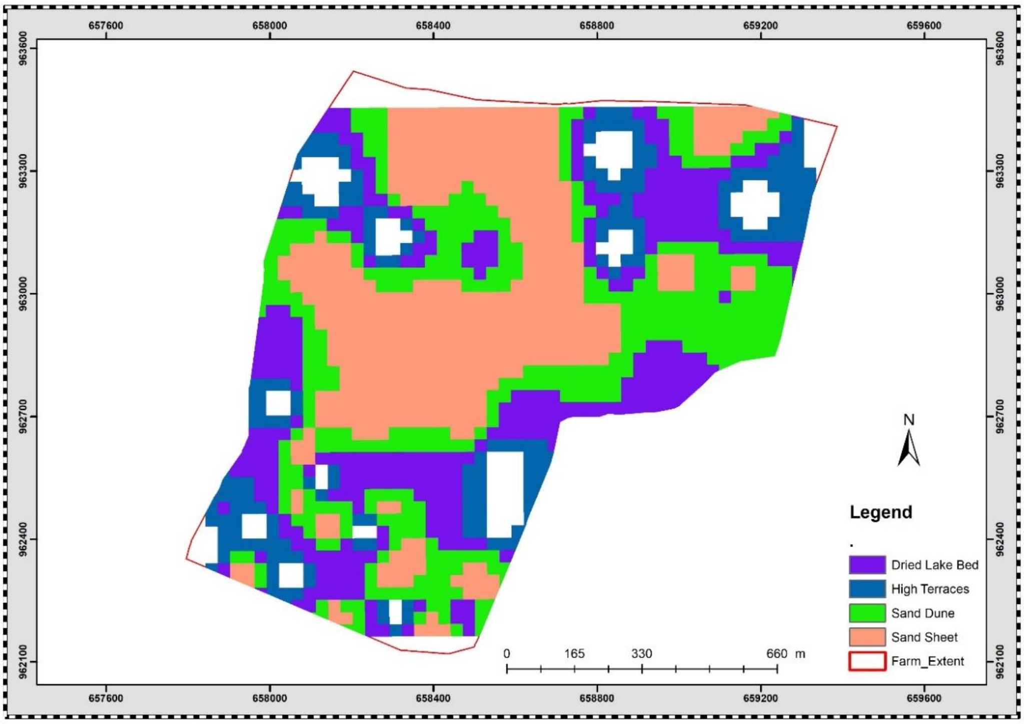

Figure 4: Landform Map of the study area

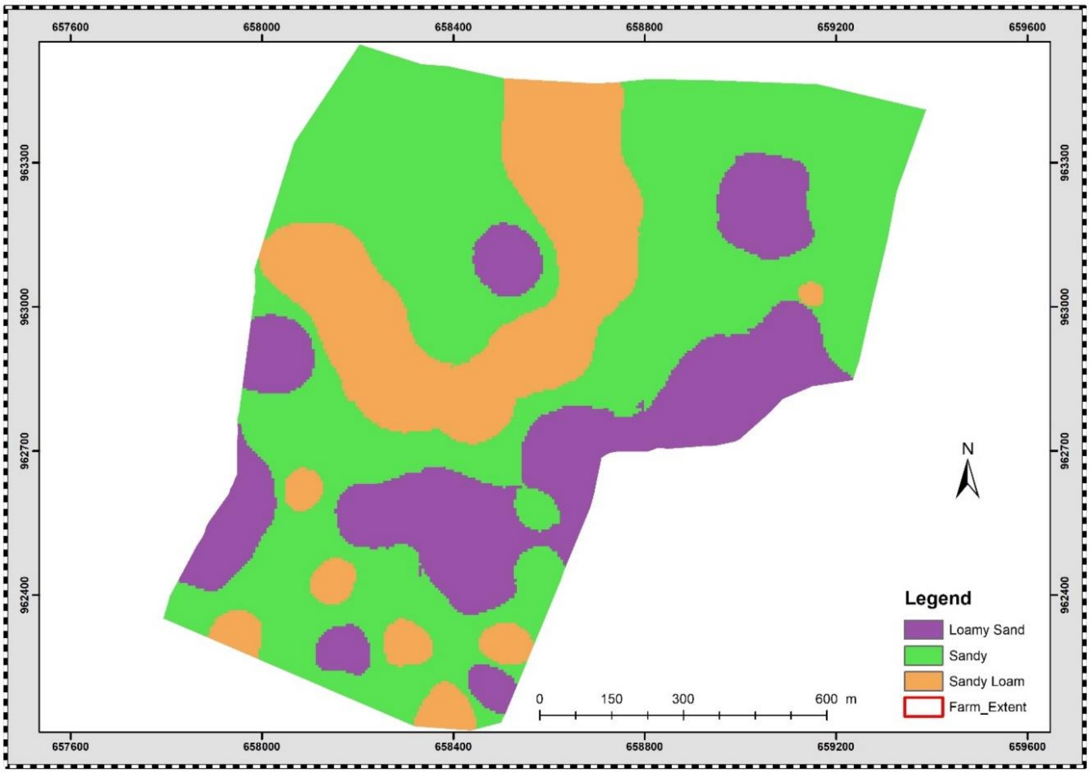

Figure 5: Soil Classification map

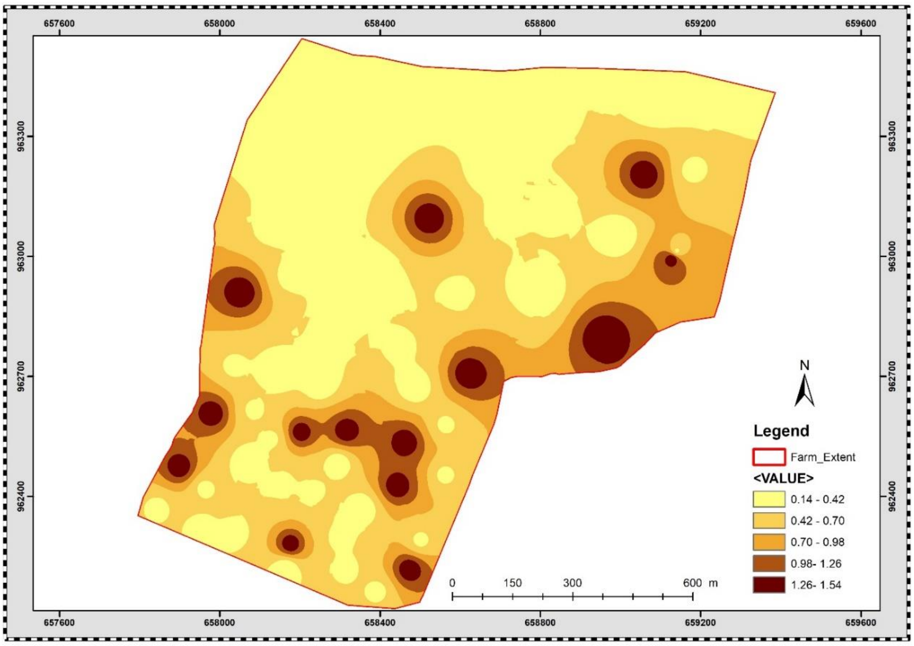

Figure 6: Spatial distribution of Ca concentration.

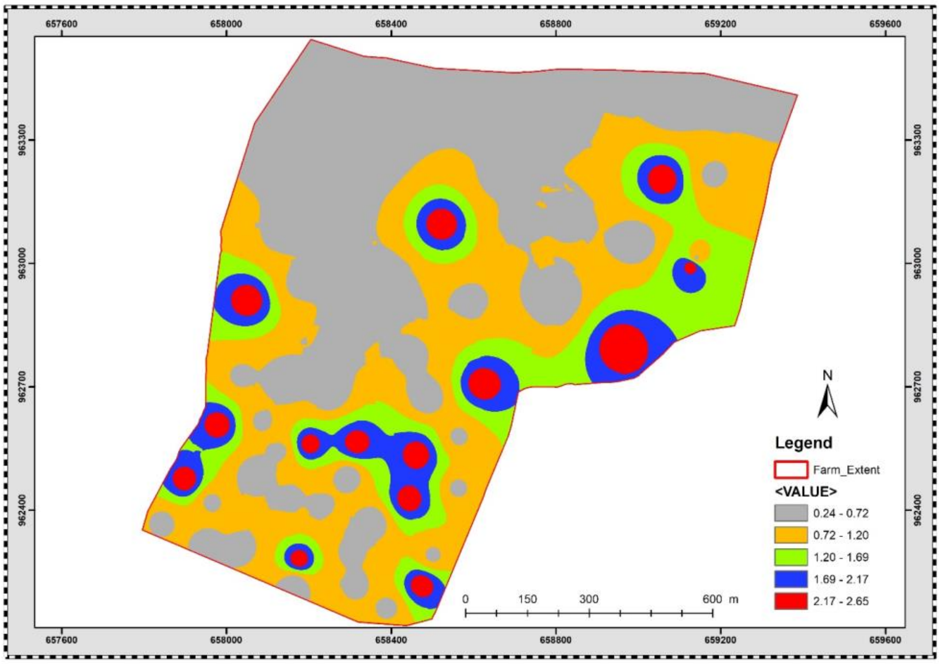

Figure 7: Spatial distribution of Mg concentration.

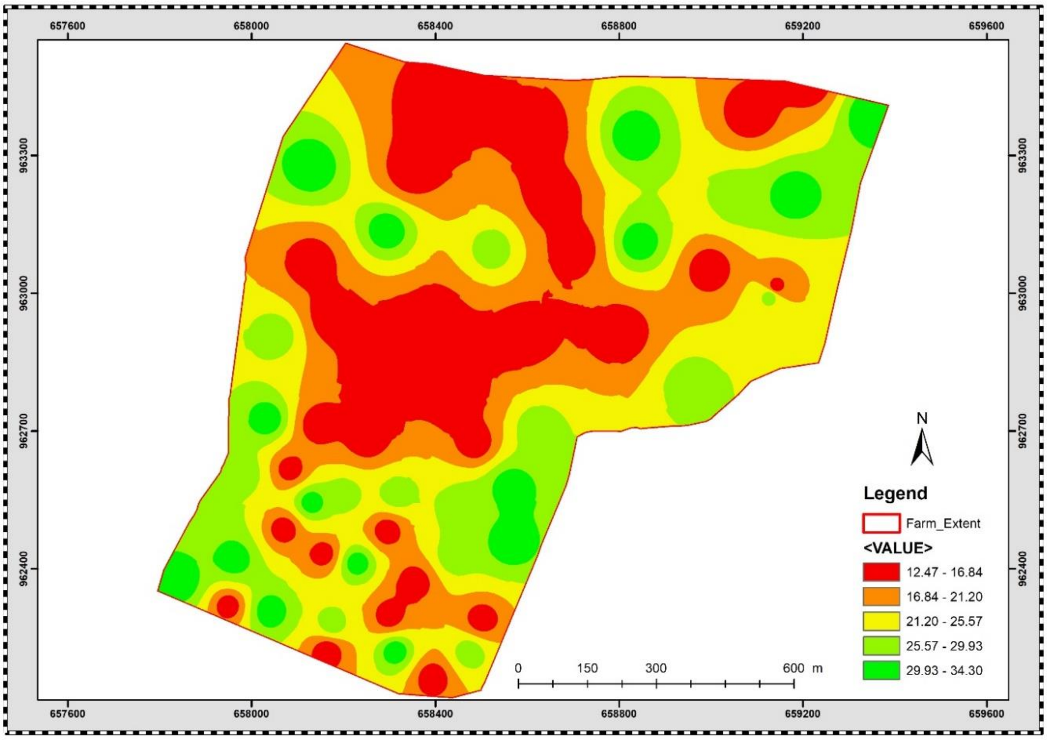

Figure 8: Spatial distribution of soil salinity.

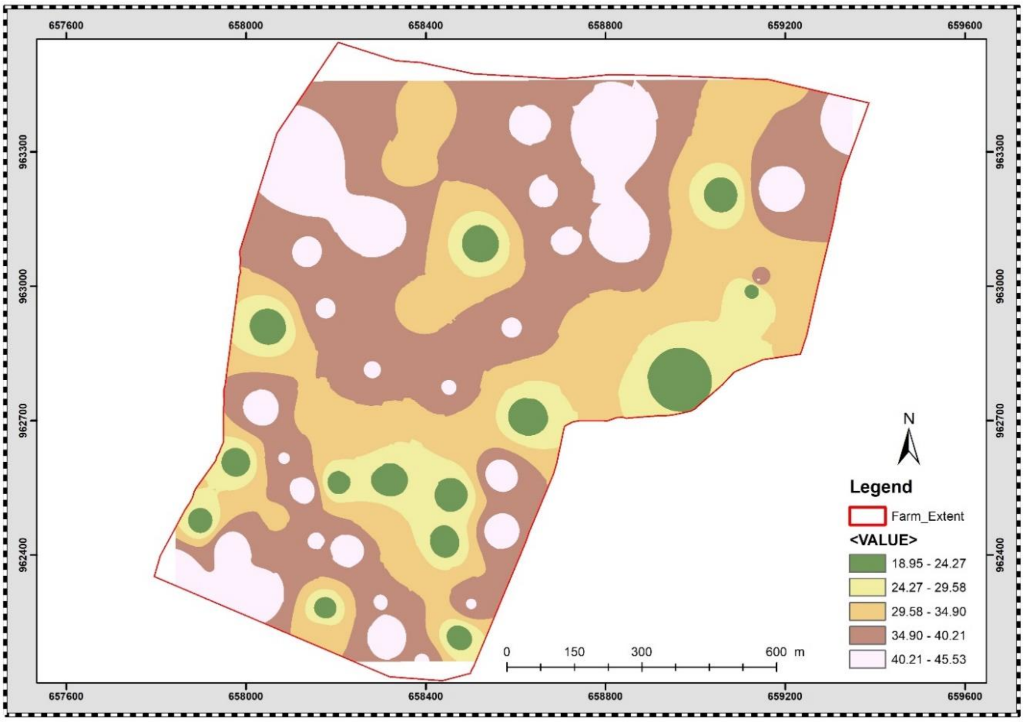

Figure 9: Spatial distribution of soil alkalinity.

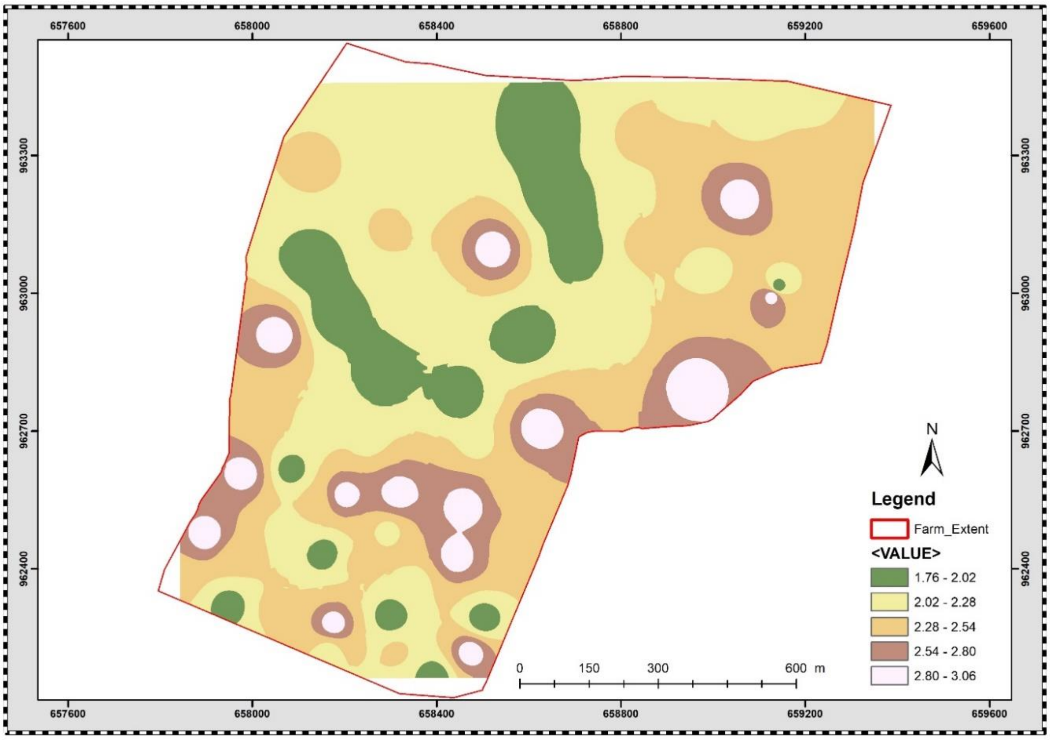

Figure 10: Spatial distribution of CEC.

Table 2: Capability classification units of the soils studied

Condition Modifier

Block	Texture	Drainage condition	K	e	h	Soil depth	FCC units
2A	S	well drained	+	+	+	+	Skeh
2B	S	well drained	+	+	+	+	
3A	S	well drained	+	+	+	+	
3B	SL	well drained	+	+	+	+	
4	LS	well drained	+	+	+	+	
OFY	LS	well drained	+	+	+	-	

K=low nutrient reserve, e=low cation exchange, h=acidic reaction OFY=operation feed yourself field, S=sandy, SL=sandy loam, LS=loam sandy, +=present, - =absent

3.4. Land capability Assessment

This part of study dealt with spatial analyses techniques to evaluate the agricultural land capability in the studied area. The landforms of the studied area were delineated by using the digital elevation model, Landsat ETM+ images and ground truth data of the studied area. The produced map, represents the landforms of the studied area, was imported in a Geo-database and considered as a base map.

The attributed data of Ca content, texture class, soil depth, salinity, alkalinity, CEC and NPK (Table 1) were linked with the units of the digitized geomorphologic map in a Geographic Information System (GIS). The incorporated attributes were used to obtain the thematic layers of spatial distribution of the above-mentioned characteristics as shown in figures 6 to 10. The produced layers include information on capability sub class, and spatial distribution for the soil characteristics. The obtained data indicated that the main limiting factors in the studied area were soil depth, acidic conditions, soil salinity, soil texture, Ca content and alkalinity. The limiting factors of soil depth, acidic condition, low CEC are associated with the Block 2A, 2B, 3A and 3B, while the soil texture and CEC are the main limiting factors in the crop Museum part of the farm. The limiting factors of the soil depth, soil texture and low CEC are dominating the soils of operation feed yourself field. These results are of great importance as they show the distribution of the constraints of productivity all over the farm. The condition modifier (soil properties or conditions which act as constraints to crop performance) used to produce the thematic layers are shown in table 2. The thematic layers of the attribute data were matched together to produce the soil capability map of the area (Figure, 11).

The land capability was classified into four categories according the rating values (ranges from II-IV), whereby the soil capability tends to increase when the rating value is closed to 1. It became clear that the highly capable soils (class II) represent 10.25% of the total area which is operation feed yourself field. The moderate capable soils (class III) dominate the block 4 while low capable soil (class IV) dominate block 2 and 3 of the farm.

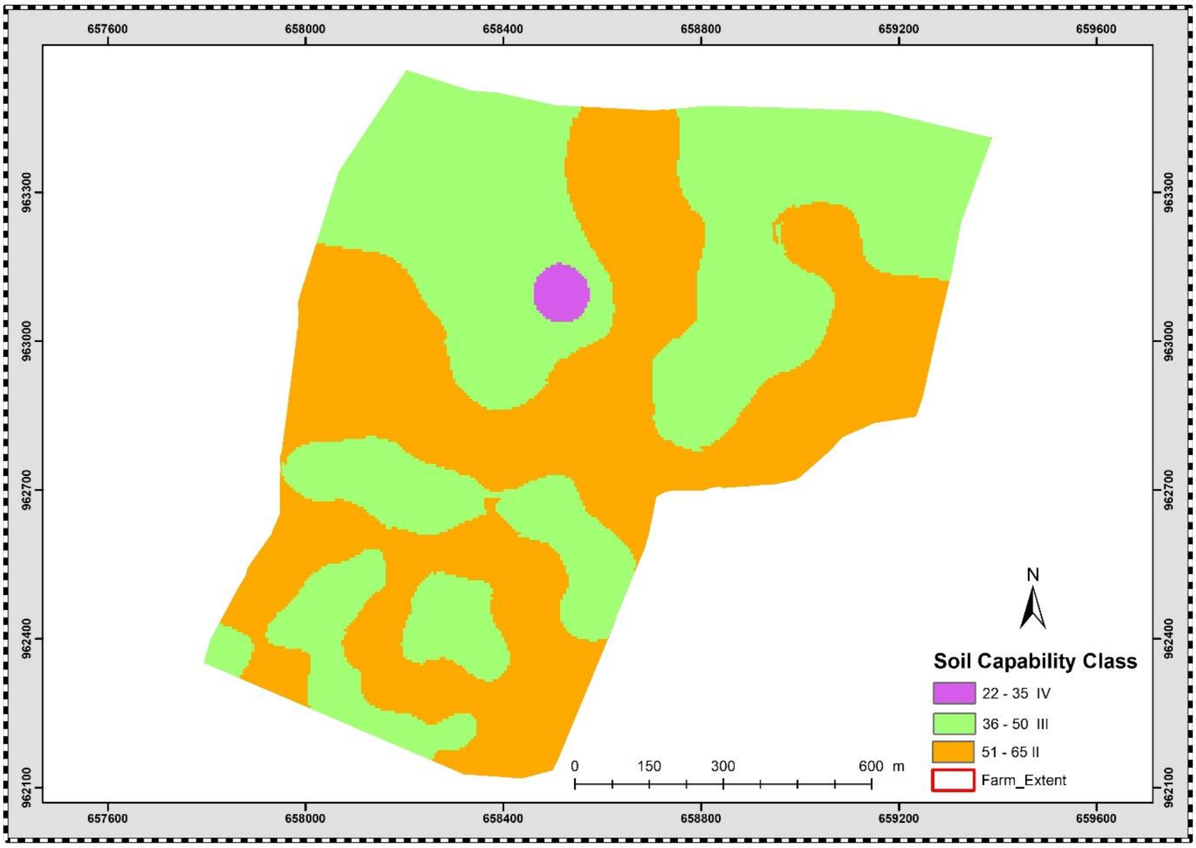

Figure 11: Land Capability Classification Map

4.0 Summary and Conclusion

This study reaffirms the importance of the Shuttle Radar Topographic Mission (SRTM) and satellite images in defining the main landforms and the soil phases of the area at a regional scale. The integration between remote sensing and land surveying data facilitates the semi-detailed soil mapping. The produced semi-detailed map highlights the relationship between landforms and soil qualities, which can be used in extrapolation of soil characteristics in the different landforms. The use of spatial analyses techniques in evaluating the soil capability, allow producing multi-thematic maps, accordingly suitable suggestions could be attained to understanding how to deal with these soils for sustainable agricultural use. The spatial distribution of limiting factors through the different landforms is particularly important when planning for the optimal land uses, also it benefits the existing land users in determining the most appropriate management practices.

4.1 Recommendation

The soils in the Teaching and Research Farm, Malete are mostly arable with some degrees of nutrient deficiencies and soil physical conditions that are properly managed. The main limitations are soil depth, low ECEC, acidic condition, soil texture etc. Therefore, this study suggested that Nutrient deficiencies can be corrected with appropriate organic and inorganic fertilizers. Other management strategies can also be put in place.

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Digital Soil Organic Carbon Mapping in Selected Soils of Southeastern Nigeria

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ABSTRACT

Geographic Information System (GIS) was applied in digital soil carbon mapping in selected soils of southeastern Nigeria. Soils underlain by six different parent materials, namely Imo Clay Shale, Ajali Sandstone, Asu River group, Afikpo Sandstone, Ogwashi-Asaba formation and Bende Ameki formation were considered. Free soil survey method aided by geology maps was used in siting the eighteen profile pits that were studied. The pits were geo-referenced with a hand-held Global Positioning System (GPS) Receiver. Soil samples were analysed in the laboratory for soil organic carbon content. Spatial analyses were done on the data obtained using Arc GIS 10.2 software. The mean and percentage coefficient of variation was calculated using Microsoft Excel. The descriptive statistics, semivariogram and cross validation were calculated using Geostatistical Wizard of Arc GIS 10.2. Ordinary kriging interpolation method was also performed and developed into attribute maps in the GIS software. Results showed that organic carbon content generally decreases down the profile with greater percentage observed at the top soil. The soils of Asu river group had the highest organic carbon content with average range of 6.5-11.7 g/kg while the soils of Ogwashi-Asaba formation had the least (3.9-5.8 g/kg). Soil organic carbon generally had high coefficient of variation down the profile in soils of the study area. The geostatistical analysis revealed that there was moderate spatial variability of soil organic carbon at different geographical scales and strong spatial dependency with spatial ratio of 5.39. The Spherical model present a semivariance with lowest nugget and highest spatial autocorrelation. The result obtained from the cross validation showed that the prediction was moderate with Mean Error (0.0525) close to zero. In conclusion, Kriged map revealed that highest percentage of organic carbon content was observed in Ezzeagu and Agbayim of Asu river group in Ebonyi State.

Key Words: Spatial analysis, Organic Carbon, Cross Validation, Kriged Map.

1.0 INTRODUCTION

Soils play major roles for the sustenance of human on the planet earth by providing essential and foundational ecosystem services. Soil provide the environment for food production by supporting plant growth (Sabastian et al., 2014). Soils provide the enabling environment for water and nutrient to reach the root of plant and also house many micro and macro organisms. Another important role soil play on planet earth is the sequestration of atmospheric carbon. Soils serve as a sink holding about 60% of the world carbon (Alexander et al., 2015).

Variation in soils of Southeastern Nigeria could be as a result of different parent material found in the area (Onweremadu, 2008). Parent material exert the most dominating influence on soil properties when compared to other pedologic factors (Ibanga, 2006). Frey et al., (2013) observed that soil physical properties affect the amount of carbon that are retained in the soil. They noted that soils with greater clay and silt content typically have greater soil organic carbon stock due to physical protection of organic materials. Soil organic carbon is a measurable component of soil organic matter (Agriculture and Food, 2023). Sequestering carbon into soil organic carbon stock has been one of the suggested ways of reducing atmospheric carbon thus mitigating climate change effects. Effective measurement of soil organic carbon is crucial for carbon accounting (Bettigole et al., 2023).

Mapping is one of the modern methods for displaying soil information as it provides readily available information in an organized and simplify format (Onwuka and Adesemuyi, 2019). Soil properties show spatial dependency and thus can be analyse using geostatistics. Many researchers have studied soil organic carbon as influenced by land use (Onwuka and Adesemuyi, 2019; Jiao et al., 2020; Ahukaemere, 2015). This research investigated soil organic carbon as influenced by parent materials in three states (Anambra State, Enugu State and Ebonyi State) of Southeastern Nigeria. The information was interpolated and presented as map using geostatistical method.

2.0 Materials and Methods

2.1 Description of the Study Sites

The study was carried out in three states in the Southeast geopolitical zone of Nigeria namely Anambra State (6° 20′ 0″ N, 7° 0′ 0″ E), Enugu States (6° 27′ 10″ N, 7° 30′ 40″ E) and Ebonyi State (6° 15′ 0″ N, 8° 5′ 0″ E). The three states were purposively chosen based on their parent materials. The six-parent material considered include Ogwashi-Asaba Formation (Oba, Ojoto and Oraifite of Anambra State), Bende-Ameki formation (Nanka, Neni and Umuona of Anambra State), Imo Clay Shale (Ojor, Ogurugu and Asaba of Enugu State), Ajali Sandstone (Enugu-Ezike, Uhunowerre and Ovoko of Enugu State), Asu River Group (Igbeagu, Inyimagu and Abofia of Ebonyi State), and Afikpo Sandstone (Amoso, Ugwuukwu and Oziza of Ebonyi State). The Southeastern Nigeria has a tropical climate with humidity and rainfall increasing toward the inland, and typified by uniformly high temperature and a seasonal distribution of rainfall (Climate-data.org, 2019). The region lies in the lowland rainforest natural vegetation belt with evergreen trees in the south and gradually gives way northward to rainfall-savanna forest characterized by trees interspersed with grass. Agriculture, cottage industries, trading, sand and stone mining and other activities are major socio-economic activities in the area.

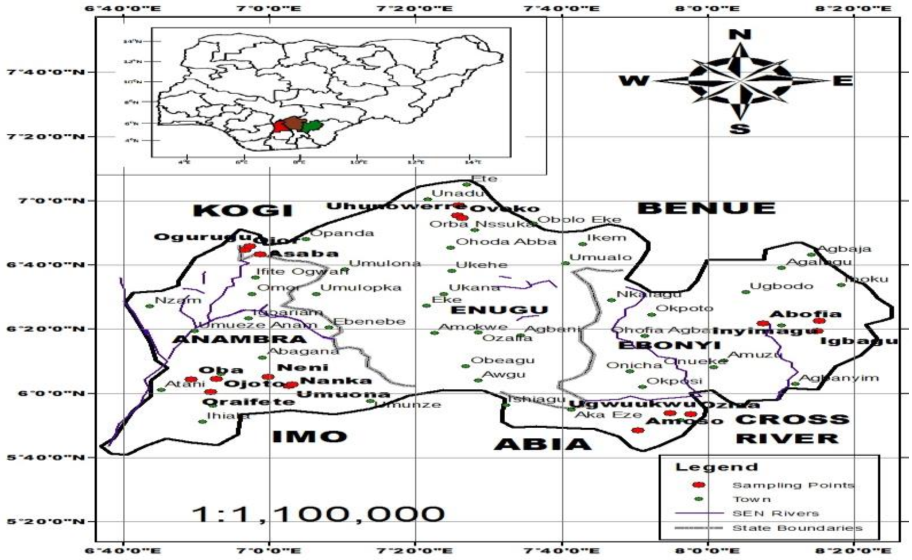

Figure 1: Location Map of Area of Interest indicating its Position in the Map of Nigeria

2.2 Soil Sampling

A reconnaissance field study was carried out for the purpose of identifying the parent materials and free survey approach (Onweremadu, et al., 2014) was used in locating sampling points with the help of a geology map. A total of six parent materials were identified and three profile pits were dug on each of them making a total of 18 profile pits. Soil profiles were sampled according to the genetic horizons from the lowest horizon to avoid contamination (FAO, 2006). All sites were geo-referenced using hand held Global Positioning Systems (GPS) Receiver, Garmin Ltd, Kansas

2.3 Laboratory Analysis

The soil samples were first of all air dried and pulverized in order to reduce the effect of clods. The soil samples were sieved using 2mm sieve and properly labelled for further analysis. Particle size distribution was determined using hydrometer method according to Gee and Or (2002). Soil organic carbon (SOC) was analyzed by Walkey and Black method as described by Nelson and Sommers (1982).

2.4 Geostatistical Analysis

The Geostatistical Wizard of the Geostatistical analyst extension of Arc GIS 10.2 was used to perform all the geostatistical analyses of this research. The ordinary kriging (OK) interpolation method was used for the prediction of the values of the unmeasured sites (un-samples locations) (Wang, 2018). Semivariogram was used as the basic tool to examine the spatial distribution structure of the soil properties based on the regionalized variable theory and intrinsic hypotheses (Nielsen and Wendroth 2003). The models that were used include the spherical model and the Gaussian Model which best-fit model with the lowest value of residual sum of squares. The spatial dependence was graded according to method detailed by Cambardella et al. (1994), thus; strong for Spatial Dependence (SD) < 25%, moderate for SD between 26% and 75% and weak for SD > 75%. Cross-validation technique was adopted for evaluating and comparing the performance of Ordinary Kriging interpolation method.

3.0 Results and Discussion

The results from Table 1a and b show predominance of sand over clay. In soils

underlain by Imo clay shale, the sand content ranged from 368- 875 gkg^{-1} and the clay content ranged from 42-404 gkg^{-1}. The high clay content of these soils may probably be due to the parent material. The soils derived from Ajali sandstone had the sand, and clay contents ranged from 625.2 – 945 gkg^{-1}, and 32-339 gkg^{-1} respectively. In soils underlain by Asu river group, the sand content ranged from 395-745 gkg^{-1} and the clay content ranged from 92- 432 gkg^{-1}. The soils underlain by Afikpo sandstone had sand content ranged from 555.2-975 gkg^{-1}, the clay content ranged from 2-339 gkg^{-1}. The sand content of the soils underlain by Ogwashi-Asaba formation ranged from 925 – 758 gkg^{-1}. The clay content ranged from 54.8 – 224.8 gkg^{-1}. In the soils underlain by Bende-Ameki formation, the sand content ranged from 529.6-935.2 gkg^{-1}, the clay content ranged from 34.8 – 404.8 gkg^{-1} while the silt content ranged from 12.8 – 85.6 gkg^{-1}. These are in line with the study of Onweremadu et al., (2011) and Okebalama et al., (2017) on soils of Southeastern Nigeria. The clay content of all the soils studied increased with depth. This may be as a result of eluviation and illuviation processes going on in the soils as reviewed by Chikezie, et al., (2010), Esu et al., (2008) and Ewulo, et al., (2002) in their studies.

Table 1a: Selected Soil Properties

IMO CLAY SHALE					**AJALI SANDSTONE**					**ASU RIVER GROUP**				
Horizon	**Depth**	**Sand**	**Clay**	**OC**	**Horizon**	**Depth**	**Sand**	**Clay**	**OC**	**Horizon**	**Depth**	**Sand**	**Clay**	**O.C.**
		<-------	**(g/kg)**	--->			<-------	**(g/kg)**	--->			<-----	**(g/kg)**	->
		OJOR					**UHUNOWERE**					**INYIMAGU**		
A	0-17	875.2	42	11.2	**A**	0-7	915.2	42	5.2	**A**	0-15	745.2	92	11.2
AB	17-42	855.2	72	5.8	**AB**	7-38	795.2	162	8.4	**AB**	15-34	515.2	262	7.4
Bt_1	42-54	775.2	132	5.4	**Bt_1**	38-107	805.2	162	4.2	**Bt_1**	34-64	455.2	302	6
Bt_2	54-121	655.2	272	4.4	**Bt_2**	107-133	755.2	202	6.2	**Bt_2**	64-89	475.2	332	3.8
Bt_3	121-150	675.2	232	3.4	**Mean**		**817.7**	**142**	**6**	**Bt_3**	89-120	475.2	272	4.2
Mean		**767.2**	**150**	**6.04**						**Mean**		**533.2**	**252**	**6.52**
		ASABA					**OVOKO**					**IGBEAGU**		
A	0-13	628	164.8	17.8	**A**	0-14	945.2	32	10	**A**	0-7	555.2	352	17
AB	13-29	488	184.8	7.6	**AB**	14-45	845.2	92	5.8	**Btg_1v**	7-28	455.2	282	11
Bg1	29-64	368	324.8	5.4	**Bt_1**	45-75	825.2	142	7.2	**Btg_2v**	28-50	535.2	232	7.2
Bg2v	64-125	398	404.8	3.8	**Bt_2**	75-97	675.2	312	5	**Mean**		**515.2**	**288.67**	**11.73**
Mean		**470.5**	**269.8**	**8.65**	**Bt_3**	97-130	715.2	272	4.2					
					Mean		**801.2**	**170**	**6.44**					
		OGURUGU					**ENUGU-EZIKE**					**ABOFIA**		
A	0-15	755.2	92	10	**A**	0-15	885.2	69.2	12.8	**A**	0-9	595.2	232	20.8
AB	15-46	575.2	232	6.6	**AB**	15-30	855.2	99.2	11	**AB**	9-25	555.2	432	8.4
Btv	46-80	478	272	4.6	**Bt_1**	30-61	645.2	319.2	8	**Bt_1v**	25-44	395.2	292	8.4
Mean		**602.8**	**198.67**	**7.07**	**Bt_2**	61-91	645.2	319.2	5	**Bt_2v**	44-70	395.2	302	6
					Bt_3	91-120	625.2	339.2	4	**Mean**		**485.2**	**314.5**	**10.9**
					Mean		**731.2**	**229.2**	**8.16**					

Table 1b: Selected Soil Properties

AFIKPO SANDSTONE					**OGWASHI-ASABA FORMATION**					**BENDE-AMEKI FORMATION**				
Horizon	**Depth**	**Sand**	**Clay**	**O.C**	**Horizon**	**Depth**	**Sand**	**Clay**	**O.C**	**Horizon**	**Depth**	**Sand**	**Clay**	**OC**
		<---	**(g/kg)**	---->			<------	**(g/kg)**	--->			<---	**(g/kg)**	--->
	UGWUKWU					**OBA**					**NENI**			
A	0-18	735.2	152	9.8	**A**	0-10	885.2	69.2	10	**A**	0-10	**935.2**	**34.8**	7.4
AB	18-59	655.2	292	7.6	**E**	10-45	925.2	59.2	6	**AB**	10-25	**895.2**	54.8	4.8
Bt₁	59-109	695.2	182	4.2	**AB**	45-71	875.2	109.2	4.4	**Bt₁**	25-65	**825.2**	134.8	3.8
C	109-145	975.2	2	0.4	**Bt₁**	71-107	845.2	129.2	3.6	**Bt₂**	65-94	**745.2**	222	5.7
Mean		**765.2**	**157**	**5.5**	**Bt₂**	107-156	855.2	139.2	4.8	**Bt₃**	94-149	**715.2**	272	4
					Mean		**877.2**	**101.2**	**5.76**	**Mean**		**823.2**	**143.68**	**5.14**
	OZIZA					**ORAIFITE**					**UMUONA**			
A	0-9	715.2	179.2	9.8	**A**	0-20	918	54.8	11	**A**	0-6	**809.6**	104.8	17.7
AB	9-24	735.2	149.2	12.6	**AB**	20-39	838	124.8	7	**AB**	6-25	**769.6**	164.8	9
Bt₁	24-47	565.2	309.2	8.4	**Bt₁**	39-62	798	174.8	4.6	**Bt₁**	25-65	**529.6**	404.8	4.8
Bt₂	47-83	575.2	319.2	6.4	**Bt₂**	62-91	788	194.8	3.4	**Bt₂**	65-102	**689.6**	264.8	4.6
Bt₃	83-120	555.2	339.2	3.6	**Bt₃**	91-148	758	224.8	2.6	**Bt₃**	102-150	**549.6**	404.8	4.4
Mean		**629.2**	**259.2**	**8.16**	**Mean**		**820.0.0**	**154.8**	**5.72**	**Mean**		**669.6**	**268.8**	**8.1**
	AMOSO					**OJOTO**								
A	0-15	755.2	162	4.6	**A**	0-10	888	54.8	7.8		**NANKA**			
E	15-37	695.2	194.8	3.2	**AB**	10-34	878	104.8	4.8	**A**	0-6	**895.2**	62	10.4
Bt₁	37-52	735.2	172	2.2	**E**	34-66	878	104.8	3.8	**AB**	6-28	**755.2**	212	8.4
Bt₂	52-103	825.2	74.8	1.6	**Bt₁**	66-95	788	124.8	2.6	**Bt₁**	28-53	**735.2**	222	4.4
C	103-170	865.2	74.8	1.6	**Bt₂**	95-126	908	74.8	2	**E**	53-92	**835.2**	152	3.8
Mean		**775.2**	**135.68**	**2.64**	**Bt₃**	126-150	888	94.8	2.4	**Bt₂**	92-125	**715.2**	252	4.2
					Mean		**871.33**	**93.13**	**3.9**	**Mean**		**787.2**	**180**	**6.24**

The differences in clay content of the sites studied could be as a result of the underlying parent materials.

The results also show that soil organic carbon generally decreases down the profile with greater percentage of it observed at the epipedon. This was in line with most studies (Onweremadu et al., 2007; Ahukaemere, et al., 2020) on soils of Southeastern Nigeria. The soils of Asu river group had the highest mean soil organic carbon content that ranged 6.5-11.7g/kg, followed by soils of Imo clay (6.04-8.7g/kg), Ajali sandstone (6.0-8.2g/kg), Afikpo sandstone (2.6-8.2g/kg), Bende-Ameki formation (5.1-8.1g/kg) and then Ogwashi-Asaba formation (3.9-5.8g/kg). These findings were in line with and Frey, et al., (2013) work which noted that soils with greater clay content typically have greater soil organic carbon stocks due to physical protection of organic minerals.

3.1 Geostatistical Analysis

The geostatistical analyses result for soil organic carbon are presented in Table 2. The results show a small nugget effect (0.007) at the range of 18553.26 m and a sill of 0.1298. Karl and Maurer, (2010) stated that an ideal situation would consist of a small nugget and a large sill indicating that there is much spatial dependence and a lot could be inferred about an unobserved location based on its distance from an observed site. The soil organic carbon also showed strong spatial dependence (Cambardella et al., 1994). This suggests that structural factors (climate, parent materials, topography and other natural factors) plays significant role in spatial variability of soil organic carbon (Shit, et al., 2016). The best fitted model was the Spherical model. Soil organic carbon had coefficient of determination (R^2) values of 0.0684. The lower the Root Mean Square Error (RMSE), the better the prediction indicating poor goodness of fit (Harisuseno et al 2020; Ikuemonisan, et al., 2020). The Root Mean Standardized Error (RMSE) indicate how closely the model predicts the measured values was 0.0525. The lower the RMSE, the better the prediction (Shit et al., 2016)

Table 2: Geostatistical Results

Soil Prop.	**Model**	**Nugget**	**Sill**	**Range (m)**	**Spatial Ratio**	**SD**	**R^2**	ME	RMSE
O.C.	Spherical	0.007	0.1298	18553.26	5.39	strong	0.0684	0.0525	2.3749

O.C- Organic Carbon, SD- Spatial Dependence, R^2- Coefficient of Determination, ME- Mean Error, RMSE- Root Mean Standardize Error

Spatial Distribution of Soil Organic Carbon

The spatial variability of soil organic carbon is displayed in Fig 2. Greater percentage of organic carbon were observed in Ezzagu and Igbeagu and soil organic carbon of 7.57-9.28gkg^{-1} covered almost the rest of Ebonyi State. Frey et al., (2013) stated that soil with greater clay content typically have greater soil organic carbon due to physical protection organic mineral. The least organic carbon content was observed in Amoso in Ebonyi States. This could be attributed to the undulating terrain. Organic carbon content of 6.38-7.57 gkg^{-1} and 5.54- 6.38 gkg^{-1} covered most of the soils of Enugu State while organic carbon content of 5.54- 6.38 gkg^{-1} and 4.35-5.54 gkg^{-1} covered most soils of Anambra State.

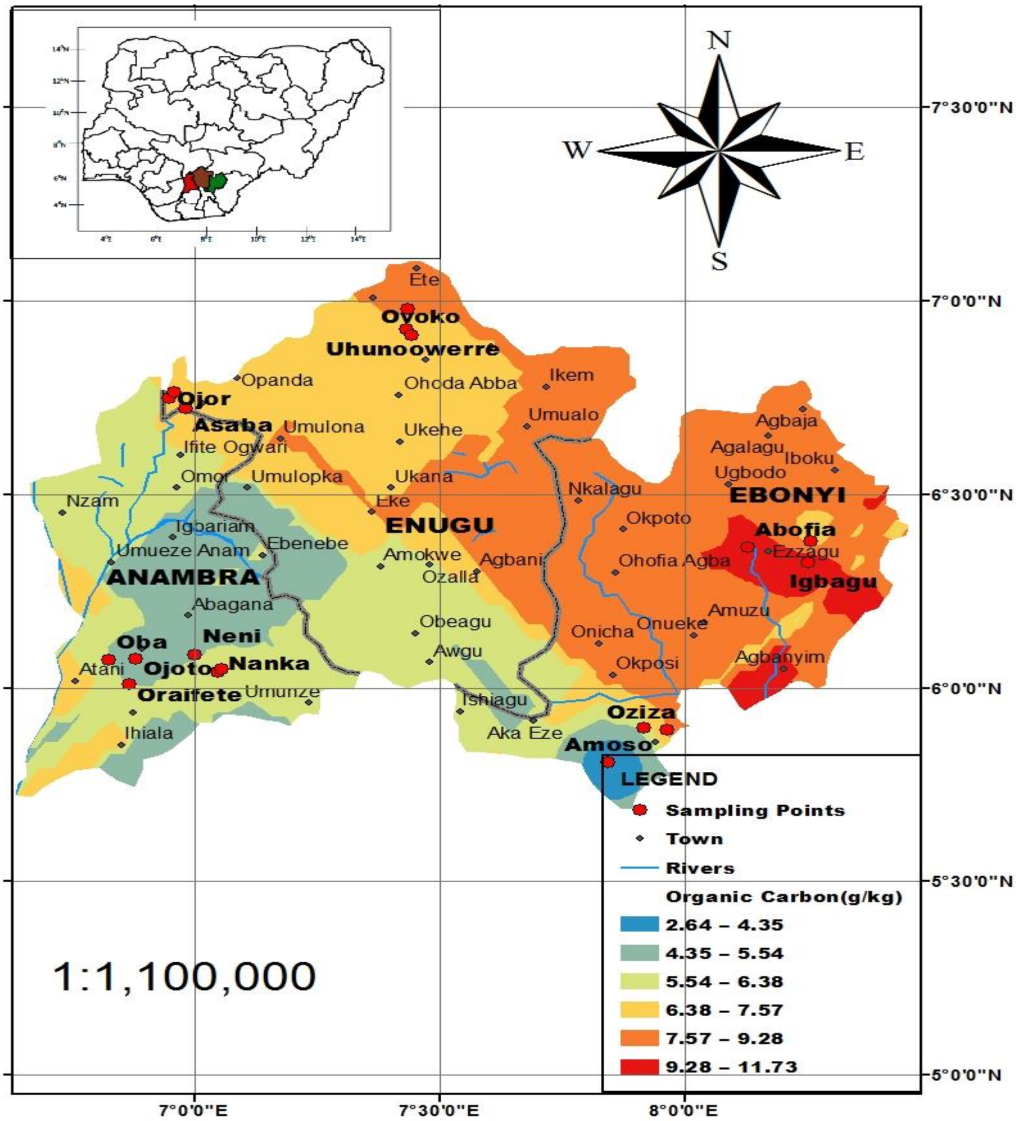

Figure 2: Digital Soil Organic Carbon map

4.0 Conclusion

The results obtained from this study revealed that soil depth as well as parent material influenced the quantity of soil organic carbon in the soil. The soil of Imo clay shale and the soils of Asu river group with the highest clay content also had the highest organic carbon content. The results of the geostatistical analyses showed that there was strong spatial dependence of soil organic and the Spherical model was the best fitted model for the semivariogram presenting a semivariance with lowest nugget and highest spatial autocorrelation. The coefficient of determination showed that the goodness of fit was poor. The mean error (ME) was close to zero and the Root mean standardized error (RMSE) was less than 1 making good predictions for the unmeasured locations. The map reveals that there is spatial variability in soil organic carbon

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SECTION TWO: SOIL CHEMISTRY, BIOCHEMISTRY, MINERALOGY, SOIL BIOLOGY AND MICROBIAL ECOLOGY

Biochemical Activities of Carbon Under Different Land Use Systems in Southern Nigeria

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ABSTRACT

The biochemical activities of carbon in soil play a crucial role in ecosystem functioning and nutrient cycling. This research investigates the impact of different land use practices on the biochemical activities of carbon in soils from Southern Nigeria, focusing on the regions of Abakaliki and Akure to understand the effects of various land uses, under two contrasting soil types and depths on some selected biochemical and microbial activities. Soil samples were collected from two land use types: fallow and intensively cultivated land, across three different depths (0-15 cm, 15-30 cm, and 30-45 cm) in Abakaliki and Akure. The methodology involved analyzing the soil samples for microbial biomass carbon, substrate-induced respiration, basal soil respiration, and carbon enzyme activities. The findings of the study revealed distinct differences between the two sites, land use and the depths. Abakaliki soils exhibited higher values of MBC, cellulose and Invertase of 9.24 g/kg. 0.80 and 0.16 (µg glucose g^{-1} soil $24h^{-1}$) respectively compared to Akure soils. These variables were also higher in fallow land compared to intensively cultivated land, suggesting the importance of land management practices in influencing soil carbon dynamics. Conversely, soils from Akure demonstrated higher rates of substrate-induced and basal respiration compared to soils from Abakaliki. Moreover, there was a consistent decrease in the observed biochemical activities with increasing soil depth. This research provides valuable insights into the microbial and biochemical activities of carbon in soils under different land use practices in Southern Nigeria. The results can inform future land use policies and management strategies to mitigate climate change and promote sustainable agricultural practices in the region.

Keywords: Carbon enzymes, Microbial biomass carbon, Soil respiration, depth, land use types, soil fertility.

1.0 INTRODUCTION

Soil is a vital component of the earth's ecosystem; it is the building block of all organic compounds and plays a crucial role in the global carbon cycle. It serves as a significant carbon pool, storing and cycling substantial amounts of carbon dioxide (CO_2) between the atmosphere, plants, and the soil (Lal, 2008). The carbon cycle involves the movement of carbon between the atmosphere, oceans, and land surface. Soil carbon is present in the form of organic matter mostly found at the soil surface. This organic matter is made up of dead plant and animal material at different stages of decomposition, substances synthesized by microorganisms and/ or chemically from the breakdown products of decomposition and living organisms and animals. Inorganic carbon is in the form of elemental carbon and carbonate materials, such as calcite and dolomite contained in the soil.

Microorganisms play a central role in the biogeochemical cycling of soil nutrients, ensuring a continuous supply of nutrients that is essential for plant growth, with soil enzymes at the forefront of these activities (Wang *et al.,* 2012; Zhang *et al.*, 2020). Soil enzymes are the key players in biochemical process of organic matter recycling in the soil system and their activities are closely related to soil organic matter (SOM), soil physical properties, and microbial activity and/or biomass. Depending on their location, enzymes can be extracellular or intracellular. Its dynamics are affected by various factors such as land use, management practices, and environmental conditions. Southern Nigeria is a region with high population density and agricultural productivity. These regions are characterized by a diverse range of land uses, including forests, grasslands, croplands, and urban areas.

Agricultural soils covering around 37 % of Earth’s land surface contain large amounts of carbon but land use changes such as deforestation, agriculture, and urbanization, significantly reduced soil organic carbon (SOC) content in urban soils in southern Nigeria (Adediran *et al.,* 2019), altering the balance of carbon stored in the atmosphere, soils, and vegetation. Also, soil microbial biomass activities were significantly affected by land use practices such as forest land conversion to agricultural land in southern Nigeria (Arowolo *et al.,* 2018). These changes affect the carbon cycle and contribute to climate change, which is one of the most significant global environmental challenges which is likely caused by increased soil disturbance and the removal of vegetation cover associated with urbanization.

The problem arises from the lack of comprehensive knowledge regarding the impact of land use management on the biological and biochemical activities of soil carbon in southern Nigeria. Although previous studies have explored soil carbon dynamics, there is a scarcity of research specifically addressing the biochemical aspects in the context of different land uses. By assessing soil respiration, C-cycling enzymes, and microbial biomass carbon, to fill the existing research gap and provide valuable insights into the influence of land use management on carbon cycling processes in this region. This is crucial for maintaining soil health, fertility, plant growth, and carbon sequestration, which are essential components for sustainable agriculture and mitigating climate change. Therefore, the research aimed to investigate the impact of different land use practices and managements under different sites and soil depths and their interactions, on some biological indices and biochemical activities of carbon in the southern part of Nigeria, to develop appropriate soil management strategies that promote sustainable agriculture and mitigate climate change.

2.0 Materials and Methods

2.1 Description of study area

The soils were collected from two geographical locations in Akure and Abakaliki, southwestern and southeastern Nigeria respectively. Akure is located in the humid tropical rainforest zone of southwest Nigeria, while Abakaliki is within the partially modified low rainforest and grassland-derived savannah. The two experimental sites are dominated by different soil textural and colloidal properties (clay loam and sandy clay loam). Akure and Abakaliki lie approximately within Lat. 7^0 20' N and Long5^0 30' E; and Lat$6^0$32'N and Long$8^0$11'E respectively. These sites were chosen because of the predominant agricultural production systems and the characteristics of the two soil types. The major types of land use in the study areas includes arable farming, plantation farming, forestry, firewood, and livestock farming. Arable farming consists of subsistence and commercial farming characterized by intensive and continuous cultivation. The main crops grown in the areas are rice, yam, cassava, maize, cocoyam, cowpea, and groundnut. Cash crops such as oil palm, cashew, cocoa, and rubber are also vigorously cultivated.

2.2 Sample collection, preparation, and experimental design

The soil samples were taken from two identified land use under fallow land (FL) and intensively cultivated (IC) systems in Akure and Abakaliki, at three different depths of 0-15 cm, 15-30 cm, 30-45 cm making a 2 x 2 x 3 factorial experiment, replicated three times in a Randomized Complete Block Design. Soils from different auger points were composted to form a sample from the locations. Samples collected were air-dried, sieved, and stored for the analysis of soil respiration, microbial biomass carbon, and soil carbon enzyme activities.

2.3 Soil respiration

Basal respiration was determined by weighing fifty grams of dried soil from each of the treatments into 50-ml plastic beakers in triplicates. Each of the samples was therefore wetted to 60 % water-filled pore space, placed into one-quart mason jars with alkali traps consisting of 10 ml of 1M NaOH jars consisting of into plastic bottles and distilled water added to make the water holding capacity to about 60 %. After the sleep duration was complete, the beaker containing NaOH was taken out and replaced at 1, 3, 7, 14, and 21 days, and 5 ml of Barium chloride (BaCl) was added inside the 10 ml of NaOH plus 3 drops of phenolphthalein (indicator), 0.5 M of Hydrochloric acid (HCl) was filled in a burette and the HCl was titrated against the NaOH to determine CO_2-C in mg/kg of soils in each sample (Anderson 1982). Substrate-induced respiration was also determined by weighing Fifty grams of soil placed in a plastic bottle, a substrate (glucose) was added to the soil and was wetted to about 60 % of the water-holding capacity (Anderson and Domsch, 1978). 10 ml of Sodium hydroxide (NaOH) was measured and put inside a short beaker and placed inside the moist soil, the container was covered and left in a dark, cool place for 24 hours. After the sleep duration was complete, the beaker containing NaOH was taken out, 5 m of Barium chloride (BaCl) was added inside the 10 ml of NaOH, and 3 drops of phenolphthalein (indicator) were added. 0.5 M of Hydrochloric acid (HCl) was filled in a burette and the HCl was titrated against the NaOH. This procedure was repeated on days 1, 3, 7, 14, and 21 and the data was recorded accordingly.

2.4 Determination of carbon-cycling enzymes

2.4.1 Invertase assay

The invertase activity assay was by the method of (Frankeberger and Johanson, 1983). Fifty grams of soil sample was measured into 100 ml of Erlenmeyer flask, 1 ml of toluene was added, 6 ml of buffer solution, and 1 ml of Sucrose solution was added and the suspension was left to incubate for 24 hours at 30^0 C. After the incubation was complete 5 ml of buffer solution was added to the suspension, it was shaken, and then filtered. Glucose solution was prepared at a different concentration, 1 ml of the filtrate was pipetted and a spectrometer was used to measure the enzyme activity in the suspension. Cellulase activity is expressed as µg g^{-1} 16 h^{-1}

2.4.2 Cellulase assay

The cellulase activity assay was carried out using the method described by Hope and Burns (1987). In the assay procedure, 1 g of moist soil was placed in an Erlenmeyer flask and 5 ml of 0.1 M acetate buffer (pH 5.5 containing 0.5 % sodium azide), and 0.5 g of avicel (substrate) were added. The flasks were incubated for 16 hours at 40 ºC in a shaking water bath. The reaction was stopped by centrifuging the mixture at 4000 rpm for 10 min. The control was prepared by adding the avicel after the incubation period before centrifugation. The amount of reducing sugars in the supernatant was determined by the DNS method (Miller, 1959). To 1 ml of the supernatant, 1 ml of prepared DNS reagent containing 30g of sodium-potassium tartrate and 20 ml of 2 N NaOH were added. The resulting solution was boiled at 90 ºC for 5 minutes and allowed to cool on ice before taking the absorbance reading of the solution at 540 nm. A graph of glucose standards was plotted to estimate the amount of reducing sugar released. Cellulase activity is expressed as µg glucose g^{-1} 16 h^{-1}

2.5 Determination of Microbial biomass carbon

The method of chloroform fumigation and extraction (FE) as described by Ladd and Amato (1989) was used to determine the microbial biomass. A 10 g field-moist soil sample, after passing through a 4 mm mesh, was put in a crucible and placed in a desiccator. A shallow dish containing 30 ml of alcohol–free chloroform was placed by it. A crucible containing a control sample (10 g) was placed in a separate desiccator without chloroform. The desiccators were covered and allowed to stand at room temperature for 5 days (Anderson and Ingram, 1998). Immediately after fumigation, 50 ml of 0.5 M K_2SO_4 solution was added to the soil samples to extract microbial carbon and nitrogen from the lysed microorganisms. The total nitrogen in the extract was then determined by the Kjeldahl method. The amount of microbial carbon in the extract was determined using the colorimetric method. An aliquot (5 ml) of the extract was pipetted into a 250 ml Erlenmeyer flask. To this were added 5 ml 1 N (0.1667 M) potassium dichromate and 10 ml concentrated sulphuric acid. The resulting solution was allowed to cool for 30 minutes after which 10 ml distilled water was added. A standard series was developed concurrently with carbon concentrations ranging from 0, 2.5, 5.0, 7.5, and 10.0 mg/ml C. These concentrations were obtained when volumes of 0, 5, 10, 15, and 20 ml of a 50 mg/ml C stock were pipette into labeled 100 ml volumetric flasks and made up to the mark with distilled water. The absorbances of the standard and sample solutions were read on a spectronic 21D spectrophotometer at a wavelength of 600 nm. The amount of microbial carbon in the extract was determined using the colorimetric method.

2.6 Data analysis

The data collected were analyzed using MINITAB Version 22. The means were separated using Tukey's test. Collected data were analyzed to test for the main and interactive effects of soil respiration, carbon enzymes, and microbial biomass carbon.

3.0 Results and Discussion

3.1 Main and interaction effects of landuse and soil depth on basal soil respiration and substrate-induced respiration

The results of the three-way analysis of variance as presented in Tables 1 and 2 indicate that there were significant differences main and interaction effects of site by depth by landuse on basal soil respiration (BSR) and substrate-induced respiration (SIR). Data on the effect of sites on the rates of basal soil respiration (BSR) were summarized in Table 1. Higher values were recorded till day 3, although no statistically detectable differences were indicated in the soils from Akure compared with Abakaliki, this may be due to the high organic matter content, relatively high base saturation, and clay-enriched subsoil. They are also typically more fertile and can support high levels of crop production. From day 7 till day 21, Akure recorded higher value and they are statistically at par. (Table 1), Abakaliki soils are characterized by low base saturation, low pH, and a highly weathered subsurface, they are generally less fertile and can support lower crop yield. This can be attributed to a study by (Ghimire *et al.*, 2016), that Akure soils have a higher BSR compared with Abakaliki, primarily due to their high organic matter content.

Data collected on the effects of land use on soil basal respiration are given in Table 1. Irrespective of sites and soil depth, there were significant differences in BSR between the two land uses. From day 1 to 21, there were significantly ($P < 0.05$) higher values recorded in fallow land throughout the 21 days of the incubation experiment (Table 1), this may be due to agricultural practices such as tillage operation, monoculture cropping, use of chemical fertilizers and pesticides, which are the main operations dominated in intensively cultivated land, and these could result in the depletion of soil organic matter, which is an essential substrate for microbial growth and respiration leading to a decrease in BSR. On the other hand, fallow land can support a high level of BSR due to its higher soil organic matter content and quality. Similarly, a study by (Felicia and Chinwe, 2022) found that the conversion of natural land to croplands resulted in a significant decrease in BSR, primarily due to the reduction in soil organic matter content and quality.

The rates of BSR decreased significantly with increase in depth (Table 1) because soil microbial communities, which are responsible for the BSR, are concentrated in the upper layers of soil where organic matter and other nutrients are most abundant. As you move down through the soil profile, the amount of organic matter and nutrients typically decreases, along with the number and diversity of microbial species. Many factors such as temperature, moisture, and oxygen availability can also vary with soil depth and can affect microbial activity and respiration rates. For example, soils at deeper depths may have lower oxygen availability, which can limit soil respiration. A study by Alan *et al.* (2019) found that BSR decreased significantly with increasing soil depth in temperate cropland soil, with the highest BSR observed in the surface layer (0-10 cm) and the lowest BSR observed in the deeper layers (20-50 cm). Our findings also corroborate this.

Table 1: Interaction effects of site by depth by land use on basal respiration of CO_2-C in mg/kg of soils

	Days after incubation				
Factors	**1**	**3**	**7**	**14**	**21**
Site					
Akure	5.03[a]	7.22[a]	5.27[a]	4.66[a]	3.06[a]
Abakaliki	4.22[ab]	5.04[ab]	3.24[b]	3.16[b]	2.60[b]
Land use					
Fallow land	5.04[a]	6.72[a]	4.19[a]	4.90[a]	2.46[b]
Intensive cultivated	4.21[b]	5.58[b]	3.23[b]	4.42[b]	3.19[a]
Depth (cm)					
0-15	9.54[a]	6.44[ab]	3.43[b]	5.73[a]	3.03[a]
15-30	6.40[ab]	4.86[b]	3.02[c]	5.07[b]	2.50[b]
30-45	4.42[ab]	3.60[c]	2.68[a]	3.18[c]	2.94[a]
P- Value					
Site (s)	*	*	*	*	*
Land use (L)	ns	ns	*	*	*
Depth (D)	ns	*	*	*	*
S x L	*	*	*	*	*
S x D	*	*	*	*	*
L x D	*	*	*	*	*
S x L x D	*	*	*	*	*
S D	1.18	1.84	1.37	2.08	1.30
CV	6.13	4.63	3.71	4.66	2.83

R^2 (%)	99.46	98.87	98.33	96.46	96.79

Means with same letter in superscript on a column for same parameter are not different ($P \leq 0.05$) from one another based on Tukey's test, ns= Not significant, *= $p \leq 0.05$

Data on the effect of sites on the rates of substrate-induced respiration (SIR) were summarized in table 2. The rate of Substrate-induced respiration is significantly higher in Akure compared with Abakaliki (Table 2) which may be due to their relatively high organic matter content, good drainage, and moderate to high fertility. Abakaliki on the other hand are generally more weathered and have a lower pH and lower fertility compared to soil in Akure. Furthermore, studies have shown factors like specific environmental conditions, management practices, substrate type used, and soil properties such as organic matter content, moisture, and pH can influence the rate of SIR in most tropical soils (Rodrigues *et al.*, 2019).

The rate of SIR was significantly higher in fallow land compared with intensively cultivated land (Table 2). This may also be due to tillage practices, monoculture cropping, use of chemical fertilizers and pesticides, which result in the depletion of soil organic matter. This is an essential substrate for microbial growth and respiration leading to a decrease in SIR; On the other hand, fallow land has a more active microbial community that can support a high level of SIR. Higher soil organic matter content and quality may attribute to the rate of SIR being significantly higher in fallow land compared to intensively cultivated land (Zhao *et al.*, 2018).

The rate of SIR generally decreased with an increase in depth (Table 2) this may be because soil microbial communities, which are responsible for substrate-induced respiration, are concentrated in the upper layers of soil where organic matter and other nutrients are abundant. Similarly, higher carbon contents recorded in the upper layers may be attributed to accumulation of plant litter on the top soil compared to the subsoil, where the litter or organic carbon accumulated. Factors such as temperature, moisture, and oxygen availability can also vary with soil depth and can affect microbial activity and respiration rates. Also, soils at deeper depths may have lower oxygen availability, which can limit microbial respiration. This can be attributed to a study published by Bastida *et al.,* (2016) that found that microbial respiration rates in a range of soils decreased significantly with increasing depth. This decrease was attributed to the low availability of organic matter and other nutrients in deeper soil layers, which can limit microbial growth and activity. Of the numerous significant interaction effects recorded among the sites, land use, and soil depth in Table 1, there were detectable significant differences from days 1 to 21 of the incubation experiment.

3.2 Microbial biomass carbon and carbon enzymes of the main and interaction effects of landuse and soil depth

The soil microbial biomass carbon C (MCB) was recorded to be significantly higher in Abakaliki compared to Akure, (Table 3), this might be because Abakaliki soils generally have higher SOC storage than Akure, they also have higher clay content, and the presence of iron and aluminum oxides that can bind organic matter. Similarly, a study by (Zhang *et al.*, 2016) compared SOC storage in different soil types, including Alfisols and Ultisols, in a forest ecosystem in China. The authors observed that Ultisols had higher SOC storage than Alfisols, which they attributed to differences in soil mineralogy, microbial activity, and plant inputs. Also, biomass carbon was recorded to be significantly higher in fallow land compared with intensively cultivated land (Table 3), this might be due to the availability and existence of litter falls accumulated over time in the form of soil organic matter, plant roots, and other macro and microflora and faunas in the undisturbed soil.

Table 2: Interaction effects of land use by site by depth on substrate-induced respiration

	Days after incubation				
Factors	**1**	**3**	**7**	**14**	**21**
Site					
Akure	13.24[a]	8.33[a]	7.92[a]	4.80[a]	3.91[a]
Abakaliki	9.55[b]	7.56[b]	5.78[c]	3.77[b]	2.78[b]
Land use					
Fallow land	10.30[ab]	10.01[a]	6.66[b]	4.61[a]	4.05[a]
Intensive cultivated	8.72[b]	7.87[b]	8.82[a]	3.96[b]	2.64[b]
Depth (cm)					
0-15	10.25[a]	9.08[a]	6.65[b]	4.63[b]	3.96[d]
15-30	8.80[b]	8.19[b]	4.49[bc]	4.20[b]	2.91[c]
30-45	6.24[c]	5.42[c]	3.38[a]	4.09[a]	2.52[c]
P- Value					
Site(s)	*	*	*	*	*
Land use (L)	ns	*	*	*	*
Depth (D)	*	*	*	*	*
S x L	*	*	*	*	*
S x D	*	*	*	*	*
L x D	*	*	*	*	*
S x L x D	*	*	*	*	*
S D	4.55	3.86	2.47	2.04	1.90
CV	9.51	8.93	7.73	4.28	3.35
R^2 (%)	99.70	99.55	98.80	98.45	82.08

Means with same letter in superscript on a column for same parameter are not different ($P \leq 0.05$) from one another based on Tukey's test. NS= Not significant, *= $p \leq 0.05$

Table 3: Interaction effects of site by land use by depth on MBC and carbon enzyme activities

Factors	MBC (g/kg)	Cellulase (µg glucose g^{-1} soil $24h^{-1}$)	Invertase (µg glucose g^{-1} soil $24h^{-1}$)
Site			
Akure	8.57^b	0.46^a	0.02^b
Abakaliki	9.24^a	0.80^a	0.16^a
Land use			
Fallow land	9.32^a	0.07^a	0.10^a
Intensive cultivated	8.49^b	0.56^b	0.87^a
Depth (cm)			
0-15	9.35^a	0.54^a	0.15^a
15-30	7.78^b	0.71^a	0.05^b
30-45	5.58^c	0.63^a	0.07^b
P- value			
Site(s)	*	ns	*
Land use (L)	*	*	ns
Depth (D)	*	ns	*
S x L	*	*	*
S x D	*	*	*
L x D	*	*	*
S x L x D	*	*	*
S D	1.08	0.37	0.11
CV	8.91	0.06	0.09
R^2 (%)	41.06	75.55	86.09

Means with same letter in superscript on a column for same parameter are not different ($P \leq 0.05$) from one another based on Tukey's test. NS= Not significant, *= $p \leq 0.05$

Compared with intensive cultivation practices, that experience practices such as tillage and monoculture cropping, these could have subsequently reduce soil organic matter and lead to the release of carbon dioxide (CO_2) into the atmosphere, causing significant impacts on biomass carbon stocks. Also, soil depth affects the amount and distribution of biomass carbon in the soil profile, as recorded in (Table 3) biomass carbon decreased significantly with an increase in soil depth, the highest biomass carbon concentration was found in the topsoil layer (0-15 cm). This might be due to greater plant litter input and microbial activity in the topsoil (Yong-Liang *et al.*, 2016). Many factors have been earlier reported to have contributed to the effects of ecosystems variables on the microbial biomass carbon and nitrogen in soils (Adeyemo *et al.,* 2023). The differences in the quantity and quality of varying litterfall and root types of plants, as well as the mineralization process with the consideration of the external edaphic and biotic factors, and associated soil nutrient status, specifically, can be an important stimulus to have influenced the population of soil microbes (Feng *et al.*, 2009). The activities of cellulose and invertase were significantly higher in the soil from Abakaliki compared to Akure. Despite their inherent low fertility, Abakaliki soils can still exhibit considerable enzyme activity (Table 3). A study by (Zhang *et al.,* 2020) conducted in Ultisols that share the same characteristics with that of southern China, reported significant β-glucosidase activity suggesting a role in organic matter decomposition and nutrient cycling even in these weathered soils. Also, the amount of enzyme activity was significantly higher in the fallow land use compared to the intensively cultivated land use (Table 3). This might be because fallow lands have a more active microbial community that can support a high level of enzyme activities, due to their great number and diversity of microbial species higher soil organic matter content and quality. Thereby attributing to the amount of enzymes activities being significantly higher in fallow land than in Intensively cultivated land (Zhao *et al.,* 2018).

There was a significant decrease in the amount of enzyme activity with an increase in depth (Table), the highest amounts were recorded in the 0-15 cm depth these significant variations could be because soil microbial communities are concentrated in the upper layers of soil where organic matter and other nutrients are most abundant. Down the soil profile, the amount of organic matter and nutrients typically decreases, along with the number and diversity of microbial species. Many factors such as temperature, moisture, and oxygen availability can also vary with soil depth and can affect enzyme activity (Zhao *et al.,* 2021).

4.0 Conclusion

It was observed that there were significant differences in the soil types from both sites in Abakaliki and Akure for both types of soil respiration, amount of microbial biomass carbon, and levels of enzyme activity. The land use system generally influenced the biochemical activities of carbon with the highest values recorded in fallow land for microbial biomass carbon, soil respiration and enzyme activities, which could be due to the presence of a more diverse and active microbial activity. In contrast, the lowest values recorded for microbial biomass carbon, soil respiration and enzyme activities were observed in intensively cultivated land in Akure, which could be due to the negative impacts of intensive agricultural practices on soil health and microbial activities. There was a general decrease with increase in depth in biochemical activities across the soil depth for both soil respirations (basal and substrate-induced) with the highest values recorded in the 0-15 cm depth. Effort must therefore be made in understanding the sustainable land use management practices such as crop rotation, cover and mixed cropping, alley cropping and reduced tillage operations to maintain soil health, enhance microbial activity and nutrient cycling and as well prevent loss of nutrients and microbial communities through land conversions and intensive land practices.

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Assessing the Availability of Exchangeable Calcium (Ca), Magnesium (Mg), and Potassium (K) in Oil Palm (Elaeis Guineensis) Plantations Grown on Coastal Plain Sand Soil of Akwa Ibom State

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ABSTRACT

A study was carried out to evaluate the content and quantitative ratios of exchangeable Calcium (Ca) Magnesium (Mg) and Potassium (k) in soils and plants in three oil palm plantation sites in Akwa Ibom State namely Ikot Obong Edong (IOE), Obioakpa (OBA) and Uta-ewa (UTE). Soil samples were taken from 0 – 20cm depth, from the three site, dried, sieved and analyzed in the laboratory. The data collected were subjected to statistical analysis and the following results were observed. The soils were sandy in texture, slightly acidic, values ranged from 4.5 (IOE) to 4.9 (UTE), exchangeable acidity were low, values ranged from 1.44 to 1.67cmol kg^{-1}, organic matter (OM)were rated low to moderate, the trend were: 1.92% (10E) < 3.33% (OBA) < 3.36% (UTE), total N and available p were moderate and salt level were low. The exchangeable Ca, Mg and K (cmol kg^{-1}) in soils and plants differ significantly within the locations, the exchangeable Ca, Mg and K (cmol kg^{-1}) in soils contribute significantly to the uptake of Ca, Mg and K ($mgkg^{-1}$) in plant. Values of Ca varies in the order; UTE (3.59$mgkg^{-1}$)>IOE(3.29 $mgkg^{-1}$)>OBA (3.03 $mgkg^{-1}$), the order of variation for Mg was UTE (2.79$mgkg^{-1}$)>IOE(2.72$mgkg^{-1}$)>OBA (2.07$mgkg^{-1}$) while K varies in the order; UTE (1.94$mgkg^{-1}$)>IOE(1.85$mgkg^{-1}$)>OBA (1.51$mgkg^{-1}$)With the low to moderate nutrient status of the soils, application of organic manure and inorganic fertilizer (NPK) as well as lime is recommended to enhance the nutrient content, increase the pH and promote higher crop yield.

Keywords: Coastal Plain Sand, Soil Texture, Oil Palm Plantations, Exchangeable Cation and Nutrient Uptake and Growth yield

Introduction

Soils are reservoirs of nutrients and water for plant growth and development. Nutrients available to plants vary widely among soils and it depends on the concentration and activity of each nutrient in the soils (Umoh *et al.,* 2017).

When a nutrient is applied in the form of fertilizers in soils, it can either be adsorbed on clay minerals, organic surfaces, used up by plants or lost through leaching. Umoh *et al.*, (2018) observed high leaching of potassium (K) and phosphorous (P) in soils formed from coastal plain sands. The rate of leaching increased with increasing amount of K and P applied. Umoh *et al.*, (2018) attributed this to the sandy nature of parent materials from which the soils were formed. This may lead to widespread nutrient deficiency and thus limit crop production. The soil properties influencing the availability of nutrients include texture, pH, organic matter, concentration of exchangeable Ca, Mg and K in soil, and amount and types of clay minerals (Schneider *et al.,* 2016)

The mineralogy of these soils is predominantly Kaolinite which is a 1:1 type of clay, which contains Fe, and Al Oxide that lead to K, and Mg deficiency. The deficiencies of Ca, Mg, and K in soils occur either because of nutrient fixation, low concentration, nutrient imbalances and activity of each nutrient element (Mei *et al.*, 2016). Soil availability of K and plant K concentration are influenced by Ca:K and Mg:K ratio in soil due to competitive effect and increased levels of exchangeable Ca and Mg in soils decreased K concentration in sesame leaf tissue grown on paddy wetland soil. (Schneider *et al.*, 2016.

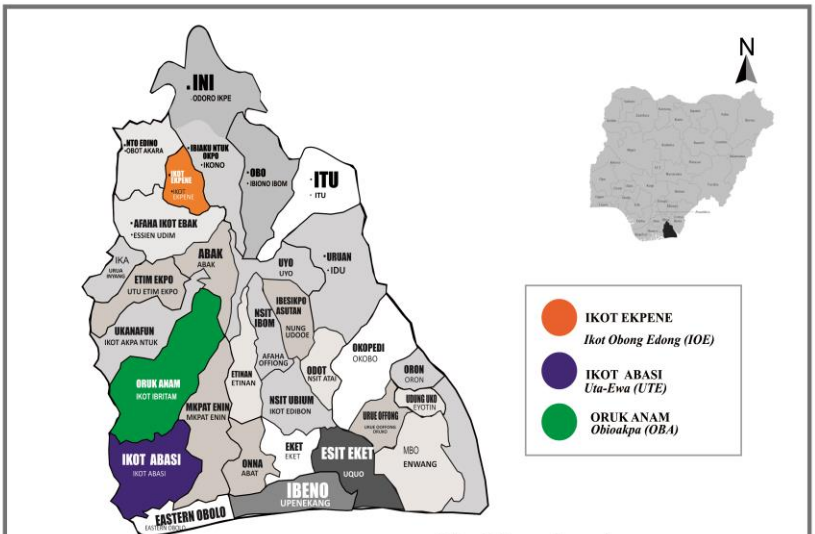
Moore *et al.,* (2008) reported that lime application in soil changes the levels of soil exchangeable cations (Ca^{2+}, Mg^{2+}, and K^{+}), improves soil fertility conditions and promotes soil productivity by alleviating Ca^{2+} deficiency, decreasing Al^{3+} toxicity and improving plant nutrient availability (Kunhikrishnan *et al.*, 2016). The Ca^{2+} cation which is the main component of lime, directly competes with K^{+} on the adsorption sites and displaced K^{+} which is consequently lost through leaching (Mei *et al.,* 2016; Umoh *et al.*, 2022). Potassium (K) uptake by crops is inhibited by high concentration of Ca^{2+} in the soil and liming increases availability of K^{+} by competitive adsorption of Ca^{2+}, and Mg^{2+} (Schneider *et al.*, 2016).

Oil palm (*Elaeis guineensis)* is a tree crop that belongs to the Palmae family, it is a monocotyledonous plant that grows to a height of 15-25m and can live for up to a century. Oil Palm is a tropical crop which thrives well on highly weathered soil. Oil palm is a heavy feeder and requires quite large quantities of fertilizers to produce good yield. The oil palm is the dominant source of vegetable oil consumed in the world. The best soil pH for profitable oil palm growth ranges from 5.0 - 6.0 while rainfall requirement ranges from 2,000 - 2,500mm per annum (Peter *et al.*, 2019). Harvesting of oil palm implies that the soil nutrients are removed and may result in a decline in soil fertility if the soil nutrient is not replenished (Hartemimik, 2015). This study was carried out to understand the relationship between some soil properties and exchangeable cations (Ca_2^{+}, Mg_2^{+} and K^{+}) and its uptake by oil palm grown on different plantations in Akwa Ibom State.

Materials and Methods

Description of the study area

The soil samples used for this study were collected from three oil palm plantations: Ikot Obong Edong (IOE), Obioakpa (OBA) and Uta-Ewa (UTE) in Akwa Ibom State. The area is in rainforest zone, characterized by heavy rainfall ranging from 2500mm in land to over 3000mm along the coast, mean temperature range from $26^{0}C$ to $28^{0}C$ with relative humidity of 75 – 80% within a year- AKSU Meteorological station, 2021). The soil is derived from coastal plain parent material. The topography of Obioakpa and Utaewa is undulating and Ikot Obong Edong has a gentle slope to flat. Other information about the locations is shown in Figure 1 and Table 1.



The Map showing the location of the study area

Table 1: Locations of the study area

Locations	Coordinates	Vegetations
Ikot Obong Edong	5°11'N,7°43'E	Rainforest, dominant plant are *Tridax spp., Imperata cylindrica, Aspillia africana*
Obioakpa	4°45N 7°37' E	Rainforest, *manihot spp, zea mays aspillia Africana*
Uta-ewa	4°30'N7°43'E	Rainforest, dominant plant are andropogon gayanus, *Tridax spp., Imperata cylindrica, Aspillia africana*

Field studies and sample preparation

Soil and plant samples were collected from three plantations, namely; Lutheran Palm Groves Limited in Ikot Obong Edong, Ikot Ekpene Local Government Area, Plantation at Akwa Ibom State University Research Farm, Obioakpa, Oruk Anam local Government Area, and Plantation at Uta-ewa in Ikot Abasi Local Government Area. Each location represents the Oil Palm ages above 15 years. Soil samples were taken randomly within the marked locations at 0-20cm depth, using soil Aaugar. The samples were placed in polythene bags and labeled. The samples collected were air-dried under shade for 3 days crushed, sieved with a 2mm mesh and stored in polythene bags. They were subsequently subjected to a laboratory analysis using standard laboratory procedures as outlined by Udoh *et al.,* (2009).

Plant samples were also collected at random within the marked area at three replicates. The frond (leaves) was taken from the three clustered fronds to the meristem or inflorescence using machete and were washed with 2% Phosphate free detergent solution and quickly rinsed with distilled water before air drying to remove moisture and then oven dried for 24 hours at 80°C. The dried plant samples were milled using stainless steel mill and sieved to obtain particles less than 2mm. The samples were placed in labelled envelopes and subjected to laboratory analyses.

Laboratory Analyses

Particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1951) 5% of a dispersing agent (calgon: sodium hexametaphosphate was used to separate sand, silt and clay particles bonded together for determination of their compositions. Soil pH was determined electrometrically using pH-meter in a soil: liquid ratio of 1:2.5 (Thomas, 1996). Soil exchangeable acidity (Al^{3+}, and H^{+}) was determined by titration method as described by Udo *et al.*, (2009). Total nitrogen was determined by the micro kjeldahl digestion method (Bremner and Mulvaney, 1996). Organic carbon was determined by Walkley and Black (1934) wet oxidation method. Available phosphorus was extracted using Bray II extractant as described by Olsen and Sommers (1982). The electrical conductivity was measured in the extract from 1:2.5 soils: water suspension using a conductivity bridge. Soil organic carbon was determined by wet oxidation method and the value was multiplied by a factor of 1.72 to obtain % organic matter Udo *et al.,* (2009). The nitrogen in the soil was determined by micro Kjeldahl distillation method. Available Phosphorous in the soil was determined by Murphy and Relay method after extraction by Bray p-1 extractant. The exchangeable cations in the soil were extracted using IN NH_4 OAC (pH 7.0). K and Na in the extracts were measured using flame photometry while Mg and Ca were determined by atomic absorption spectrophotometry. Effective Cation Exchange Capacity (ECEC) was obtained by the summation of the exchangeable cation and exchangeable acidity was extracted with in KCL and determined by titration with 0.05N. NaOH using phenolphthalein indicator. Base Saturation (%) was calculated using the formula: $\frac{TEB}{ECEC} X \frac{100}{1}$ where TEB = total exchangeable bases and ECEC = effective cation exchange capacity as described by Udo *et al.*, (2009).

Statistical Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using Genstat (2007) and significant means compared using Fisher's Least Significant Difference (F-LSD) test. And regression analysis was also done.

Results and Discussion

The Physicochemical Properties of the Soils Studied

Results of selected physical and chemical properties of the soils used in this study are presented in Table 2. Though significant differences were observed in sand, silt and clay contents, the was sand. The highest sand content of 94.47% recorded in IOE and the lowest (85.13%) in (UTE) Utaewa location but UTE recorded the highest silt content of 4.00% and 10.87% clay, while Ikot Obong Erong (IOE) had the lowest silt (2.20%) and clay 3.33%.

The relatively higher sand content and lower silt and clay contents in each of the locations may indicate dominance of erosion over soil formation and accumulation and may also attributed to the undulating terrain of the area. This observation agrees with the findings of Ellerbrock and Gerke (2013). The soil pH were slightly acidic, the electrical conductivity (EC) of the soil were low, organic matter (OM) content were low. The values vary in this order; UTE (3.36%)> OBA (3.33%)> IOE (1.92%), these values were rated low to moderate for the soils and the moderate OM of UTE and OBA could be attributed the accumulation of liters over the years. The observation agrees with the findings of Umoh *et al.,* (2021) who evaluated nutrient statues on different land use system. The exchangeable acidity values were less than 4(cmolkg-1) in the soil. The value reflects the slightly acid pH of the soils (Udo *et al.,* 2019). The concentrations of Total Nitrogen ranged from 0.57% in IOE to 0.42% in UTE and available P values ranged from 6.5% in IOE to 7.31 in UTE and were moderate based on the ratings of Udo *et al.,* (2009). This suggests that the soils were fragile and of inherently low fertility. Umoh *et al.,* (2018) observed high leaching loss of exchangeable K in coastal plain sand soils and attributed this to the sandy texture of the soils. The effective cation exchange capacity ranged from 4.52 cmolkg^{-1} (UTE) < 4.57 cmolkg^{-1} (OBA) < 4.89 cmolkg^{-1} (IOE) respectively. The exchangeable bases were below the critical requirement for oil palm production base on the rating of Udo *et al.,* (2009). Base saturation ranged from 73.0% (UTE) to 77.3% (IOE). The variation in the percentage observed could be due to excessive leaching of the bases element in soils. (Umoh *et al.,* 2018; Sunday *et al.,* 2020).

Levels of exchangeable Ca, Mg and K in the Soil

Table 3 shows the values of exchangeable Calcium (Ca), Magnesium (Mg) and Potassium (K) in the soils. Calcium was the dominant cation with values ranging from 2.01cmol kg^{-1} (IOE) to 1.85 cmol kg^{-1} (OBA). There was a significant difference in the concentration of Mg, Ikot Obong Erong (IOE) having the highest exchangeable Mg of (1.50 cmolkg^{-1}) while Utaewa (UTE) had the lowest concentration of 1.31 cmolkg^{-1} respectively. There were also significant differences in Potassium (K) concentration among the soils. The concentration of K were IOE (1.32) > OBA (1.24) > UTE (1.05) cmol kg^{-1} the value were moderate according to the rating of Udo *et al.,* (2009). The moderate concentration of Ca, Mg and K may have been due to the accumulation of liter over the years on the surface layer which corroborates with similar work done by Umoh *et al.,* (2021). The higher concentration of K (IOE) could be due to high concentration of Ca and Mg which may competes with K^+ on adsorption sites and displaced K to release in soils (Schneider *et al.,* 2016). The low concentration of K observed in UTE could be linked to the displacement of this mobile K^+ to leaching. This observation is in agreement with the findings of Umoh *et al.,* (2018) and Umoh *et al.,* (2022) who revealed high release and leaching of K in soils of Obioakpa due to high concentration of Ca and the sandy nature of the soil.

Concentration of Ca, Mg and K in Plant

Table 4 shows the concentration of Ca Mg and K in the leaves of the oil palm. The exchangeable Ca concentration was significantly different within the soils. The trend were 3.59 (UTE) > 3.29 (IOE) > 3.03mgkg-1) (OBA). Magnesium (Mg) concentration in UTE and IOE were statistically similar. Values ranging from 2.07 OBA to 2.79 $mgkg^{-1}$ in UTE while potassium concentration were similar ranging from 1.51$mgkg^{-1}$ (OBA) to 1.94 $mgkg^{-1}$ (UTE). This observation indicated that the soils cations contributed positively to uptake of Ca Mg and K in plant, as the ratio of Ca:Mg 3:1 to 5:1 and K:Mg 1:1 is the normal range for this soils rated by Udo *et al.*, (2009) and also indicated that above the ranged will cause inhibition of Mg and P and below the ranged deficiency of Ca occurs. This result conform with the report Umoh *et al.,* (2015) and Umoh *et al.*, (2016) for sandy soils

Correlation of soil properties and nutrient accumulation in plant

The link between the soil properties and nutrient accumulation in plant is presented in Table 5. Silt, Clay, pH, EC, OM, EA and Exchangeable Ca, Mg and K correlated negatively with sand this contributing to the acidic nature of the soil. Organic matter (OM) correlated positively with silt and clay, thus showing that, Calcium (Ca), Magnesium (Mg) and Potassium (K) in soil correlated positively with Ca (plant), Mg (plant) and K (plant) showing that, the exchangeable Ca^{2+}, Mg^{2+} and K^{+} in soils contributed to the uptake of Ca, Mg and K. Similar finding was observed by Peter *et al.,(* 2019).

Regression of nutrients in plant with the soil properties

Table 6 shows the regression of nutrients in plants with the soil properties. Calcium (Ca^{+}) in plant increased as EC increases by a factor of 11.6 and the intercept (2.735) which is the amount of Ca that would have been obtained if the values of EC was 0, Mg in plant increased as EC increases by a 1.670 with the highest R^2 values of 86.79, Mg in plant increased as exchangeable magnesium increases by a factor of 4.83, Mg in plant also increased with increasing exchangeable K by a factor 2.070, while potassium (K^{+}) in plant increased with increasing Electrical conductivity (EC) by a factor of 1.165 with the lowest R^2 values of 48.49. The result shows a weak relationship with K uptake in the plantation site. Similar finding was observed by Peter *et al.,* (2019).

Table 2: Some physicochemical properties of soils at the studied locations

Location	Sand %	Silt %	Clay %	Texture	pH(H_20)	EC dSm^{-1}	OM %	TN %	AV.P %	EA $Cmolkg^{-1}$	ECEC $Cmolkg^{-1}$	BS %
IOE	94.47a	2.20b	3.33c	Sand	4.57b	0.057b	1.92b	0.57b	6.5b	1.44b	4.89a	77.3a
OBA	88.47b	3.07ab	8.47b	Sand	4.97a	0.052c	3.33a	0.62a	6.8b	1.48b	4.57b	75.5b
UTE	85.13c	4.00a	10.87a	Sand	4.89b	0.063a	3.36a	0.60a	7.3a	1.67a	4.52b	73.0c

Means that do not share a letter are significantly different

EC – Electrical Conductivity, OM – Organic Matter, EA – Exchangeable Acidity, IOE – Ikot Obong Edong , OBA – Obio Akpa, UTE – Uta-ewa

Table 3: Concentration of Ca, Mg and K in the soils studied

Location	Ca	Mg	K
	←	$cmolkg^{-1}$	→
IOE	2.01b	1.50a	1.32a
OBA	1.85c	1.43b	1.24b
UTE	2.13a	1.31c	1.05c

Means that do not share a letter are significantly different
Ca – Calcium, Mg – Magnesium, K – Potassium IOE – Ikot Obong Edong , OBA – Obio Akpa, UTE – Uta-ewa

Table 4: Concentrations of Ca, Mg and K in the leaves of the oil palm

Location	Ca	Mg	K
	←	mg kg^{-1}	→
IOE	3.29b	2.72a	1.85a
OBA	3.03c	2.07b	1.51a
UTE	3.59a	2.79a	1.94a

Means that do not share a letter are significantly different
Ca – Calcium, Mg – Magnesium, K – Potassium IOE – Ikot Obong Edong , OBA – Obio Akpa, UTE – Uta-ewa

Table 5: Correlation of soil properties and nutrient accumulation in plant

	Sand	**Silt**	**Clay**	**pH**	**EC**	**OM**	**EA**	**Ex. Ca**	**Ex. Mg**	**Ex. K**	**Ca(plant)**	**Mg(plant)**
Silt	-0.931**											
Clay	-0.995**	0.890**										
Ph	-0.771*	0.616*	0.795*									
EC	-0.04	0.216	-0.009	-0.547								
OM	-0.890**	0.832**	0.885**	0.816**	-0.247							
EA	-0.931**	0.752*	0.957**	0.880**	-0.269	0.888**						
Ex. Ca	0.197	0.053	-0.26	-0.115	0.079	-0.177	-0.377					
Ex. Mg	-0.264	0.167	0.285	0.569	-0.727*	0.572	0.450	-0.213				
Ex. K	-0.053	0.168	0.02	-0.326	0.697*	-0.198	-0.179	0.130	-0.636			
Ca(plant)	-0.373	0.495	0.332	-0.149	0.848**	0.118	0.077	0.046	-0.581	0.837**		
Mg(plant)	0.072	0.089	-0.114	-0.548	0.932**	-0.366	-0.366	0.230	-0.813**	0.848**	0.866**	
K(plant)	-0.156	0.45	0.072	-0.31	0.696*	-0.025	-0.156	0.427	-0.525	0.446	0.554	0.579

** significant at 1% level of probability , * significant at 5% level of probability, *EC – Electrical Conductivity, OM – Organic Matter, EA – Exchangeable Acidity, Ex. Ca – Exchangeable Calcium, Ex. Mg – Exchangeable Magnesium, Ex. K – Exchangeable Potassium, Ca – Calcium, Mg – Magnesium, K – Potassium*

Table 6: Regression of nutrients in plants with the soil properties

Dependent variable	Independent Variable	Regression equation	R^2 (%)
Ca(plant)	EC	Ca(plant) = 2.735 + 11.61 EC	71.88
Mg(plant)	EC	Mg(plant) = 1.670 + 17.50 EC	86.79
Mg(plant)	Ex. Mg	Mg(plant) = 4.827 - 1.011 Ex. Mg	66.12
Mg(plant)	Ex. K	Mg(plant) = 2.070 + 0.517 Ex. K	71.92
Mg(plant)	Ca(plant)	Mg(plant) = -1.398 + 1.188 Ca(plant)	75.05
K(plant)	EC	K(plant) = 1.164 + 12.33 EC	48.49

Ca – Calcium, Mg – Magnesium, K – Potassium , EC – Electrical Conductivity, Ex. Mg – Exchangeable Magnesium, Ex. K – Exchangeable Potassium, Ca – Calcium, Mg – Magnesium, K – Potassium

CONCLUSION AND RECOMMENDATION

The study showed that, the pH of the three plantations were low. The values varied in the order; 4.57 (IOE) <, 4.97 (OBA) < 4.89 (UTE) indicating a slightly acidic condition. Electrical conductivity and organic matter were low. The values increase from UTE > OBA > IOE the texture of the soils were sand. The concentration of Ca, Mg and K in soils varied in the locations, UTE plantation, had the highest Ca concentration (2.13 cmolkg^{-1}) while OBA had the lowest (1.85 cmolkg^{-1}) and were significantly different. IOE had the highest Mg concentration of (1.50) while UTE had the lowest concentration of (1.31 cmolkg^{-1}). The potassium (K) concentration was lower in UTE than OBA and IOE. When linking the concentration of Ca, Mg, and K in soil and plant, the concentration were significantly different and values ranged from Ca: (UTE) 3.59 > 3.29 (IOE) and 3.03 mgkg^{-1}in OBA: Mg: UTE (2.79 mgkg^{-1}) > IOE (2.72mgkg^{-1}) > OBA (2.07mgkg^{-1}). K: UTE (1.94mgkg^{-1}) > IOE (1.85mgkg^{-1}) > OBA (1.51 mgkg^{-1}). The result also shows that Mg Ca, K (cmolkg^{-1}) in soils contributed significantly to uptake of Mg Ca, and K (Mgkg^{-1}) in the three plantations. With the low nutrient status of soils and the acidic nature, little lime is recommended to be applied to raise the pH of soil to a level that will gives optimum yield.

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Assessment of Sulphur Status in Soils of Ilorin West Local Government, Kwara State

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ABSTRACT

Inventory of soil sulphur status plays a crucial role in assessing its bioavailability and determining areas where a targeted nutrient application is necessary for profitable crop production. This study aimed to evaluate the sulphur status and their relation with soil properties of Ilorin West LGA, Kwara state. Thirty composite samples were collected from fifteen evenly distributed observation points at two depth intervals (0 – 15 cm and 15 – 30 cm) in Ilorin West Local Government, Kwara State. These samples were analyzed for soil organic carbon (SOC), soil pH total nitrogen (TN), cation exchangeable capacity (CEC), available sulphur and phosphorus. The soil fertility status was assessed using nutrient index value and sulphur availability index (SAI) based on a specific rating chart. The result revealed deficiency in TN, CEC, available sulphur and phosphorus, while soil pH and SOC were found to be at moderate to high levels respectively. Based on the nutrient index, the soils were classified as high for pH and SOC, while for other nutrients it is classified as low. Surprisingly, despite the low sulphur content, a significant portion of the soil exhibited a medium (40%) to high (33.33%) SAI while only a small fraction (2.67%) of the soil samples were categorised as having low SAI. The possible reason for this result, is that at higher pH level, sulphate ions remain in the soil solution rather than being adsorbed onto soil particles, leading to their greater mobility and leaching. These findings highlight the need for appropriate fertility management practices, including the use of organic and inorganic fertilizers, to achieve balanced soil nutrient composition.

Keywords: nutrient index; sulphur availability index; available sulphur.

INTRODUCTION

Sulphur is the fourth most important nutrient after nitrogen, phosphorus and potassium and it is required for optimum growth, metabolism and development of all plants (Rathore et al, 2015). It plays an essential role in different physiological and biochemical functions in plants which include protein synthesis, enzyme activation, and chlorophyll formation (Sharma *et al.*, 2024). It is taken up by plants in the form of sulphate-S (SO_4^{2-}) and its availability depends on the mineralization of organic S in soils. The availability of sulphate is controlled by pH, organic carbon and clay content of soils through some adsorption-desorption mechanism (Padhan *et al.*, 2016).

The main source of sulphate in soils is through clay content and organic matter addition from plant and animal sources and inorganic fertilizers. Sulphur however finds its way into the soil system through atmospheric depositions (wet and dry). The wet deposition is dissolved in rain while the dry deposition involves compounds containing sulphur e.g. parent materials. The sulphur deposited through these systems may be lost in the soil in many ways either by runoff, leaching, burning, microbial and plant uptake and a larger proportion of it may be unavailable (fixed) to plants (Ogeh *et al.*, 2012).

The sulphur deficit has been widely attributed to reduced atmospheric sulphur deposition, increased use of low sulphur mineral fertilizers, low utilization of animal manure, continuous cultivation with low nutrient inputs and high crop residue removal, intense use of high-yielding crop cultivars, etc. (Habtegebrial & Singh, 2009; Zenda *et al.*, 2021). Insufficient availability of sulphur to crop plants will not only decline their growth and yield but can also deteriorate the quality of crops and food nutrition (Neina & Adolph, 2022). However, there is a dearth of information on the current sulphur status of soils of Ilorin West. This study therefore aimed to evaluate the sulphur status and their relation with soil properties of Ilorin West LGA, Kwara state.

MATERIAL AND METHOD

Description of The Study Area

The research was carried out in Ilorin West Local Government Area of Kwara State, Nigeria. Ilorin West Local Government Area lies between latitude $8^0$34' 16" N and longitude 4^0 43' 42" E (Kwara State Ministry of Information, 2002). The research area falls within the Southern Guinea Savannah ecological zone of Nigeria (Ejieji, 2011). Maximum and minimum temperatures range between 28.9^{o}C and 35.8^{o}C and between 19.5^{o}C and 23.5^{o}C respectively. The rainfall pattern is bimodal with the two peaks occurring usually in June and September respectively (Alao, 2012). The annual rainfall averages 1252 ±239 mm (Ejieji, 2004).

Soil Sampling

Fifteen evenly distributed observation points were selected to represent Ilorin West Local Government Kwara State Nigeria (Table 1). In each location, ten subsamples from 0 – 15 cm and 15 – 30 cm depth were collected and mixed to form a composite sample. All composite soil samples were mixed, quartered, and reduced to 1 kg, and sealed with plastic bags. Each composite sample was further divided into three parts, to form three replicates. The soil samples were air-dried at room temperature, ground using mortar and pestle, and passed through a 2 mm mesh sieve to prepare for laboratory analysis, All the soil samples were further divided into three replicates.

Table 1. The locations and coordinates where soil samples were collected

S/N	Location	Latitude	Longitude
1	A	$4^o 29' 55''$ E	$8^o 31' 31''$ N
2	B	$4^o 29' 56''$ E	$8^o 30' 30''$ N
3	C	$4^o 29' 55''$ E	$8^o 30' 29''$ N
4	D	$4^o 30' 54''$ E	$8^o 28' 21''$ N
5	E	$4^o 30' 54''$ E	$8^o 28' 22''$ N
6	F	$8^o 30' 54''$ E	$8^o 28' 22''$ N
7	G	$4^o 32' 54''$ E	$8^o 29' 20''$ N
8	H	$4^o 32' 26''$ E	$8^o 29' 9''$ N
9	I	$4^o 32' 19''$ E	$8^o 29' 12''$ N
10	J	$4^o 31' 13''$ E	$8^o 29' 43''$ N
11	K	$4^o 31' 38''$ E	$8^o 29' 44''$ N
12	L	$4^o 30' 30''$ E	$8^o 29' 47''$ N
13	M	$8^o 30' 38''$ E	$8^o 30' 20''$ N
14	N	$8^o 30' 46''$ E	$8^o 29' 59''$ N
15	O	$8^o 30' 54''$ E	$8^o 29' 26''$ N

Laboratory Analysis

The soil reaction (pH) of a 1:2.5 soil-to-water suspension was measured using a digital pH meter (Rayment and Higginson, 1992). The total nitrogen content of the soil was determined by the Kjeldahl method (Bremner & Mulvaney, 1982), and Soil organic carbon was determined by a modified Walkley-Black method (Nelson and Sommers 1996). The available phosphorus (P) was determined by the Bray P1 method (Olsen & Sommers, 1982). Available sulphur (S) was measured using 0.15% calcium chloride ($CaCl_2$) as an extractant (Tabatabai 1996)

The exchangeable bases (Ca, Mg, K, & Na) were extracted from the soil using the ammonium acetate method, the extract was then analyzed for Ca^{2+} and Mg^{2+} by the use of atomic absorption spectrophotometer and the K^+ and Na^+ were determined by the use of flame photometer (Sparks, 1996). Effective cation exchange capacity (ECEC) was determined by the summation of exchangeable bases (Ca, Mg, Na, and K) and exchangeable acidity ($A1^{3+}$ and H^+). The Sulphur Availability Index (SAI) was calculated by the formula outlined by Donahue *et al.* (1977) as follows:

SAI = (0.4 × $CaCl_2$ extractable $SO4^{2-}$ in mg kg^{-1}soil) + % organic matter

Pearson correlation was carried out to determine the relationship between the measured soil properties and the Sulphur Availability Index (SAI)).

Nutrient index

To evaluate the fertility status of soils in Ilorin West, the nutrient index for organic carbon, total nitrogen, effective CEC, available phosphorus and available sulphur were calculated based on the specific rating chart (Table 2). Nutrient index values (NIV) were computed using the formula developed by Parker *et al.*, (1951) as modified by Motsara (2002).

$$\text{Nutrient index} = \frac{(L \times 1)+(M \times 2)+(H \times 3)}{Total\ number\ of\ soil\ samples}$$

where, L = No. of soil samples of low status; M = No. of soil samples of medium status and H = No. of soil samples of high status.

The results of the calculated nutrient index were thereafter classified using Table 3, which classified soils into low, medium or high according to the nutrient index values obtained.

Table 2. Rating chart for interpreting selected soil properties

Parameter	Category Rating			Source
1. Soil pH				
	Low	Medium	High	
Range	< 6.5 (Acidic)	6.5 – 7.5 (Neutral)	>7.5 (Alkaline)	Hadole *et al.*, 2020
2. Organic Carbon (OC)				
	Low	Medium	High	
Range (%)	< 1	1 – 1.5	> 1.5	Udo *et al.*, 2009
3. Available Phosphorus (AP)				
	Low	Medium	High	
Range (mg kg^{-1})	< 2.2	2.2 – 5.4	> 5.4	Ravikumar & Somashekar, 2013
4. Available Sulphur (AS)				
	Low	Medium	High	
Range (mg kg^{-1})	< 10	10 – 20	> 20	Patil *et al.*, 2019
4. Total Nitrogen (TN)				
Range (%)	< 0.15	0.15 – 0.25	> 0.25	Hazelton & Murphy, 2007
5. Cation Exchange Capacity (CEC)				
Range (%)	< 6	6 – 12	> 12	Hazelton & Murphy, 2007

Table 3. Nutrient index with range and remarks.

Nutrient index	Range	Remarks
I	Below 1.67	Low
II	1.67 – 2.33	Medium
III	Above 2.33	High

Ravikumar & Somashekar, 2013

Results and Discussion

The descriptive statistics of the measured physicochemical parameters of soils collected from the study area are presented in Table 4.

SOIL pH: The pH values ranged from 7.35 to 7.99 with a mean value of 7.73. indicating the existence of neutral to slightly alkaline soils. The soils in the study area were found to be slightly alkaline except for location D and 0 – 15 cm in Location E which were neutral. As the majority of plant nutrients are easily available in the pH range from 6 to 7, this range is often considered the most optimal for plant development.

Table 4. Descriptive statistics of the measured soil parameters

Statistical Parameters	pH	SOC	TN (%)	CEC	Avail. S	Avail. P	SAI
Minimum	7.35	0.18	0.01	0.71	1.05	0.02	0.95
Maximum	7.99	6.94	0.04	3.41	2.69	0.58	12.70
Mean	7.73	3.82	0.02	1.68	1.78	0.21	7.40
Standard Error	0.03	0.36	0.00	0.14	0.06	0.03	0.60
Median	7.76	4.69	0.02	1.56	1.75	0.17	8.78
Standard Deviation	0.18	1.99	0.01	0.74	0.31	0.16	3.28
Sample Variance	0.03	3.98	0.00	0.55	0.10	0.02	10.73
Kurtosis	-0.36	-0.79	-0.50	-0.18	2.43	0.78	-0.63
Skewness	-0.59	-0.79	0.87	0.78	0.86	1.20	-0.81

Soil Organic Carbon (SOC)

The SOC ranged from 0.18 to 6.94% with an average of 3.82% (Table 4). The SOC of the studied area was high (>1.5%) in 76.67% of the study area, but low to moderate in 20 and 3.33% of the study area, respectively (Table 5). Soil structure and soil organic matter are two of the most dynamic features that are particularly responsive to crop and soil management (Kumar *et al.*, 2013).

Total Nitrogen (TN)

TN of all the soil samples ranged from 0.01 to 0.04 % with a mean of 0.02%. All the soil samples were deficient in

TN. The soils thus need judicious application of both organic manure and nitrogenous fertilizers to meet the N requirement of crops grown in them.

Available Sulphur (AS)

AS value ranged from 1.05 to 2.69 (mean 1.783) mg kg^{-1} in the soils of the studied area and it is categorised as low. Low levels of sulphur-bearing minerals, coarse texture and soil conditions that favour sulphur leaching may contribute to the low AS levels (Patra *et al.*, 2012). It could also be related to the relatively high soil pH (Patil *et al.*, 2019), In neutral to alkaline soils, there is little adsorption of sulphur (Shahsavani *et al.*, 2006; Cui *et al.*, 2006). In sulphur-deficient areas, soil sulphur and its fractions can be an effective measure for better management practices in the future (Rai & Singh, 2018).

CEC: The ability to detain nutrients in the soil and avoid leaching them beyond roots is called cation exchange capacity (CEC). The relation between CEC and soil fertility is proportional. The higher the CEC of the soil the more fertility the soil has. (Abou Yuossef & Salah, 2020). The CEC is low (<6 cmol kg^{-1}) in all the soil samples in the study area, ranging from 0.71 to 3.41 (mean 1.684) cmol kg^{-1} (Table 3). The low CEC of the soil could be attributed to the fact that soil in this area is strongly weathered, have little or no content of weathered materials in sand and silt fractions and have predominantly kaolinite in their clay fraction (Korieocha *et al.*, 2010). Similarly, Abe *et al.*, (2010) noted that these types of findings are suggestive of characteristics that are frequently affected by soil parent materials and weathering intensity governed by rainfall (or irrigation inputs) in West African lowlands.

Available Phosphorus (AP)

AP is the second most limiting factor often affecting plant growth, which exists in the soil in both organic and inorganic forms (Ravikumar & Somashekar, 2013). In Ilorin West, the AP value ranged from 0.02 to 0.58 mg kg^{-1} with a mean of 0.208 mg kg^{-1} and thus fell into the low category. Soils with pH values between 6 and 7.5 are ideal for P availability (Thomas, 2010). Although the pH falls between the range ideal for P availability, the low AP in the studied areas could be because of low content in the parent material and the sorption of this nutrient on the mineral surface (Brady & Weil, 2013). This might also be attributed to losses associated with erosion and limited or no biomass return to the soil (Mulat *et al.*, 2021).

Nutrient Index

The nutrient index values (NIV) were calculated for the soils of Ilorin West LGA to assess its overall fertility status (Table 5). Based on the criteria given in Table 2, 90% of the soil in the study area had pH categorised as high and only 10% is categorised as medium. The NIV of pH is 2.90, which indicate that the fertility status of pH in the soil is high. For SOC, 76.67% of the soil in the study area were categorised high, 20% as low and only 3.33% as medium. The NIV of SOC is 2.57, which indicate that its fertility status is also high. The available sulphur, available phosphorus, total nitrogen and CEC were deficient in all soil of the study area. This may be attributed to the low CEC, which indicate low ability of the soil to detain nutrients and are therefore easily leached beyond the roots.

Table 5. Nutrient Index Values (NIV) for soil in Ilorin West

Parameters	Per cent samples			NIV	Remarks
	Low	Medium	High		
Soil pH	0	10	90	2.90	High
SOC (%)	20.00	3.33	76.67	2.57	High
Avail. S (mg kg^{-1})	100	0	0	1.00	Low
Avail. P (mg kg^{-1})	100	0	0	1.00	Low
Total Nitrogen	100	0	0	1.00	Low
CEC	100	0	0	1.00	Low

Sulphur Availability Index (SAI)

Sulphur is taken up by plants in the form of sulphate-S (SO_4^{2-}). Donahue *et al.*, (1977) proposed the sulphur availability index (SAI) based on the organic matter content of the soil along with sulphate sulphur (SO_4^{2-} S) content. Based on this idea, soil with sulphate content just above the critical threshold and low organic matter is not considered sufficient in available sulphur, as the low organic matter cannot adequately support the inorganic fraction if depletion occurs (Patra *et al.*, 2012).

The SAI is the key to the assessment of available S status in soils (Basumatary and Das, 2012). Based on SAI values, the soils were divided into three groups according to their level of sulphur availability: low (<6.0), medium (6.0 to 9.0), and high (>9.0). The SAI ranged from 0.95 to 12.70 with a mean of 7.40 (Table 4). Based on the values of SAI, 33.33% of soils in the study area were found to be high while only 2.67% were found to be deficient (Table 6). The medium to high SAI of the soil in Ilorin West shows that the soil has good potential to supply sulphur to plants.

Table 6. Sulphur status of Ilorin West soils based on SAI

Grade	SAI (Range)	Mean	No. Samples (%)
Low	0.95 – 4.31	2.41	2.67
Medium	6.92 – 9.04	8.40	40.00
High	9.25 – 12.70	10.19	33.33

Relationship Between Sulphur Availability Index (SAI) and Soil Properties

Correlation coefficients of SAI with some important soil parameters are presented in Table 7. The pH showed a significant negative correlation with organic carbon ($p < 0.05$). Organic matter on decomposition releases organic acids, leading to lower soil pH values. In addition, relatively high pH values accelerate the decomposition of soil organic carbon (Wang *et al.*, 2016).

The SAI had a significant positive correlation with soil OC ($p<0.01$), this indicate that as the amount of organic carbon in the soil increases, the availability of sulphur also tends to increase. The positive significant correlation observed between SAI and

SOC corresponds with the findings of Padthan *et al.*, 2016 and Jigyasu *et al.*, 2023.

The SAI had a significant negative correlation with pH ($p < 0.05$), the possible reasons for this might be because of the neutral to slightly alkaline nature of the soil in the study area. In neutral to alkaline soils, there is little adsorption of sulphur (Shahsavani *et al.*, 2006; Cui *et al.*, 2006). In a similar research by Patra *et al.*, 2012 and Padthan *et al.*, 2016, they found a significant negative correlation between SAI and pH in an acidic soil. The retention capacity of sulphate in soils decreases with increasing soil pH due to changes in the adsorption behavior of soil colloids. As soil pH increases, these colloids lose their positive charges, reducing their ability to adsorb sulphate ions. Consequently, sulphate ions remain in the soil solution rather than being adsorbed onto soil particles, leading to greater mobility and leaching of sulphate at higher pH levels (Srinivasarao, 2004).

CONCLUSIONS

Based on the results of the nutrient index, the soils of Ilorin West were characterized as high for pH and organic carbon; and deficiency in total nitrogen, CEC, available sulphur and phosphorus were observed. Most of the soil in the study area exhibited a medium (40%) to high (33.33%) SAI while only a small fraction (2.67%) of the soil samples (location A, K, L, & M) were categorised as having low SAI. The SAI of the soil in the study area had a negative correlation with pH ($p<0.05$) and a positive correlation with organic carbon ($p<0.01$). The medium to high SAI of the soil in Ilorin West shows that the soil has good potential to supply sulphur to plants, but the pH of the soil increases the mobility of sulphate in the soil and its leaching beyond the root

Table 7. Correlation matrix for the soil properties

	pH	OC	TN(%)	CEC	Avail. S	Avail. P	SAI
pH	1						
OC	-0.440*	1					
TN(%)	0.046	0.110	1				
CEC	0.136	-0.228	0.286	1			
Avail. S	-0.120	-0.255	-0.040	0.143	1		
Avail. P	-0.195	-0.186	0.253	0.145	0.025	1	
SAI	-0.425*	0.989**	0.089	-0.249	-0.252	-0.188	1

** Correlation is significant at $p < 0.01$, * Correlation is significant at $p < 0.05$

zone. Incorporation of organic matter, balanced fertilization, and precision nutrient management can improve soil structure and nutrient retention of the soil. Further research is needed to evaluate the long-term effects of sulphur management on soil health and crop productivity.

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Exchangeable Base Concentrations and Cation Exchange Capacity of Aggregate-Size Fractions of Soils Overlaying Contrasting Geologic Formations in South-East Nigeria

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ABSTRACT

Cation exchange capacity and exchangeable base cation concentrations of fine aggregate-size fractions of soils are important for the effective management of soils for optimum crop production and soil conservation. A study was carried out in 2022, using soil samples from five locations underlain by different geologic formations in Southeastern Nigeria namely; Clay Shale and Limestone (CSL); Shale and Limestone (SHL); False Bedded Sandstone Coal and Shale (FBS); Sand and Clay (SCL) and Siltstone and sandstone (SST), to assess the CEC and some exchangeable base cation concentrations of fine size fractions of soils of these areas. Thirty soil auger samples were randomly collected in three replicates at 0 – 20 and 20 – 40 cm soil depths from geologic formations. The soil samples were air-dried and sieved using 4.75- and 2-mm mesh. The wet sieving method was used in separating samples into different sieve sizes of 4.75 – 2.0, 2.0 – 1.0, 1.0 – 0.5, 0.5 – 0.25 and < 0.25 mm respectively. Results indicated that the CEC values of the fine aggregate-size fractions ranged from 7.59 to 12.79 cmol/kg in the increasing order of SHL < SST < FBS < SCL < CSL. Calcium ranged from 0.57 to 1.55 cmol/kg in the order of FBS < SST < SCL < SHL <CSL, whereas magnesium ranged from 0.41 to 1.53 cmol/kg in the order of FBS < SCL < SST < SHL < CSL. Water Stable Aggregates showed significant ($P \leq 0.05$) variation in only in the CEC. Calcium was significantly ($P \leq 0.05$) higher in topsoil than subsoil. CEC and exchangeable base were apparently higher in the macroaggregate fraction (2 mm) of the topsoil than the other fractions. Cation exchange capacity, Ca^{2+} and Mg^{2+} varied at the various geologic formations. The study therefore concludes that the geologic formations strongly influenced the CEC, Ca^{2+} and Mg^{2+} of the overlaying soils, with soils from FBS, SCL and SST having a low concentration of exchangeable Ca^{2+} and Mg^{2+} than SHL and CSL soils.

Keywords: Base cations, Cation Exchange Capacity, Aggregates, Geologic formation

INTRODUCTION

Soils generally contain the same components (mineral, organic, water and air) (Anon, 2001) but vary in their properties such as nutrient content, texture, organic matter content, pH, etc. (Effiong and Ibia, 2009; Randy and Thompson, 2006; Obasi, 2004). Afu *et al.*, (2017), reported this variability in soil properties as a function of landforms, geomorphic elements, soil forming factors and soil management. Whereas Obi and Udoh (2011) and Obi, (2015b), attributed the major changes in soil properties to pedogenesis occurring within a certain period depending on the climate, topography, vegetation and parent material of the region. In understanding changes in soil build up and development, studies on landforms (lithology and morphology) are important. Akamigbo and Asadu (1982), observed that soil geology or parent material has a very significant influence on the overlying soil when the soil is formed *in-situ* from the parent material. Soils of Southeastern Nigeria are dominated by Coastal plain sands, false bedded sandstone, clay shale and limestone, siltstone and sandstone, shale and limestone etc as the geologic formations (Orajaka, 1975). The mineralogy and geochemistry of different geological formations such as shale, sandstone, coastal plain sand etc, influence to a large extent the nature of the overlying soils (Szilas *et al.*, 2005). Parent materials have great influence on soil productivity and their ability to retain nutrients as indicated by their cation exchange capacity (Nwaoba *et al.*, 2021).

Cation exchange capacity (CEC) which is known as the exchange site (Enloe *et al.*, 2006) is a commonly used soil chemical property that describes the maximum quantity of cations a soil or substrate can hold while being exchangeable with the soil solution. Basic cations which include calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}) play an important role in the maintenance of good quality soil and sustainable crop production. Their uptakes do not depend only on their concentrations in soil but also on their ratios; although ratio changes because of many factors. Parent materials strongly influence Calcium and Magnesium concentrations via mineral weathering and soil formation processes, which subsequently affect the cation exchange capacity (CEC) and base saturation of exchange sites (Huntington *et al.* 2000; Bailey *et al.* 2004). Soil aggregate is referred to as an assemblage of two or more soil separates which more strongly cohere together than the surrounding mass (Agim *et al.*, 2019). Soil aggregation is a soil quality indicator that provides information on the soil's ability to function as a basic part of the environment and influences the transportation of liquids, gases and heat as well as physical process such as infiltration and aeration (Nimmo, 1997). Aggregate sizes vary from one another and from one soil to another in their physical and chemical properties (Ihem *et al.*, 2017). For instance; clay content, organic matter and exchangeable cations vary from one individual aggregate size fraction to another (Cambardella and Elliot, 1993; Cruvinel *et al*., 1990). Igwe (2001) observed that smaller aggregate sizes were more enriched with soil organic carbon.

There is a knowledge gap in information relating to some exchangeable base cations and Cation Exchange Capacity concentration of aggregate-size fraction of soils on selected geologic formations in Southeastern Nigeria. Based on the above, the major objective of this work is to study the Exchangeable base concentrations and Cation Exchange Capacity of aggregate-size fractions of soils overlaying contrasting geologic formations in Southeastern Nigeria. The specific objectives were to (i) determine the calcium and magnesium concentrations and cation exchange capacity at the geologic formations and aggregate-size fractions, (ii) study the effects of soil depths on the calcium and magnesium concentrations and cation exchange capacity at the contrasting geologic formations, (iii) compare the values of cation exchange capacity, calcium and magnesium of the aggregate-size fractions at the top soil and subsoil; and (iv) recommend soil management options for increased agricultural productivity.

MATERIALS AND METHODS

Site Description

The study area, southeastern Nigeria lies between latitudes 04°75' and 07°00'N and longitudes 05°34' and 09°24'E (Unama *et al.,* 2000). It is made up of Abia, Akwa Ibom, Anambra, Cross River, Ebonyi, Enugu, Imo, and River States and occupies a land mass of about 12% of the total land area of Nigeria (Odurukwe *et al.,* 1995). It covers an area of about 37,845km^2 land mass with 60% of this area covered by the tropical rainforest (Njoku *et al.,* 2006). The climate is essentially humid Tropical with an annual rainfall total not exceeding 3500 mm (Njoku *et al.,* 2006). The area is characterized by bimodal rainfall pattern. There are two marked seasons in the study area: the wet and the dry seasons. The wet season begins in late April and lasts, till October with heavy rainfalls recorded in the months of June, July and September. There is usually a decline in rainfall in August. This is usually referred to as "August break" (Obasi *et al.,* 2015). The current mean maximum temperature of the area is 32°C while the mean minimum is 21°C, and a relatively high mean annual relative humidity, exceeding 75% (Njoku *et al.,* 2006). Akamigbo and Asadu (1982), described the topography of the entire area as generally gently undulating. Agriculture and cottage industries are major socio-economic activities in the study area. Crops mostly cultivated in the study area include; *Elaeis guineensis, Irvingia spp; Cocus nucifera, Panraclethra spp, Theobroma Coaco, Edulis spp, Raphia* spp, and *Citrus* spp, *Oryza sativa, Zea mays, Discorea spp, Colocasia esculenta, Manihot spp, Vigna unguiculata, Arachis hypogeae* and *Cajanus cajan* (Onweremadu *et al*., 2011).

Soil Sampling

Five parent materials from five locations in Southeastern Nigeria were selected for the study, which was conducted in 2022. Geologic map of the area (Figure 1) was used to guide the location of the sampling areas based on their lithologies. The parent materials were Clay shale and limestone (Adani), False bedded sandstone coal and shale (Enugu-ezike), Shale and limestone (Mgbowo), Sand and clay (Obinze), then lastly, Siltstone and sandstone (Oko). Differences in geologic formations guided the choice of the different locations. Soil samples were collected at random using a soil auger at a depth of 0-20 cm and 20-40 cm from each sampling point and the geographical coordinates of the sampling sites were geo-referenced with the use of a hand-held Global Positioning System (GPS) receiver, these depths were adopted to determine the concentration of exchangeable cations and CEC between the surface soil (0-20 cm) and the sub surface soil (20-40 cm). This was done in three replicates from each location. In each of the geologic formations, six soil samples were collected, thus a total of thirty soil samples were generated for the study. The thirty soil samples generated from the field were air-dried at room temperature, crushed and sieved through a 4.75 mm and 2 mm sieve. The two set of sieves used was to obtain aggregates.

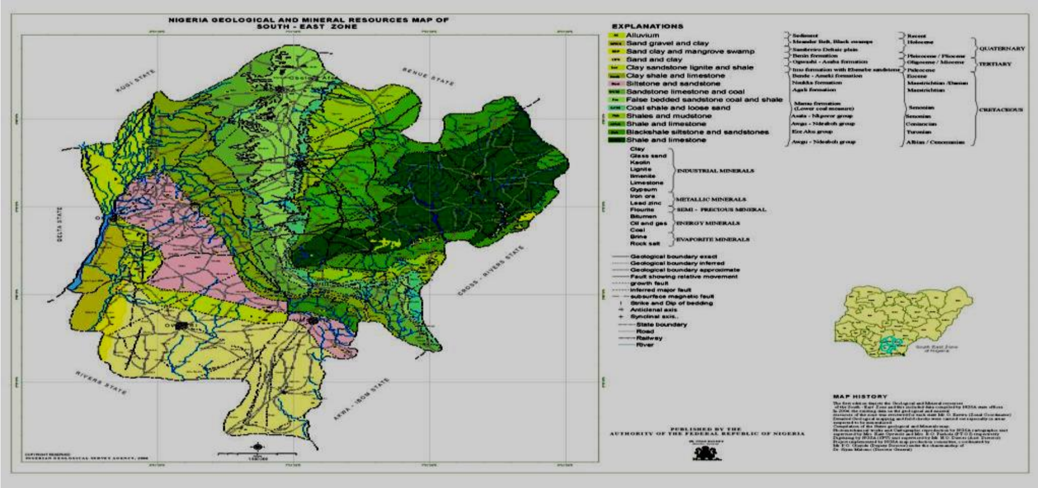

Figure 1: Nigeria Geological and Mineral Resources Map of South-East Zone

Separation of Aggregate-size Fractions by Wet sieving method

The separation of aggregate-size fractions was carried out using the aggregate machine, where 200 g of the sieved aggregate sample were put in the topmost of a nest of four sieves of 2.0, 1.0, 0.5, and 0.25 mm mesh size and pre-soaked for 5 minutes in the aggregate machine containing water. Thereafter, the nest of sieves and its contents were oscillated vertically in water for 35 times using 4 cm amplitude, at the rate of one oscillation per second. This process was carried out simultaneously for all thirty samples. The water in the aggregate machine was changed after each sample, this is because the <0.25 mm particle size separates always mix together with the water in the machine, which are later collected after settling at the bottom of the machine. After wet sieving, the resistant soil materials on each sieve including the <0.25mm soil size separate were transferred into small containers, properly labeled and air dried at room temperature for 72 hours.

Laboratory Methods

Cation exchange capacity was determined in each aggregate size fraction obtained through wet sieving by ammonium acetate method at a pH 7 (Soil Survey Staff, 2003). After leaching the soils with 1N ammonium acetate solution, exchangeable Calcium and Magnesium were equally determined in each of the aggregate size fractions using ethylene diamine tetra-acetic acid (EDTA) by the complexometric method (Jackson, 1958).

Data Analyses

Data were analysed with analysis of variance ANOVA. Significant means were separated using least significant difference (LSD) at 5% probability.

RESULTS AND DISCUSSION

Mean Values of Exchangeable Calcium and Magnesium and Cation Exchange Capacity of the Soils Overlaying the Geologic Formations

The results of the mean values of exchangeable calciun and magnesium, and Cation Exchange Capacity of the soils overlaying the geologic formations are presented in Table 1. The mean values of the exchangeable calcium and magnesium concentration across the geologic formations ranged from 0.57 cmol/Kg – 1.55 cmol/Kg for exchangeable calcium and 0.41 cmol/Kg

– 1.53 cmol/Kg for exchangeable magnesium. These values of exchangeable Ca^{2+} were less than 2 cmol/Kg critical level recommended by Esu (1991), hence it was considered low. This low level of the exchangeable calcium in all the geologic formations most especially in False bedded sandstone (0.57 cmol/Kg) and Siltstone and sandstone soils (0.80 cmol/Kg) was typical of the report of Onweremadu *et al.*, (2011) which reported low exchangeable calcium in soils of Southeastern Nigeria and attributed the low results to the sandiness of the soils which encourages leaching of calcium. Clay shale and limestone soils had a significant higher ($p<0.05$) value (1.55cmol/Kg) of exchangeable calcium which could be attributable to higher clay content of the soil and also to the composition of the materials from which soil is formed. Exchangeable magnesium concentration means values ranged from 0.41 cmol/Kg (False Bedded Sandstone, Coal and Shale) – 1.53 cmol/Kg (Clay shale and limestone) with the trend as (CSL> SHL> SST> SCL> FBS) was rated medium to high according to critical limit also recommended by Esu, (1991). Higher values were obtained in soils developed from Clay Shale and Limestone, and Shale and Limestone. Afu *et al.*, (2017) reported high values of exchangeable Mg^{2+} in soils developed from Limestone in Southeastern Nigeria. This could be attributed to the influence of the parent material. Cation Exchange Capacity (CEC) of the soils overlaying the geologic formations which showed a significant ($p<0.05$) relationship was higher in Clay shale and Limestone soils (12.79 cmol/Kg), attributable to higher clay content of the soils followed by Sand and Clay soils (12.16 cmol/Kg), False Bedded Sandstones soils (11.15 cmol/Kg), Siltstone and Sandstone soils (8.34 cmol/Kg) and Shale and Limestone soils (7.59 cmol/Kg). These mean values are medium to high compared with the critical limit (6 - >12 cmol/Kg) recommended by Esu (1991) for arable crop production.

Table 1: Mean Values of Exchangeable Calcium and Magnesium and Cation Exchange Capacity of the Soils Overlaying the Geologic Formations

Geologic Formation	Locations	Ca^{2+} (cmol/Kg)	Mg^{2+} (cmol/Kg)	CEC (cmol/Kg)
Clay Shale and Limestone (CSL)	Adani	1.55	1.53	12.79
False Bedded Sandstone Coal and Shale (FBS)	Enugu-ezike	0.55	0.41	11.15
Shale and Limestone (SHL)	Mgbowo	0.91	1.14	7.59
Sand and Clay (SCL)	Obinze	0.89	0.71	12.16
Siltstone and sandstone (SST)	Oko	0.80	0.86	8.34
	LSD (≤0.05)	0.237	0.547	1.860

Ca^{2+} = Exchangeable calcium, Mg^{2+} = Exchangeable magnesium, CEC = Cation Exchange Capacity, LSD= Levels of significant difference.

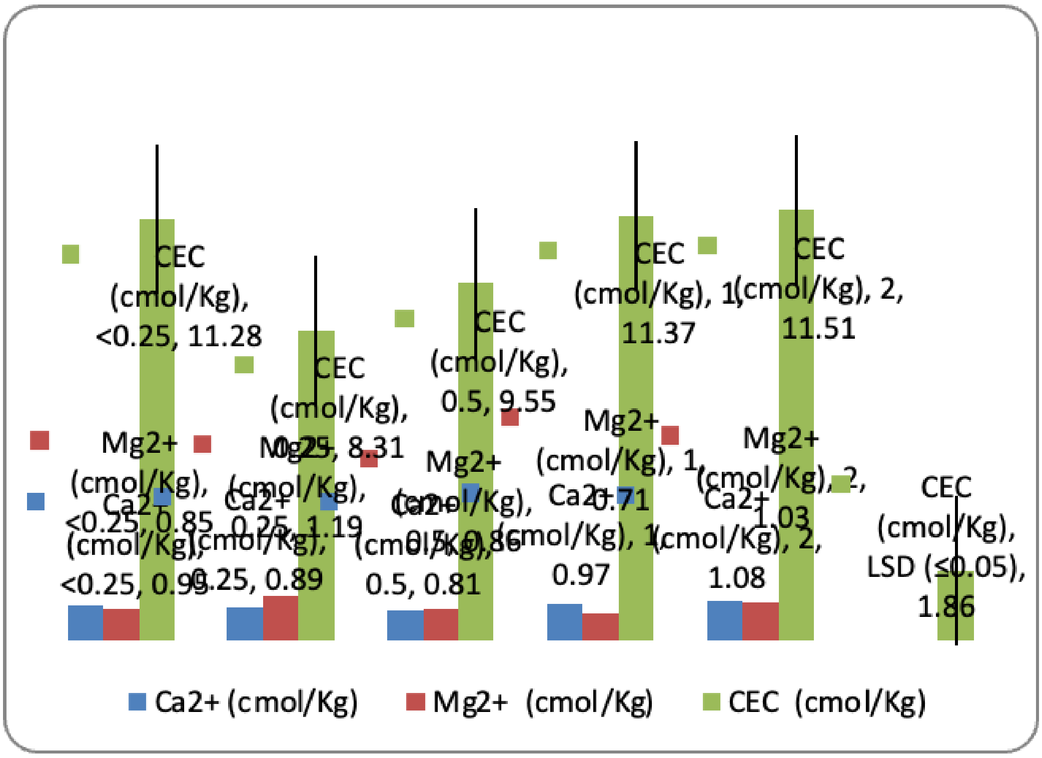

Fig 1: Graphical Representation of Concentration of Exchangeable Calcium and Magnesium, and Cation Exchange Capacity of the Various Aggregate size Fractions across the Geologic Formations

Exchangeable Calcium and Magnesium Concentrations, and Cation Exchange Capacity of the various Aggregate-size Fractions across the Geologic Formations

Across the geologic formations (Fig. 1), the exchangeable Ca^{2+} recorded mean of (1.08, 0.97, 0.81, 0.89, 0.95) cmol/Kg in aggregate-size fractions of (2.0, 1.0, 0.5, 0.25, <0.25) mm respectively and exchangeable Mg^{2+} recorded mean of (1.03, 0.71, 0.86, 1.19, 0.85) cmol/Kg in aggregate-size fractions of (2.0, 1.0, 0.5, 0.25, <0.25) mm respectively. Generally, exchangeable Ca^{2+} was low and Exchangeable Mg^{2+} was moderate (Esu, 1991). The low and moderate levels of calcium and magnesium concentration at the aggregate sizes are dependent on the nature of parent materials and the extent of weathering (Osujieke *et al.*, 2018). The concentration of exchangeable calcium was lower in the clay fraction than in the coarser fraction. The result obtained is similar to those of Hendrick and Ogg (1916); and Kaila and Ryti (1968). The three English soils analysed by Hall and Russell (1911), fifteen soils of Southeastern Nigeria by Igwe and Nkemakosi (2007) and in ten American soils by Brown and Byers (1932) indicated that the concentration of exchangeable calcium was higher in the clay fraction and in the finer silt material. This difference may be attributed to differences in the mineralogical composition and in the stage of weathering of the mineral material and locations (Kaila and Ryti, 1968). Exchangeable magnesium on the other hand appears to be at its highest in the silt and clay fraction. Igwe and Nkemakosi, (2007) observed a similar result; exchangeable Mg^{2+} was high in the clay fraction of soils and less in coarser material. The cation exchange capacity concentration was high on the coarser fraction and clay fractions across the geologic formations. The CEC of the aggregate-size fractions was generally moderate (Esu, 1991). Akamigbo and Igwe (1990), Igwe *et al.*, (1999) have reported these soils to have low to moderate CEC in the fine-earth fraction. Caravaca, F. *et al.*, (1999) reported that the CEC concentration in clay size fraction, on average was four times greater than that of fine silt size fraction. The CEC concentration of the studied soils been high on coarse fraction could be attributed to nature of the parent material and its low content of silt due to rate of weathering. Ojanuga *et al*. (1981), emphasized that soils of Southeastern Nigeria formed on unconsolidated coastal plain sands are characterized by the dominance of sand-textured fragments comprising larger quantities of coarse over fine textured materials. Akamigbo (1984), asserted that soils of Southeastern Nigeria are low in silt as a result of the high degree and extent of weathering and leaching they have undergone.

The mean values of Exchangeable Calcium and Magnesium Concentrations, and Cation Exchange Capacity of the Two Soil Depths across the Geologic Formations

The mean values of Exchangeable Calcium and Magnesium Concentrations, and Cation Exchange Capacity of the Two Soil Depths across the Geologic Formations presented in Fig. 2 shows that across the geologic formations, exchangeable calcium concentration was low, exchangeable Magnesium and CEC concentration were medium in topsoil and subsoil. However, the mean values of the exchangeable calcium (1.06 cmol/Kg), magnesium (0.92 cmol/Kg) and CEC (10.74 cmol/Kg) concentrations across the geologic formations were higher in the topsoil and it decreased with depth. Similarly, Afu *et al.*, (2017) and Okoli *et al.*, (2016) reported the distribution of exchangeable cations and CEC to be higher at the soil surface and again at a lower depth. They attributed this higher concentration of exchangeable calcium, magnesium and CEC to high organic matter content of the surface horizon.

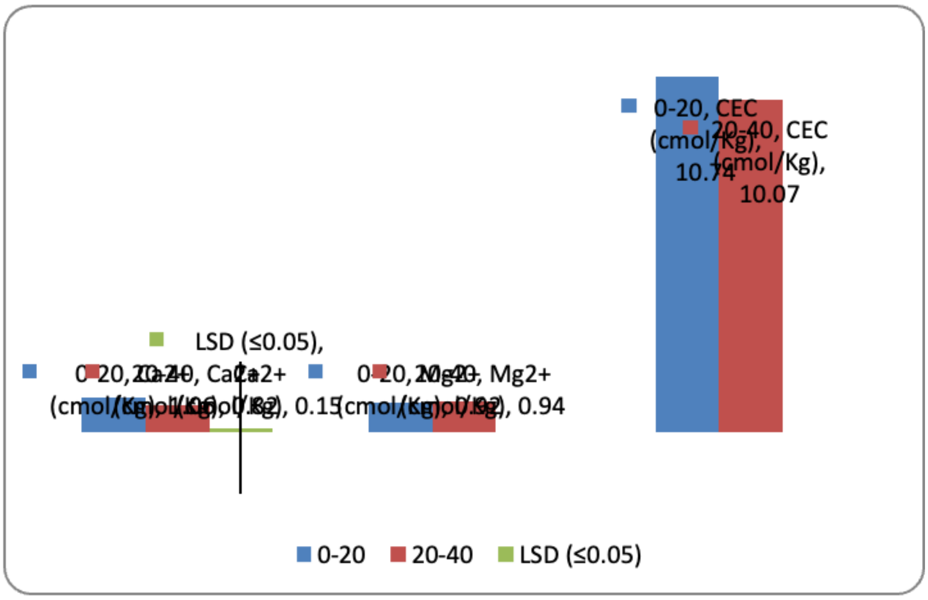

Fig 2: Graphical Representation of the Mean Values of Exchangeable Calcium and Magnesium Concentrations, and

Cation Exchange
Capacity of the Two Soil Depths across the Geologic Formations

Table 2: Concentration of Exchangeable Calcium and Magnesium, and Cation Exchange Capacity at the Geologic Formations and among the various Aggregate-size Fractions

Geologic Formations	Locations	ASF (mm)	Ca^{2+} (cmol/Kg)	Mg^{2+} (cmol/Kg)	CEC (cmol/Kg)
Clay Shale and Limestone (CSL)	Adani	<0.25	1.30	1.23	10.60
		0.25	1.47	1.57	12.40
		0.50	1.67	1.90	14.60
		1.00	1.97	1.70	13.20
		2.00	1.37	1.27	13.13
False Bedded Sandstone Coal and Shale (FBS)	Enugu-ezike	<0.25	0.70	0.43	12.20
		0.25	0.53	0.47	7.27
		0.50	0.43	0.33	9.20
		1.00	0.50	0.27	14.40
		2.00	0.57	0.53	12.67
Shale and Limestone (SHL)	Mgbowo	<0.25	0.73	1.23	7.87
		0.25	0.90	1.50	6.40
		0.50	0.90	1.00	6.40
		1.00	1.00	0.70	10.47
		2.00	1.03	1.27	6.80
Sand and Clay (SCL)	Obinze	<0.25	0.93	0.47	14.93
		0.25	0.80	1.90	9.93
		0.50	0.57	0.40	9.47
		1.00	0.73	0.33	10.00
		2.00	1.40	0.47	16.47
Siltstone and sandstone (SST)	Oko	<0.25	1.07	0.90	10.80
		0.25	0.77	0.53	5.53
		0.50	0.47	0.67	8.07
		1.00	0.67	0.57	8.80
		2.00	1.01	1.61	8.50
		LSD (≤0.05)	NS	NS	4.158

ASF= Aggregate-size fraction, Ca^{2+}= Exchangeable calcium, Mg^{2+}= Exchangeable magnesium, CEC= Cation Exchange Capacity, LSD= Levels of significant difference, NS= Not Significant

Concentration of Exchangeable Calcium and Magnesium, and Cation Exchange Capacity at the Geologic Formations and among the Various Aggregate-size Fractions

As shown in Table 2, only soils from False bedded sandstone Coal and Shale in Enugu-ezike had concentration of exchangeable calcium higher in clay fractions, the rest had higher concentration of exchangeable calcium in coarser fractions. Kaila and Ryti, (1968) observed this to be as a result of differences in the mineralogical composition and in the stage of weathering of the mineral material and locations. However, soils from CSL, SHL and SCL geologic formations had higher concentration of exchangeable magnesium in their fine silt size fractions whereas soils of Enugu-ezike and Oko formed from FBS and SST respectively had higher concentration of exchangeable magnesium in their coarser fraction. This could be attributed the differences in the mineralogical compositions of the parent materials (Mastalerz *et al.*, 2005).

The Cation Exchange capacity concentrations of soils developed from CSL, FBS SHL and SCL were higher on coarse fractions. Interestingly, Siltstone and Sandstone soils had higher CEC concentrations on the clay size fraction. These differences in the CEC concentration on the aggregate-sizes of these soils could be attributed to the influence of parent materials on the soil properties (Ritter, 2006). According to Esu (2005), the soil properties so influenced are nutrient content, particle size, colour and structure.

Table 3: Concentration of Exchangeable Calcium and Magnesium, and Cation Exchange Capacity of the Soils Overlaying the Geologic Formations at the Two Soil Depths

Geologic Formations	Locations	Soil Depth (cm)	Ca^{2+} (cmol/Kg)	Mg^{2+} (cmol/Kg)	CEC (cmol/Kg)
Clay Shale and Limestone (CSL)	Adani	0-20	1.96	1.52	12.19
		20-40	1.15	1.55	13.39
False Bedded Sandstone Coal and Shale (FBS)	Enugu-ezike	0-20	0.59	0.43	12.13
		20-40	0.51	0.39	10.16
Shale and Limestone (SHL)	Mgbowo	0-20	0.80	0.96	7.17
		20-40	1.03	1.32	8.00
Sand and Clay (SCL)	Obinze	0-20	1.07	0.97	13.31
		20-40	0.71	0.45	11.01
Siltstone and sandstone (SST)	Oko	0-20	0.88	0.73	8.88
		20-40	0.71	0.98	7.80
		LSD (≤ 0.05)	0.335	NS	NS

Ca^{2+}= Exchangeable calcium, Mg^{2+}= Exchangeable magnesium, CEC= Cation Exchange Capacity, 0-20cm= Topsoil, 20-40cm= Subsoil, LSD= Levels of significant difference, NS= Not Significant.

Concentration of Exchangeable Calcium and Magnesium, and Cation Exchange Capacity of the Soils Overlaying the Geologic Formations at the Two Soil Depths

Soils derived from CSL, FBS, SCL and SST as indicated in Table 3 had a significantly ($p<0.05$) higher concentration of Exchangeable calcium on the topsoil. This could be attributed to high organic matter content on the surface horizon in these locations as earlier stated. This higher concentration of exchangeable calcium on the topsoil contrasted in soils from SHL which recorded higher concentration of exchangeable calcium on the subsoil and this can be attributable to leaching due to high rainfall (Madueke *et al.*, 2020). Interestingly, (although with the exception of FBS and SCL soils); Soils developed from CSL, SHL and SST had higher concentration of exchangeable magnesium on the subsoil. This finding is in trend with the work carried out by Tennakoon (2003) and Kamaljit *et al.*, (2005) which reported high amount of exchangeable magnesium in higher depths. Kamaljit (2005) concluded that the variability in concentration of nutrients may have been as a result of extent of weathering across depths and other biophysical and chemical activities which vary with locations. Almost all the soils from the contrasting geologic formations had higher CEC concentration on the topsoil with the exception of soils from Adani and Mgbowo which are formed from Limestone. These soils had higher CEC concentration on the subsoil and it can be attributed to illuviation and thus signifying the possibility of lateral movement of nutrient element from topsoil to subsoil (Lawal *et al.*, 2013).

Concentration of Exchangeable Calcium and Magnesium, and Cation Exchange Capacity between the Two Soil Depths and among the Aggregate-size Fractions

The trend observed in the profile distribution of exchangeable calcium and magnesium among the aggregate-size fractions across the geologic formations as presented in Fig. 3 was Ca^{2+} > Mg^{2+} with the exception of the subsoil, where the mean Mg^{2+} values tended to be marginally higher than Ca^{2+} in mostly the coarse and fine silt size fractions. Enloe *et al.*, (2006), however stated that Ca^{2+} dominate the exchange site with Mg^{2+}, K^{+}, $NH3^{+}$ and Na^{+} having lower concentrations. The anomaly observed in the trend was probably as a result of high concentration of Mg^{2+} in the profile of some geologic formations like CSL, SHL and SCL which may be attributed to pedoturbation due to the influence of topography (erosional/ depositional) and probably formation of texture contrast soils (Phillips, 2007) that could have mineralogical implications. Irrespective of the aggregate-size fractions, the CEC concentration of these studied geologic formations was higher in the topsoil. This could be due to accumulation of organic matter on the surface horizon.

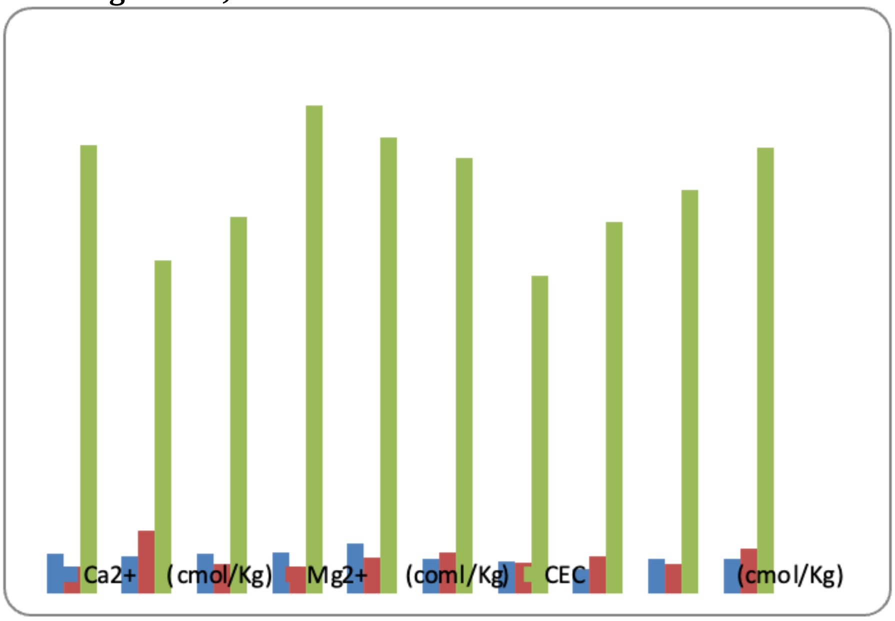

Fig 3: Graphical Representation of the Concentration of Exchangeable Calcium and Magnesium, and Cation Exchange Capacity between the Two Soil Depths and among the Aggregate-size Fractions

Table 4: Interaction between Geologic Formations, Locations and Soil Depth on the Exchangeable Calcium and Magnesium, and Cation Exchange Capacity at the Aggregate-size Fractions

Geologic Formations	Locations	Soil Depth (cm)	ASF (mm)	Ca^{2+} (cmol/Kg)	Mg^{2+} (cmol/Kg)	CEC (cmol/Kg)
Clay Shale and Limestone (CSL)	Adani	0-20	<0.25	1.40	1.13	9.60
			0.25	2.00	1.40	12.93
			0.50	2.40	1.80	13.60
			1.00	2.20	1.80	12.13
			2.00	1.80	1.47	12.67
		20-40	<0.25	1.20	1.33	11.60
			0.25	0.93	1.73	11.87
			0.50	0.93	2.00	15.60
			1.00	1.73	1.60	14.27
			2.00	0.93	1.07	13.60
False Bedded Sandstone Coal and Shale (FBS)	Enugu-ezike	0-20	<0.25	0.80	0.47	12.80
			0.25	0.47	0.53	7.73
			0.50	0.47	0.40	6.93
			1.00	0.53	0.27	20.13
			2.00	0.67	0.47	13.07
		20-40	<0.25	0.60	0.40	11.60
			0.25	0.60	0.40	6.80
			0.50	0.40	0.27	11.47
			1.00	0.47	0.27	8.67
			2.00	0.47	0.60	12.27
Shale and Limestone (SHL)	Mgbowo	0-20	<0.25	0.53	0.33	7.73
			0.25	0.73	2.20	5.87
			0.50	0.93	0.73	6.67
			1.00	0.87	0.33	9.33
			2.00	0.93	0.67	6.27
		20-40	<0.25	0.93	2.13	8.00
			0.25	1.07	0.80	6.93
			0.50	0.87	1.27	6.13
			1.00	1.13	1.07	11.60
			2.00	1.13	1.33	7.33
Sand and Clay (SCL)	Obinze	0-20	<0.25	1.13	0.33	14.67
			0.25	0.93	3.27	11.07
			0.50	0.67	0.27	10.80
			1.00	0.87	0.33	13.07
			2.00	1.73	0.67	16.93
		20-40	<0.25	0.73	0.60	15.20
			0.25	0.67	0.53	8.80
			0.50	0.47	0.53	8.13
			1.00	0.60	0.33	6.93
			2.00	1.07	0.27	16.00
Siltstone and Sandstone (SST)	Oko	0-20	<0.25	1.20	1.07	12.40
			0.25	0.67	0.60	4.93
			0.50	0.53	0.60	10.13
			1.00	0.80	0.67	7.60
			2.00	1.20	0.73	9.33
		20-40	<0.25	0.93	0.73	9.20
			0.25	0.87	0.47	6.13
			0.50	0.40	0.73	6.00
			1.00	0.53	0.47	10.00
			2.00	0.83	2.49	7.66
			LSD($\leq$0.05)	NS	NS	NS

0-20cm= Topsoil, 20-40cm= Subsoil, ASF= Aggregate-size fraction, Ca^{2+}= Exchangeable calcium, Mg^{2+}= Exchangeable magnesium, CEC= Cation Exchange Capacity, LSD= Levels of significant difference; NS= Not Significant.

Interaction between Geologic Formations, Locations and Soil Depth on the Exchangeable Calcium and Magnesium, and Cation Exchange Capacity at the Aggregate-size Fractions

Table 4 shows no significant ($p<0.05$) relationship observed across the geologic formations, locations and soil depth on the exchangeable calcium and magnesium, and Cation Exchange Capacity at the aggregate-size fractions. However, Significant relationship between geologic material and soil texture, soil reaction, total exchangeable bases, total acidity, soil depth, colour, profile drainage and gravel content have earlier been reported (Akamigbo and Asadu, 1982; Esu, 2010). This could be as a result of difference in location, origin and mineralogical composition of the parent materials.

CONCLUSION

In conclusion, results showed that variations occur in the exchangeable cations and Cation Exchange Capacity across geologic formations and aggregate size fractions. Soils from the contrasting geologic formations in Southeastern Nigeria had low concentration of exchangeable calcium and medium to high concentration of both exchangeable magnesium and CEC. However, there were appreciably more exchangeable calcium and magnesium, and CEC in the topsoil than in the subsoil, with exchangeable calcium showing a significant ($P < 0.05$) higher value between the topsoil and the subsoil across the geologic formations. Also, more CEC, exchangeable calcium and magnesium were in the 2.0 mm aggregate-size fractions when compared to other fractions, with Cation Exchange Capacity having a significant ($P < 0.05$) higher value among the various aggregate-size fractions. The impact of parent material was clear. Soils derived from FBS, SCL and SST had low concentration of exchangeable calcium and magnesium than SHL and SHL soils. Furthermore, soils from CSL and SHL had high accumulation of Mg^{2+} which could deteriorate soil structure due to the nature of their parent material. The mineral weathering, mineralogical compositions and stage of weathering of the geologic material in the study locations influenced the exchangeable base concentrations and CEC at the soil depth and aggregate size fractions. Geologic materials have a strong controlling influence on exchangeable calcium and magnesium concentration on the soils. Soil management practices should differ based on the geologic formations the soils are derived from.

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Assessment of Microbial Diversity in Soil Contaminated with Xenobiotic Compound in Ajaokuta Kogi State

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ABSTRACT

The work aimed at assessing the effect of xenobiotic chemicals on soil microbial diversity in Ajaokuta, Kogi State. The effect of xenobiotic was assessed soils collected from industrial, arable and fallowed lands at 0 – 15 cm and 15 – 30 cm depths using standard methods. The result of microbial count showed that at both depths, fallowed land had the highest bacterial counts of 5.25×10^{11} and 8.5×10^{8} cfu/g respectively; while soil under industrial and arable lands had the lowest bacterial counts of 3.35×10^{11} and 1.65×10^{4} cfu/g respectively. Fungal counts were recorded highest at both depths on fallowed land 8.5×10^{8} and 1.8×10^{5} cfu/g respectively; while soil under industrial land had the lowest fungal counts of $4.15 \times 10^{4}$and 1.2×10^{2} cfu/g respectively. Result of the microbial isolate shows that at 0 – 15 cm depth, six (6) different species of bacteria (Bacillus, Pseudomonas, Clasdoporium, Micrococcus, Enterococcus and Nocardia) and five (5) species of fungi (Aspergillus, Alternaria, Fusarium, Clasdoporium and Penicillium) were isolated. At 15 – 30 cm depth, four (4) species of bacteria (Bacillus, Pseudomonas, Micrococcus and Enterococcus) and five (5) species of fungi (Aspergillus, Alternaria, Fusarium, Clasdoporium and Penicillium) were isolated. This study reveals higher microbial count in fallowed land at both depths compared to industrial and arable lands indicating gross impact of xenobiotics in the ecosystem. Although there was more fungal diversity at the subsurface of industrial land, more microbial diversity occurred at the surface of the soils. Studies on the biodegradability of xenobiotic by these identified microbes are encouraged.

KEYWORDS: Xenobiotic, Ecosystem, Microbial Diversity, Microbial Population

1.0 Introduction

The environment certainly surrounds everything and has a daily impact on our existence on the land. A harmless and healthy environment is vital for survival on earth. Nevertheless, in the time of innovative industrial development and expansion, various human caused actions are mostly accountable for the introduction of toxic and dangerous contaminants such as environmental xenobiotics (Embrandiri *et al*., 2016; Malla *et al.*, 2018; Bhatt *et al*., 2020; Rodriguez *et al*., 2020). Industrial development and rigorous farming actions as a result of increase in world populace has led to group of a vast number of contaminants called xenobiotics. Past scientists have stated that, xenobiotic substances have been introduced into the environment as a result of industrial and agricultural activities that obligate the use of intensive organic, inorganic *a*nd harmful compound (Ecobichon, 2001; Bleise *et al.*, 2003; Pirrone *et al.*, 2010). Xenobiotics are chemical elements not obviously formed or likely to be existing within organisms. The term "xenobiotic" is usually used in the context of ecological impurities refer to artificial compounds formed in huge volumes for industrial, farming and domestic use (Embrandiri *et* *al*., 2016; Atashgahi *et al*., 2018; Dinka, 2018). Barbara *et al.* (2009) also defined it as both organic and inorganic anthropogenic compounds that are introduced into the environment at concentrations that cause unwanted properties, which are extraneous to the land.

Due to continuous use of organic, inorganic chemical and harmful compounds in considerable quantities, xenobiotic chemicals and their degraded products may accumulate in the soil environment. Understanding microbial ecology in the xenobiotic environment is significant because soil microorganisms play a serious role in soil functioning. Soil microorganisms mostly bacteria, fungi, algae and protozoa have contributed to soil fertility through their primary catabolic role in the degradation of xenobiotic chemical in the cycling of the organic and inorganic nutrients content of soil (Barbara *et al.,* 2009). Microorganisms are universal in nature, and various microbial communities thrive in natural and extreme stress environments, including soil, water, the human gut, hydrothermal vents, acid mine runoff, and oil reservoirs (Cycon and Piotrowska-Seget, 2016; Jalowiecki *et al*., 2016; Ding *et al*., 2017; Aguinga *et al.*, 2018; Wang Y. F. *et al*., 2018; Zierer *et al*., 2018; Delegan *et al*., 2019; Arora, 2020; Shekhar *et al*., 2020). Furthermore, the scientific community's ability to disseminate knowledge about the uncultivated microbial world has reached a new limit due to the direct study of microorganisms in a contaminated environment, including the entire microbial population (Zepeda *et al*., 2015; Zhao *et al*., 2017; Panigrahi *et al*., 2019; Yan *et al*., 2020).

According to Gianfreda and Rao (2008), microbial diversity is important because soil microorganisms play a critical role in soil functioning, soil health restoration, maintenance of basic resources for food production and terrestrial biodiversity maintenance. More so, microorganism plays a crucial role in metabolizing recalcitrant xenobiotic compounds e.g. pesticides, and thus is essential in global processes contributing to the health and life cycles of plants and animals (Gianfreda and Rao, 2008). Previous report by Gianfreda and Rao (2008) has stated the essential roles of microorganism in biogeochemical cycles (e.g., carbon and nitrogen) and changes in their community composition or activities may affect the availability of essential nutrients, thus affecting soil functions. Studies have reported that, xenobiotic-induced stress on dynamics of the soil microbe by eliminating sensitive soil microbial population (Giller *et al.,* 1998; Gianfreda and Rao, 2008). Furthermore, studies have shown that, xenobiotics may interact with the soil and its indigenous microorganisms by altering microbial diversity and community composition, through this influence biochemical reactions and enzymatic activity in the soil, ultimately ecosystem functions and services (Hussain *et al.*, 2009; Muñoz-Leoz *et al.*, 2011)

In recent times attention has been directed to study the soil physical and chemical properties, which are soil quality. The soil quality is not only link to physical and chemical properties of soil but closely linked to the soil microbiological properties because microorganisms are vital for soil fertility and for the degradation of organic matter and pollutants in soils. The xenobiotic contamination in the environment and soil microorganism has been assumed great importance and of environmental concern. Therefore, this study aimed to study the effects of xenobiotic chemical on soil microbial diversity in Ajaokuta, Kogi State.

2.0. Materials and Methods

2.1. Site Location and Description

Ajaokuta is located in Ogura village near Nigeria bridge Ajaokuta, absolutely located between Latitude 7°44'N to 7°52'N and longitude 6°40'E to 6°45'E and covering an area of 1.362 sq.km. The climate of Ajaokuta is classified under the tropical savanna type and the Koppen AW climate group. There are two main season that characterize the area; the wet and dry season. The wet season starts from May to November and the dry season from November to April. The mean annual temperature is 27°C. The lowest temperature occurs between December to February which ranges between 21.50°C to 24.8°C while the highest temperature occurs between April and May and it ranges between 26°C to 38°C. The total averaged rainfall received in the area is between 1,250 to 2,500 mm. Ajaokuta vegetation is characterized by derived savannah, riparian vegetation and Aquatic evergreen. Ajaokuta has tall trees with broad leaves; the trees are scattered and deciduous. Most of the trees are economic trees. The economic trees found are cashew (*Anarcardin - accidentalis*), mango (*Magnifera indica*), mahogany, locus beans and palm trees (Tokula and Eneche, 2018).

2.2 Sample Collection

Using disinfected soil auger, 6 soil samples were collected from three (3) different lands (i.e. industrial, arable and fallowed) at 0 – 15 and 15 – 30 cm; composite samples were taken from each land for microbial analysis. Industrial land has been contaminated with xenophobic from the ceramic and other industries while arable land has been contaminated with xenobiotic from agricultural pesticides. Fallowed land is situated 10 km away from the industrial area and presumed to not have received any dose xenobiotic.

2.3 Sample preparation

Ten gram (10 g) of each soil sample was weighed into a sterile 250-ml Erlenmeyer flask, serially diluted (ten-fold dilution) until a dilution 10^{-10} was obtained. Diluted 10^{-3} was used as inoculum for fungi isolation, while dilution 10^{-10} was used as inoculum for isolation of bacteria.

2.4 Preparation of Media

2.5.1 Nutrient Agar and Saboraud Dextrose Agar

Two media were used for the analyses. Nutrient agar (NA) and Saboraud Dextrose agar (SDA) for bacteria and fungi isolation respectively. They were both prepared according to manufacturer's specification. Ten percent (10%) lactic acid was added to the SDA after sterilization for the inhibition of bacteria growth.

2.5.2 Inoculation of Media

The pour plate technique of inoculation was adopted. One ml (1 ml) of each sample was introduced into sterile petri dishes. Duplicate plates were prepared. Cool molten medium (about 20 ml) was added to the petri dish containing the inoculum. The plates were switched gently to properly mix the medium and were allowed to solidify. The incubation of the NA plates was done for 24 hours at 35°C and SDA plates at 28°C to 72 hours.

Microbial count: colonies grouping on the plate were compared after incubation and recorded as colony forming units per (cfu/g)

2.5.3 Observation and Identification of Isolation:

This was carried out as described by Cheesebrugh (2000) and Ogbo (2005).

3.0 Results and Discussion

3.1 Results

3.1.1 Microbial Population Under Different Land Use Type

Table 1 shows the microbial population (bacteria and fungi) at 0 – 15 cm and 15 – 30 cm depths of the soil across the different lands. At 0 – 15 cm depth, soil under fallow land had the highest bacterial count (5.25×10^{11} cfu/g) while the soil under industrial land had the lowest bacterial count (3.35×10^{7} cfu/g). At 15 – 30 cm depth, fallow land had the highest bacterial count (7.50×10^{7} cfu/g) while arable land had the lowest bacterial count (1.65×10^{4} cfu/g). At 0 – 15 and 15 – 30 cm depths, soil under fallow land had the highest fungal count at both depths (8.5×10^{8} and 1.8×10^{5} cfu/g).

3.1.2 Microbial Isolates

Table 2 and 3 shows the microbial isolate (bacteria and fungi) at 0 – 15 cm and 15 – 30 cm depths of the soil across the different lands. At 0 – 15 cm depth, six (6) different species of bacteria (*Bacillus, Pseudomonas, Clostridium, Micrococcus, Enterococcus* and *Norcadia* spp.) and five (5) species of fungi (*Aspergillus, Altenaria, Fusarium, Clasdoporium* and *Penicillium*) were isolated. At 15 – 30 cm depth, four (4) different species of bacteria (*Bacillus, Pseudomonas, Micrococcus* and *Enterococcus*) and five (5) species of fungi (*Aspergillus, Altenaria, Fusarium, Clasdoporium* and *Penicillium*) were isolated.

Table 1: Effects of xenophobic chemical on microbial population under different lands and depths

Land use types	Depth (cm)	Bacteria (cfu/g)	Fungi (cfu/g)
Industrial	0 – 15	3.35×10^{7}	4.15×10^{4}
	15 – 30	2.20×10^{5}	1.2×10^{2}
Arable land	0 – 15	3.20×10^{8}	1.55×10^{5}
	15 – 30	1.65×10^{4}	9.5×10^{3}
Fallow land	0 – 15	5.25×10^{11}	8.5×10^{8}
	15 – 30	7.50×10^{7}	1.8×10^{5}

Tables 2: Effects of xenophobics on fungi diversity on soils of different lands

Presumptive identification	**Presence in soil**					
	Industrial land		**Arable land**		**Fallowed land**	
	0 – 15 (cm)	**15 – 30** (cm)	**0 – 15** (cm)	**15 – 30** (cm)	**0 – 15** (cm)	**15 –30** (cm)
Aspergillus niger	+	+	+	+	+	+
Aspergillus tubingentis	+	+	+	-	+	+
Aspergillus flavus	+	+	-	-	+	+
Altenaria sp.	-	-	+	-	-	-
Fusarium spp.	-	+	+	-	-	-
Clasdoporium spp.	-	+	+	-	+	+
Penicillium sp.	+	+	-	+	+	+

Key: + present in sample, - Not present

Table 3: Effects of xenobiotics on bacterial diversity of soils of different lands

Presumptive identification	Presence in soil					
	Industrial land		Arable land		Fallowed land	
	0 – 15 (cm)	**15 – 30** (cm)	**0 – 15** (cm)	**15 – 30** (cm)	**0 – 15** (cm)	**15 – 30** (cm)
Bacillus subtilis	+	+	+	+	+	+
Bacillus mycoides	+	-	+	-	+	-
Bacillus megaterium	+	+	-	+	+	+
Bacillus licheniformis	-	-	+	-	-	-
Clostridium	+	-	_	-	-	-
Pseudomonas spp.	+	-	+	+	-	-
Micrococcus sp.	+	-	+	+	+	+
Enterococcus feacalis	+	-	+	-	+	+
Norcadia spp.	+	-	+	-	+	-

Key: + present in sample, - Not present

4.2 Discussion

4.2.1 Microbial Population

The microbial (bacteria and fungi) count of soils at different lands shows ranged between 1.65×10^4 to 5.25×10^{11} cfu/g for bacteria and 1.2×10^2 to 8.5×10^8 cfu/g for fungi. The 0 - 15 cm depth had the highest microbial count compared to the 15 – 30 cm. This indicated that the microbial population reduced with increased in the depth. The study conducted by Tripathi *et al*. (2018), showed similar result on relative number and biomass of microorganism species at 0-15 cm depth of soil. Similarly, studies conducted by Fierer *et al*. (2013) showed decreasing microorganism population with increasing soil depth. The fallowed soil had the highest microbial count while those from industrial and arable land showed reduced population of microorganism. This indicates that chemical (xenobiotics) compounds affected microbial population. The effect of xenobiotics compound released into the soil from the industrial and arable land reduced the micro-organisms population of the soil by inhibiting their normal metabolism. Some xenobiotics compounds have been reported to alter cellular morphology, in addition to biochemical changes (Eichorst *et al*., 2017).

4.2.2 Microbial Diversity

The microbial isolates show different species of fungi isolated in the soils with varying depth. *Aspergillus niger* was observed to be present in all soils with respect to depth and lands. Other fungi species observed include, *Aspergillus turbingentis*, *Aspergillus flavus*, *Alternaria spp*., *Fusarium spp.*, *Clasdosporium spp.* and *Penicillium sp.* The bacteria species found includes *Bacillus subtilis*, *Bacillus mycoides*, *Bacillus megaterium*, *Bacillus licheniformis*, *Clostridium*, *Pseudomonas spp.*, *Micrococcus sp.*, *Enterococcus feacalis* and *Norcadia spp*. It was observed that the diversity of bacterial species decreased with depth in all soils; whereas more fungal diversity was observed at the subsurface. Some surface-dwelling microbes showed reduced survival in the subsurface soil owing to the strong effect of xenobiotics compound that might have leached into the ground (Day and Bassuk, 2014); in addition, it could be as a result of the presence of more microbial life at the top soil. These findings are consistent with previous studies on soil microbial community diversity in response to depth across paddy soils (Hansel *et al*., 2018), grassland soils (Eilers *et al*., 2012), forest soils (Brady and Weil, 2012), and tundra soils (Stine and Weil, 2012). Nine major bacterial species observed in this study is similar to a previous study in which nine dominant groups were obtained from various soils ranging from agricultural land and grassland to pristine forest (Liu *et al*., 2018). This study also observed more microbial diversity at industrial and arable lands compared to fallowed land which could be a result of the sources of contamination.

5.0 Conclusion

The intensive use of chemicals on arable land and the generation of large quantities of chemical waste from industries have aroused public concern as to how these compounds might affect the environment by their long-term persistence, and slow to no biodegradation in the ecosystem. This study reveals higher microbial count in fallowed land at both depths compared to industrial and arable lands indicating gross impact of xenobiotics in the ecosystem. Although there was more fungal diversity at the subsurface of industrial land, more microbial diversity occurred at the surface of the soils; this is obviously a function of the contamination sources. Studies on the biodegradability of xenobiotic by these identified organisms are encouraged.

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Nodulation and Atmospheric Nitrogen Fixation in Soybean (*Glycine Max* L.) and Bambara Nut (*Vigna Subterranean* L.) Under Contrasting Cropping Systems and NPK Fertilizer

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ABSTRACT

Biological nitrogen fixation (BFN), a vital mechanism for supplying nitrogen in soils are often affected by soil and crop management techniques. We evaluated simple and interactive effects of NPK fertilizer and intercropping on nodulation and atmospheric nitrogen fixation in bambara nut (*Vigna subterranea* L.) and soybean (Glycine max L.) The experiment was conducted using a split plot in a randomized complete block design (RCBD) with three replications. NPK 20: 10: 10) fertilizer at the rate of 200kg ha^{-1} occupied the main plots and cropping system (sole or intercropping) as sub- plot treatment. Total Nitrogen Difference method (Peoples *et al.,* 1989) was employed in estimating nitrogen fixation. Maize served as a companion crop. The result shows that Soybean and bambara nut did not differ significantly from each other in total number of nodules plant^{-1}, number of effective nodules plant^{-1}. amount of nitrogen derived from the atmosphere (%Ndfa).and N – fixed. However, intercropping significantly ($P<0.05$) decreased total number of nodules plant^{-1}, from 97.1 in sole cropped to 46 in intercropped plants. While, number of effective nodules were 51.4 and 34.0 for sole and intercropping respectively. Similar trend was observed in %Ndfa but cropping system did not significantly influence the total amount of N-fixed. Application of NPK fertilizer significantly ($P<0.05$) increased total number of nodules plant^{-1} but, lead to reduction in, number of effective nodules plant^{-1}. %Ndfa and N – fixed. Fertilized plants produced an average of 57 nodules plant^{-1} as against 19 in non-fertilized plants. Plants grown in mon- fertilized plots produced 54.2% N while that of fertilized plot was 42%. There was significant interaction between NPK fertilization and cropping system in %Ndfa and N – Fixed by the legumes.

Key Words: symbiotic nitrogen fixation, Bambara nut, Soybean, Intercropping, NPK fertilizer

INTRODUCTION

Nitrogen is the second most limiting factor constraining crop growth and development (Vitousek and Howarth, 1991; Ladha *et al.*, 2022). It is primarily sourced through synthetic fertilizers produced from ammonia. However, before the era of synthetic nitrogen, the primary source of nitrogen in soils was through biological nitrogen fixation (BNF) which ensured a sustainable and regenerative agroecosystem with lower environmental footprints. Whilst the use of synthetic nitrogen fertilizer brought enormous benefits, when applied in excess, exists in deleterious forms (ammonia, nitrate, and nitrogen oxides) escaping into the surrounding ecosystem, resulting in a myriad of environmental and economic concerns (Dent and Cocking, 2017). On the other hand, nitrogen obtained from BNF are slowly available to plants and thus synchronize supply with demand (Costa *et al*., 2021, Ladha *et al*., 2022,). Numerous studies (Dabessa, *et al*, 2018, Ferreira *et al.* 2016) have demonstrated that improvements of BNF are possible with well-targeted land management practices.

Fujita *et al.* (1992) reported that nitrate – tolerance by legumes and mutual shading by component crops in Cereal / legumes intercropping influence biological nitrogen fixation (BNF) and yield of the associated legume. According to Mndzebele, *et al.* (2020) intercropping has a modifying effect on temperature, soil moisture, light interception and photosynthesis, available nutrient use and activity of the native rhizobia, all of which affect nodulation and nitrogen fixation by the legumes. Konlan *et al.* (2015) reported that intercropping significantly ($P<0.05$) reduced growth parameters and nitrogen fixation of groundnut genotypes. While, Mogale *et al*. (2023) reported that N accumulation in cowpea at two locations (Ofcolaco and Syferkuil, South Africa) were 30 and 36%, respectively more in sole cultures compared with binary cultures. Similarly, Vesterager *et al.* (2008) reported that cowpea fixed around 60% of its N from the atmosphere amounting to 70 kg N ha^{-1} under sole and 36 kg N ha^{-1} under intercropping as estimated by the 15N isotope dilution method around peak biomass production. A study by Giambalvo *et al.* (2011) on forage production, N uptake, N_2 fixation, and N recovery of berseem clover grown in pure stand and in mixture with annual ryegrass under different managements revealed that total amount of N fixed by berseem was higher in pure stand than in mixture and when plants were arranged in the same row rather than in alternating rows.

There are contradictory reports on influence of fertilizers on biological nitrogen fixation in legumes. For instance, Malik *et al.* (2006) observed that application of 30kgN/ha as starter dose did not affect nodulation of soybean grown under phosphorus nutrition but Otieno *et al.* (2007) noted that application of 20kgN/ha as ammonium nitrate depressed nodulation and nitrogen fixation in soybean. Ike *et al.* (2020) observed higher nodulation (number of nodules and nodule mass) at physiological maturity in cowpea when 25% of recommended NPK was applied, serving as starter N, P, and K, and thus stimulating nodule formation for symbiotic functioning. But at 100% NPK rate, nodule formation was inhibited confirming the assertion that higher mineral NPK levels tend to inhibit nodule formation in legumes (Clayton *et al.* 2004).

Tahir *et al*. (2009) opined that the use of starter N fertilizer has synergistic effect on N_2 fixation by stimulating nodule formation, nitrogenase activity, and plant growth, especially in infertile soils. However, at higher fertilizer doses or fertile soils, the suppressive effects of N fertilizers on legume N_2 fixation may be felt. Habinshuti *et al*. (2021) reported that plants not fertilized with N, showed greater nodule fresh weight, higher N derived from fixation, increased amount of N, greater ureide concentration in stems and petioles, higher % relative ureide-N abundance, and low soil N uptake.

Amba (2011) noted that legumes vary significantly in their ability to fix nitrogen probably due to their promiscuous behavior such as in soybean. There are a lot of studies on biological nitrogen fixation in Nigeria but little efforts have been made in assessing how fertilizer application and cropping system affect BNF singly or collectively in Soybean and Bambara nut. An understanding of the impacts of NPK fertilizer application and intercropping system on BNF of Soybean and Bambara nut will optimize their production and improve soil fertility

The objective of this study was to determine the nodulation and symbiotic nitrogen fixation by Bambara nut (*Vigna subterranea* L.) and Soybean (Glycine max L.) as influenced by NPK fertilization and intercropping systems.

MATERIALS AND METHODS

Experimental Site

The research was conducted at the Research and Demonstration Farm, Department of Agricultural Technology, Enugu State Polytechnic, Iwollo. Southeastern Nigeria which lies between co-ordinates 06^0 26.35′N and 07^0 16.83′E. Its annual rainfall ranges from 1700 to 1800 mm, a mean annual maximum (day) and minimum (night) temperatures of 31^0C and 21^0C respectively, with an average relative humidity that rarely go below 60%.

Treatments, Experimental Design and Crop Management

The experimental design was a split plot in a randomized complete block design (RCBD). The NPK fertilizer rate (200Kgha^{-1} NPK fertilizer, no – fertilizer) served as the main plot while two cropping systems involving sole Bambara nut (*Vigna subterranean*), Soybean (*Glycine max* L.), Maize (*Zea mays* L.) and mixed cropping of each of the legumes with maize giving a total treatment combination of 10, as the sub – plot treatments. Each treatment combination was replicated three times. Maize served as a reference crop in determining symbiotic nitrogen fixation by N – difference method.

An area 396m^2 (36m by 11m) was marked out from the field, ploughed and harrowed. They were demarcated into two (Main plot and Subplot) separated by 2 m space. The main or sub plot was further divided into three blocks separated by1m space. Each block was demarcated into plots measuring 3 by 3 m and separated from each other by 0.5 m. Maize was planted at a spacing of 75 x 25 cm, Soybean by 50 x 20 cm and Bambara nut 75 x 10 cm. In the intercropping systems, each legume was placed in alternate pattern with maize. Weeds were chemically controlled using Pendimethalin at inception but later was manually controlled by roughing. Insect pests were controlled by single spray of Cypermethrin + DImethoate 10 EC at the rate of 100 ml in 15 ml of water. Team - a fungicide was used to control fungal diseases.

Soil Analysis

Composite soil sample was collected prior to experimentation, to determine the physical and chemical condition of the soil. The collected soil samples were air dried, sieved using 2 – mm mesh sieve. Particle size distribution was determined by the hydrometer method, as described by Gee and or, 2002), using distilled water and calgon (sodium hexametaphosphate) as dispersing agents and textural class was obtained from the USDA soil textural triangle; soil pH was determined electrometrically in a soil to solution ratio of 1:2:5 (Hendershot et al., 1993). Total nitrogen was estimated by Micro Kjeldahl digestion method (Bremmer and Muluaney, 1982). Exchangeable Ca^{2+}, Mg^{2+}, K^t and Na^+ were estimated with IN ammonium acetate buffered at pH 7.0 (Chapman, 1965), Exchangeable $Ca^{2+}$and Mg^2 were determined by EDTA complexometric titration while exchangeable K^t and Na^+ were estimated by flame photometry (Jackson, 1982).

Estimation of nodulation and nitrogen fixation

Eight weeks after planting, five plants were randomly sampled in each plot and harvested carefully with a shovel to include most of the roots. The roots were washed with distilled water to remove adhering soils. Nodulation was determined by counting the number of nodules on the roots. Similarly, ten representative nodules where randomly selected from each plot, dissected using a sharp razor blade to determine their effectiveness. Nodules with pink colours were classified as effective whereas those with colours other than pink were considered ineffective. The sample size of ten nodules were taken to represent 10% of the overall nodule number.

The entire plant (shoot and roots) was oven dried at 65^0C for 48 hours, after oven drying, they were ground and allowed to pass through a 0.5 mm mesh before analysis for total N concentration using the Micro Kjeddhl method (Bremmer and Muluaney (982).

Computation / Estimations of nitrogen fixation

Total Nitrogen Difference method (Peoples *et al.*, 1989) was employed in estimating nitrogen fixation.

Thus:

Total nitrogen fixed

N fixed = N yield (Legume) – N yield (reference crop -maize) …………………Equation.1

Percentage of plant nitrogen derived from atmosphere

%Ndfa = 100(N yield (Legume) – N yield (reference crop -maize) / N yield Legume).…Equation 2

Where:

% Ndfa = percentage of plant Nitrogen derived from atomsphere

N yield (Legume) = N yield from Soybean or Bambara nut

N yield (reference crop - maize) = N yield from Maize

Statistical Analysis

All the data collected were subjected to analysis of variance (ANOVA) test. Significant means were separated using F-LSD at 5% level of probability.

RESULTS AND DISCUSSION

The soil of the experimental site was sandy clay loam in texture, pH (H_2O), 3.9; organic carbon, 1.17 %; total N, 0.21%; available P, 1.15 mg kg $^{-1}$; and exchangeable cations (cmol kg^{-1}) of Mg^{2+} 9; Ca^{2+} 6 and K^+ 0.14 as shown in Table 1.

Table 1: Properties of experimental soil prior to planting.

Properties	Unit	Value
Clay	(g kg^{-1})	276
Silt	(g kg^{-1})	229.2
Sand		494.8
Texture		Sandy Clay Loam
pH ($H_2$0)		3.9
Organic carbon=	(%)	1.17
Total N	(g kg^{-1})	21
Available P	(mg kg^{-1})	1.15
Exchangeable K	(cmol kg^{-1})	0.141
Exchangeable Ca	(cmol kg^{-1})	6
Exchangeable Mg	(cmol kg^{-1})	9
Cation exchange capacity	(cmol kg^{-1})	12

Effect of Cropping Systems on nodulation and N- fixation by soybean and Bambara nut

The effects of cropping system on nodulation (number and effective nodules), percent nitrogen derived from atmosphere (%Ndfa**),** nitrogen fixed by Soybean and Bambara nut were shown in Table 2. Bambara nut and Soybean did not differ significantly in their ability to produce nodules and fix nitrogen in the soil. The low pH of the soil (Table 1) did not hinder nodule formation. This is contrary to the assertion by Evans *et al*. (1990) `that in low pH soils, nodule formation in Soybean reduced by >90% and nodule dry weight by >50%.

Intercropping on the other hand significantly (P<0.05) decreased the total number and effective nodules as well as %Ndfa in both Soybean and Bambara nut**.** Total number of nodules reduced from 95.7 to 50.6 $plant^{-1}$, effective nodules from 51.4 to 34.0 and %Ndfa from 62 .6 to 52.7%. The amount of total nitrogen fixed by the legumes did not differ with cropping system.

There were significant (p <05) interactions between cropping system and type of legume in nodulation (total number and effective nodules) produced but not in percent nitrogen derived from the atmosphere (%Ndfa**)** and total nitrogen fixed. Sole Soybean and Bambara nut were superior in total number and effective nodules to when intercropped with maize.

The observed reduction in total number and effective nodules of intercropped Bambara nut and Soybean when compared to sole crop treatments may be attributed to shading by more aggressive component (maize). This is explained by the fact that nodule growth and function require light – dependent photosynthates. Similar results were obtained by Egbe and Egbo (2011) and Egbe and Bar – Nyam (2011) who reported decreased nodulation in intercropped cowpea and pigeon pea due to adverse effect of shading. Several authors reasoned that reduced nodulation observed in inter-cropping system in comparison with sole cropping could be as a result of competition with companion crop due to their proximity, especially for below-ground resources (Mndzebele *et al.* 2020; Nyoki and Ndakidem, 2018). The findings were however, contrary to that of Fletcher *et al*. (2016) and Jensen *et al*. (2020) who noted that intercropped legume has higher % Ndfa than sole legume crop.

Table 2: Effect of cropping system on nodulation and nitrogen fixation in soybean and Bambara nut plants.

Treatments		Total number of nodules plant^{-1}	Number of effective nodules plant^{-1}	%Ndfa	N - Fixed
Legume Types					
Soybean		87.5	43.5	56.5	49.1
Bambara nut		60.6	44.3	58.8	47.1
F – LSD (0.05)		NS	NS	NS	NS
Cropping system (CRS)					
Sole		97.5	51.4	62.6	54.2
Intercrop		50.6	34.0	52.7	43.7
F – LSD (0.05)		27.04	1.9	4.36	NS
Legume Type X Cropping system					
Soybean	Sole	119.9	53.0	60.2	56.9
	Intercrop	55.0	33.9	52.6	41.3
Bambara	Sole	75.0	49.7	65.0	48.2
nut	Intercrop	46.1	38.8	52.6	46.0
F – LSD (0.05)		5.568	3.349	NS	NS

F- LSD $_{0.05}$ = Fisher's Least Significant Difference at 5% level of probability, NS = non-significant at 5 % level of probability.

Effect of NPK fertilizer on nodulation and nitrogen fixation in Soybean and Bambara nut plants.

Table 3 shows the effect of NPK fertilizer on total number and effective nodules, %Ndfa and N- fixed by Soybean and Bambara nut. The crops did not differ significantly from each other in these parameters except where Soybean produced significantly ($p < 0.05$) higher number of effective nodules than Bambara nut**.** Application of NPK fertilizer significantly ($p < 0.05$) increased number of nodules from 19 in non - fertilized plot to 57.0 in fertilized plot. However, number of effective nodules were higher in non-fertilized plots. Similarly, non-fertilized plots had higher %Ndfa (61.9%) and N-fixed (54.2 g plant^{-1}) than fertilized plots which were 53.4% and 42.0 g plant^{-1}.

There were significant ($p < 0.05$) interaction between legume type (Soybean, Bambara nut) and NPK fertilization. Soybean significantly ($p < 0.05$) produced higher number of nodules (80) than Bambara nut (34) under fertilizer application. But in unfertilized fields, Soybean and Bambara nut did not differ significantly from each other in number of nodules produced. On the contrary, number of effective nodules produced in Soybean were significantly the same in both fertilized and unfertilized plots. But in Bambara nut, unfertilized plots produced significantly ($p < 0.05$) higher (3.0) number of effective nodules. The result also indicates that there was non-significant interaction between legume type and fertilizer application in % Ndfa and N- fixed.

In line with Amba (2011) assertion that legumes vary significantly in their ability to fix nitrogen, Soybean produced significantly higher number of effective nodules. But their activities were not significant enough to influence the %Ndfa and N- Fixed. This implies that factors other than legume type influence nodulation and nitrogen fixation.

The result was in tandem with the findings of Ike *et al.* (2020) who reported that at rates greater than 100% recommended rate of NPK, nodule formation was inhibited confirming the assertion that higher mineral NPK levels tend to inhibit nodule formation in legumes (Clayton *et al.* 2004). The of the NPK fertilizer was felt in number of nodules produced by Soybean but most of the nodules produced were ineffective leading to inhibition on nitrogen fixation. The reported increase in number of ineffective nodules cannot be explained. Similar results were obtained by Habinshuti *et al*. (2021).

Table 3: Effect of NPK fertilizer on nodulation and nitrogen fixation in soybean and Bambara nut plants.

Treatments		Total number of nodules plant^{-1}	Number of effective nodules plant^{-1}	%Ndfa	N – Fixed g plant^{-1}
Legume type					
Soybean		48.1	2.92	56.5	49.1
Bambara nut		27.9	1.54	58.8	47.1
F – LSD (0.05)		NS	1.005	NS	NS
Fertilizer (NPK)					
No Fertilizer		19.0	2.83	61.9	54.2
NPK Fertilizer		57.0	1.62	53.4	42.0
F – LSD (0.05)		21.16	1.005	8.00	11.82
Legume Type X Fertilizer					
Soybean	No Fertilizer	16.5	2.67	59.8	54.0
	Fertilizer	79.7	3.17	53.2	44.3
Bambara nut	No Fertilizer	21.5	3.00	64.1	54.4
	Fertilizer	34.3	0.08	53.6	39.8
F – LSD (0.05)		29.92	1.62	NS	NS

F- LSD $_{0.05}$ = Fisher's Least Significant Difference at 5% level of probability, NS = non-significant at 5 % level of probability.

Interactive effects of NPK fertilizer and cropping systems on nodulation and nitrogen fixation in soybean and Bambara nut

There was non-significant interaction between cropping system and NPK fertilization on nodulation of Soybean and Bambara nut (Table 4). In %Ndfa, cropping system and NPK fertilization significantly ($p < 0.05$) interacted with each other. For instance, %Ndfa under unfertilized sole cropping was 71.7 % but 52.1% which was unfertilized intercrop, it was 52.1 which significantly ($p < 0.05$) lower than the sole counterpart. While, under NPK fertilization, there was non-significant difference between sole and intercropping. The amount of nitrogen fixed in a particular cropping system whether fertilized or not did not differ significantly. But are significantly different when compared across cropping systems.

From the result, it could be deduced that fertilizer application significantly reduced %Ndfa in sole cropped legumes but unaffected when intercropped with cereals like maize. Under sole cropping, the nitrogen in the NPK fertilizer at the high rate applied, may have suppressed N_2 fixation. This agrees with Vieira *et al*. (1998) and Li *et al.* (2009) who reported that high concentrations of NH_3 can inhibit *nod*-gene expression, nodule formation, and nitrogenase activity, thus reducing their symbiotic N yield.

Table 3: Interactive effects of NPK fertilizer and Cropping systems on nodulation and nitrogen fixation in soybean and Bambara nut plants.

Treatments		Nodule number per plant	Number of effective nodules per plant	%Ndfa	N - Fixed
Cropping systems					
Sole		57.5	2.12	62.6	40.4
Intercrop		18.5	2.33	52.7	43.7
F – LSD (0.05)		21.78	NS	4.36	9.32
Fertilizer					
No Fertilizer		48.1	2.94	61.9	54.2
NPK fertilizer		27.9	1.42	53.4	42.0
F – LSD (0.05)		NS	1.005	4.36	9.32
Cropping system X Fertilizer					
Sole	No Fertilizer	77.4	2.12	71.7	64.7
	Fertilizer	37.7	2.92	53.3	64.7
Intercrop	No Fertilizer	18.8	2.33	52.1	43.7
	Fertilizer	18.1	1.54	53.4	43.7
F – LSD (0.05)		NS	NS	6.16	13.9

F- LSD $_{0.05}$ = Fisher's Least Significant Difference at 5% level of probability, NS = non-significant at 5 % level of probability.

CONCLUSION

In conclusion, nodulation indicated by total number of effective nodules as well as N_2 fixation were sensitive to cropping system and NPK fertilization. Soybean did not differ significantly from Bambara nu in biological nitrogen fixing activities in the soil. Applying synthetic NPK fertilizer did not significantly affect nodulation and nitrogen fixation. When these crops were intercropped with maize, nodulation and nitrogen fixation were significantly reduced.

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Effects of Biopesticides on Soil Bacterial Population and Diversity Associated with Bell Pepper (*Capsicum Annuum*) Cultivation

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ABSTRACT

Bell pepper *(Capsicum annuum)* is affected by biotic factors during growth, and these have negative effects on the production and quality of its fruits. Control measures are necessary to avoid economic losses that occur during its cultivation, which makes it difficult to manage populations of Capsicum, hence the use of bio-pesticides to eliminate soil- borne insect pests and diseases associated with the crops. The aim of this study was to determine the effect of bio-pesticide on bacterial population and diversity in a bell pepper cultivated soil. This study was carried out at the Rivers State University Teaching and Research farm using a Randomized complete block design (RCBD) replicated three times. Two bio-pesticides; Effective microorganisms (EM-5) and Hot leaves (HL) were prepared and used. Each treatment was applied on the cultivated soil at two (2) weeks before planting and four (4) weeks after planting. A total of 18 soil samples were collected for analysis from the treated plots and the control plots. Bacteria were isolated after culturing using ten-fold serial dilution for population count whereas molecular techniques were used to identify bacterial diversity. Results showed EM5 increased beneficial bacterial diversity and population after planting. Population count went from 26 x 10^9cfu/g before planting to 27.00 x10^9 cfu/g after planting. HLreduced from 25.67a x10^9cfu/g before planting to 3.00 x 10^9 cfu/gafter planting. Bacteria at the control plot increased from 26 x 10^9 cfu/g before planting to 27.33 x 10^9 cfu/g after planting. Molecular identification revealed the presence of fifteen (15) bacteria in all treatment plots which include the following; *Proteus mirabilis, Staphylococcus aureus knock down, Staphylococcus aureus sub specie aureus newman, Streptococcus anginosus, Sphingobacteria bacterium, Bacteroides dorei.* Eight were pathogenic and seven were beneficial. The control plots after planting revealed higher bacterial population and diversity than the plots with the bio-pesticides after planting which suggests that the bio-pesticides reduced the bacterial population of plot both treatment plots but increased beneficial bacterial diversity in the plots with the EM-5. Molecular identification helped evaluate prominent plant growth promoting Rhizobacteria (PGPR) which are very important in biogeochemical cycles and prevention of the deleterious effects of phytopathogenic organisms.

Keywords: Bacteria, Bio-pesticides, Diversity, Control plot

INTRODUCTION

Bio-pesticides are substances that naturally occurring from living organisms (natural enemies) or their products (microbial products, phytochemicals) or their by-products (semiochemicals) that can control pest by nontoxic mechanisms (Salma and Jogen, 2011).

Microbial communities in soil ecosystems provide various important functions like decomposition of organic material, recycling of nutrients, nitrogen and carbon cycle, storage and release of nutrients, plant growth promotion and providing a major food source at the base of food webs(Gupta,*et al.*, 2013). . Microbes are also capable of degrading

soil-associated organic pollutants and can thus contribute to remediation of contaminated ecosystems which reduces the effect of pollution. Thus, many microbial functions are critical to crop production,soil sustainability, andenvironmental quality. Therefore the impact of pesticides on the diversity of soil microbial communities and enzymatic activities become vital (Gupta,*et al*., 2013). Non target organism exposure and offsite mobility of the applied pesticides have become a major concern in respect to keeping the environment contaminants free; (Hafez and Theimann, 2003). The adverse effect of pesticides may also affect soil fertility,continuous use of synthetic pesticides leads to development of resistant plant pathogen strains leading to their resurgence as observed by (Schuster and Schroder 1990). Also,Synthetic pesticides kill non-target beneficial organisms such as pollinators, predators and antagonists thereby disrupting biodiversity (Schuster and Schroder 1990).
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An ideal pesticide should be biodegradable and toxic to only the target organisms. Based on the nature and origin of the active ingredients, bio--pesticides fall into several categories such as botanicals, antagonists, compost teas, growth promoters, predators and pheromones.(FAO 2015) Peppers are mostly prone to attack caused by pests and microbial organisms such as fungi, bacterial and nematodes that are pathogenic (Ademoh,*et al.,* 2015). Due to attack by pathogenic microbial organisms, pepper fruit usually get rot before they get to consumers, as a result, millions of naira is being lost by both the farmers and sellers of this farm produce. These fruit rot microbial organisms could be introduced into the crop through the seed itself, during crop growth in the field, during harvesting and post-harvest handling, or during storage distribution (Barth,*et al.,*2009). Among the disease that affects Capsicum, soil-borne diseases caused by pathogens of the genus *Phytophthora*, *Fusarium, Pythium* and *Rhizoctonia* are especially significant. For the control of these biotic agents, chemical synthesized pesticides have been traditionally used, which have generated several controversies due to their toxicity in humans and animals, and their damaging effects to the environment(Barra-Bucarei and Ortiz, 2020).Bio-pesticides exhibit different modes of action against pathogens and are reported to have various management success on different pest and diseases.

In traditional and modern agricultural field, crop damage due to these microbial infestationsis always encountered by farmers. There are harmful effects associated with the use of synthetic pesticides such as toxicity and poisoning. Therefore, this study aims at investigating the effects of bio-pesticide on population and diversity of bacteria associating in a bell pepper cultivated soil using molecular techniques.

MATERIALS AND METHODS

The experiment was conducted at the Rivers State University Teaching and Research Farm, Nkpolu-Oroworukwo. Port Harcourt, Nigeria, which lies between latitude 4° 48 14.1" and longitude E6°58 34.8", with an elevation of 8 km above sea level. This islocated within the humid rainforest region of the southern Nigeria with mean annual rainfall that ranged between 2,000mm - 3,000mm per annum. The average annual temperature ranges between 23°C and 29°C.(Ikati and Peter, 2019)

BIOPESTICIDES PREPARATION

HotLeafpreparationandapplication

One hundred (100) g of pepper,(100)g of ginger, (100)g of garlic and (100)g of Neem leaves were grinded and mixed with 4L of water and filtered to obtain the extract allowing it to ferment for three days. The extract was sprayed on the soil two (2) weeks before planting and four (4) weeks after planting) on the leaves and soil using knap sack sprayer.

EM-5 PREPARATION AND APPLICATION

The EM-5 was prepared from water 60%, molasses 10%, EM-1 10%, vinegar 10%, alcohol 10%, 15% of hot leaves. And total volume was produced in a 5L Keg and stored for 14 days before usage. EM-5 (2L) was added into 1L of water and sprayed on the soil and plants (two weeks before planting and 4 weeks after planting respectively.

Preparation of Beds

The research was an open field experiment where beds were raised. The plot had subplots (beds 4m×4m) and seedlings were planted in 2m x2 m beds. Spacing within and between rows was 2m apart. The bell pepper seedlings were transplanted one per hole. Each bed had 4 plants giving a total of 36 plants in 10 m x 10 m plot size.

SAMPLECOLLECTION

Soil samples were collected randomly from the various plots using hand trowel from 0-20 cm depths within the study plots and put in well labeled sterile bottles which were carefully taken to the laboratory for analysis.

LABORATORY ANALYSIS

The samples were subjected to most appropriate analysis in the laboratory which include; serial dilution, Plate pouring method of inoculation which was used for the isolation of the bacteria contained in the samples. A sterile pipette was used to take 1ml each of the serial dilution prepared samples into the corresponding labeled petri dishes. Nine (9) milliliters of molten prepared nutrient agar (NA) was dispensed into the petri dishes. The petri dishes were inoculated under room temperature for 24hrs.

Determination of Bacterial Load

The samples were determined visibly by counting the colony forming units after 24 hours. The bacterial load/ml was determined by the formula of Cheesbrough (2004) as:

Count/ml = No of colonies on plate x 1
Amount plated (dilution factor)

Bacterial DNA Extraction

Molecular identification of bacterial isolates was done by extracting the various bacterial DNA using bacterial DNA extraction kit from soil samples (ABM Ontario Canada).

Workflow of Library Preparation for Next Generation SequencingDNAShearing:

The input DNA was sonicated (exposed to hydrodynamic shearing) into small fragment
With a mean fragment size of 165bp and a fragment size range of 150 to 180bp (before adaptor ligation) using a covaris™ S2 system.

DNA P1 and P2 adaptors were ligated to the ends of the end-repair DNA. The ligated, purified DNA was run on a solid™ library size selection gel. The correctly sized ligation products (200 to 23bp) were electrophoresed to the collection wells of the size selection gel. The elute from the solidlibrary size selection gel went through nick translation and subsequently amplification using library PCR primers 1and 2 and platinum® PCR amplification mix. After amplification, PCR samples were purified with the SOLID™ library column purification kit. Quantitative PCR (qPCR) was performed. Then contents of the tube was mixed and centrifuged briefly. The tube was incubated in a thermal cycler at 94ºc for 3mins to completely denature the template. The samples can be stored at -20ºc until used and amplification products were analyzed by agarose gel electrophoresis and visualize by ethidium bromide or safe view by (cat. No G18) staining. If 2x pcr taq plus master mix with dye was used, the samples will be loaded directly without additional loading dye. Molecular weight standard was used appropriately.

BioinformaticsAnalysisofNucleotideSequencing

The nucleotide sequences obtained from the various bacterial isolates were analyzed by searching and comparing with the National Center for Biotechnology Information (NCBI) Website and a blast search was conducted on all the nucleotide sequences and the identities of the isolates were revealed.

RESULTS

Bacterial Population of Soils Treated with Hot Leafs (HL), Effective Microorganisms (Em-5) and the controlbefore and After Planting.

Results of the Bacterial Population of Soils treated with Hot Leafs [HL], Effective Microorganisms [Em-5) and the control before and After Planting are presented on table 1. Results shows that after application of treatments was done 2 weeks before planting and four (4) weeks after planting, there was a reduction in colony forming unit (cfu/g) from 25.67 x 10^9before planting to 3.00 x 10^9 after planting. EM5 increased bacteria population from 26.00 x10^9 before planting to 27.00 x10^9after planting and the control increased from 26.00 x10^9 before planting to 27.33 x109 after planting. There was no significant difference among the treatments before and after planting at (P<0.05). The plot treated with Hot Leaf (HL) had a mean value of 25.67x10^9 before planting and decreased significantly to 3.00x10^9 with the application after planting which is also the least value recorded among the treatment plots.

Table 1: Bacterial Population of Soils Treated with Hot Leaf (HL)Effective Microorganisms [Em-5) and the control before and After Planting.

Treatment	Sampling time Before/After planting	Cfu/g soil
Control	Before	26.00a x10^9
Control	After	27.33a x10^9
EM5	Before	26.00a x10^9
EM5	After	27.00a x10^9
HL	Before	25.67a x10^9
HL	After	3.00b x10^9
L.S.D (P<0.05)		67.83

Means followed by the same letter(s) in the same column are not significantlydifferent from one another at 5% level of probability using least significant different (L.S.D)

Molecular Identification of Bacteria Isolates from the Study Plots

Fifteen species of bacterial were identified in the study plots treated with hot leaf, Effective microorganisms (EM-5) and the Control plot (without treatment). Among the bacterial diversity identified are; *staphylococcus epidemidis, staphylococcus aureus, Bacillus lichenfomis, Proteus mirabilis, Streptococcus anginosus,* *Sphingobacteria bacterium, Streptococcus mutans, Bacteroides dorei, Zymomona mobilis, Streptococcus mutans HACO4 strain, Uncultured spingobacteria bacterium whole geno, Staphylococcus aureus knock down, Escherichia coli, Uncultured sphingobacteria bacterium, uncultured bacteria.* Eight were pathogenic and seven were beneficial. At the plottreatedwith the hot leaf (HL) diversity also decreased while beneficial microbes increased at the plot treated with EM-5. Microbial diversity did not change at the control plot.

Table 2: Molecular Identification of Bacterial Isolated from the Treatment plot and controlbefore and afterplanting.

Treatment		Isolates	Beneficial/PathogenReferences
Hot Leaf (HL)	Before	*Staphylococcus aureus (subspp aureus newman)*	PathogenicPrithiviraj, *et al,(2005)*
		Streptococcus anginosus	PathogenicBudziaszek, *et al*,(2023)
		Staphylococcus aureus	PathogenicGerken ,*et al*,(2022)
		Bacillus lichenfomis	BeneficialAkhtar,*et al*,(2020)
		Proteus mirabilis	BeneficialAmaresan ,*et al*,(2021)
	After	*Staphylococcus epidemidis*	BeneficialChaudh and Pati*(2016)*
		Sphingobacteria bacterium	BeneficialWang, *et al*,(2022)
Effective microbes(EM-5)	Before	*Sphingobacteriabacterium*	Beneficial*Wang, et al,(2022)*
		Streptococcus mutans	PathogenicGledhill and Casida(1969)
		Bacteroides dorei	BeneficialLarsbrink and McKee (2020)
		Staphylococcus aureus	PathogenicPrithiviraj,*et al*,(2005)
		Streptococcus sp	PathogenicZhao,*et al*,(2015)
	After	*Sphingobacteria bacterium*	BeneficialWang,*et al*,(2022)
			BeneficialAkhtar, *et al*,(2020)
		Bacillus lichenfomis	BeneficialMartien,*et al*,(2021)
		Zymonoma mobilis	
		Proteus mirabilis	BeneficialDrzewiecka (2016)
Control	Before	*Bacteroides dorei*	PathogenicLarsbrink and McKee (2020)
		Streptococcus anginosus	PathogenicBudziaszek,*et al*,(2023)
		Spingobacteria spp	BeneficialWang,*et al*,(2022)
		Staphylococcus aureus (knock down)	PathogenicZhao,*et al*,(2017)

	Streptococcus mutants	Pathogenic Gledhill and Casida(1969)
	Escherichia coli	BeneficialHabteselassie ,*et al*,(2008)
	Staphylococcus epidemidis	Beneficial *Chaudh and Pati (2016)*
After	*Bacteroides dorei*	PathogenicLarsbrink and McKee (2020)
	Streptococcus anginosus	Pathogenic*Budziaszek, et al, (2023)*
	Spingobacteria spp	BeneficialWang,*et al*,(2022)
	Staphylococcus aureus (knock down)	PathogenicZhao,*et al*,(2017)
	Streptococcus mutants	PathogenicGledhill and Casida(1969)
	Escherichia coli	Beneficial Habteselassie ,*et al*, (2008)
	Staphylococcus epidemidis	Beneficial Chaudh and Pati (2016)

DISCUSSION

The plot treated with Hot Leaf (HL) had a mean value of $25.67x10^9$ before planting and decreased significantly to $3.00x10^9$ with the application of treatment after planting. According to Elazouni,*et al.*, (2019), several mechanisms are known to be responsible for suppressing the growth of a microorganism by biological control agents and these include the production of antagonistic metabolites, hydrogen cyanide or siderophores, competition for nutrients and space, parasitism, and induced systemic resistance such as phenolicsand polyphenols (flavonoids, Quinone, tannins, coumarins), terpenoids, alkaloids, lectins and polypeptides which are antimicrobial.The antimicrobial action of plant extracts depends on the chemical composition of the extract and the microbial targets. Despite the antimicrobial action of plant extracts, their use as food preservatives is limited by their stability under processing or storage conditions. Okur, *et al.* (2010) discovered a decrease in microbial and enzymatic activity when plants extracts were used as pesticides. Kurma, *et al.* (2019) also observed that plant extract bio- pesticides also negatively affected soil microorganisms by limiting their biological services in the production of certain plant growth-promoting traits. The increase in the microbial population after the application of EM-5 after planting conforms to the findings of Han and Lee (2006). They observed that by maintaining healthy soil ecology, that harmful microorganisms that cause plants diseases can be suppressed. They further emphasized, that there is a balanced interaction in the soil system between harmful microbes and billions of beneficial microbes working together to provide protection. Schnürer and Magnusson (2005) observed that the EM introduces and increases the population soil microorganisms. According to Ongena and Jacques (2008) the bacteria could be one of the major sources of potential microbial bio-pesticides because it retains several valuable traits. Beneficial microbes in soil promote healthy plant growth, which leads to increased crop yields and better crop quality. When beneficial bacteria are introduced to soils and plants by EM, pests are controlled or managed. Inoculants containing microorganisms compete with pests and diseases and are used naturally to decrease or manage pests Singh *et al.*, (2003).

CONCLUSION

This study emphasizes on the soil Bacterial population and diversity in bell pepper cultivated soils from plots treated with EM-5, Hot leaf (HL) and control (without treatment). Study revealed that EM-5 increased beneficial bacterial population while (HL) reduced beneficial bacterial population and at the control plot, there was no significant difference in population and diversity when compared with the treated plots. Bacteria could be a major source of potential microbial bio pesticide as seen with the EM-5.

EM-5 could be used by farmers as a bio-pesticide and large-scale farmers. And as part of the monitoring activities of farmers, soil microbial analysis should be done regularly to evaluate prominent members of the microbial communities in their farmland. Farmers should adopt the use of bio pesticides because they are effective in very small quantities and often decompose quickly, resulting in lower exposures and largely avoiding the pollution problems caused by conventional inorganic pesticides. Molecular identification helped evaluate prominent plant growth promoting Rhizobacteria (PGPR) which is very important in biogeochemical cycles and prevention of the deleterious effects of phyto-pathogenic organisms.

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Effects of Rates of Abattoir Effluent on Soil Properties, Microbial Population and Yield of Pepper (Capsicum Annum L.) in Acidic Ultisol, Akwa Ibom State

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ABSTRACT

A pot experiment was carried out in the greenhouse of Faculty of Agriculture, AkwaIbom State University, ObioAkpa campus to evaluate the effects of different rates of abattoir effluent on selected soil properties, microbial population and yield of chillipepper (*Capsicum anum* L.) in acidic ultisol of AkwaIbom State. The experiment was laid in a completely randomized design (CRD) with five treatments each replicated thrice. The treatments consisted of four rates of abattoir effluent (50, 100, 150 and 200mls/5kg of soil) and without treatment (0ml/5kg) to serve as the control. Data were collected on soil properties before and after experiment, growth parameters and yield of pepper. The data generated were analyzed statistically and means were compared using Fishers Least Significant Difference (FLSD) at 0.05 probability level. The results revealed that, the application of abattoir effluent significantly improved the soil pH (7.47), organic matter (6.24%), available P (42.10 mg/kg^{-1}), exchangeable Ca (7.20 cmol/kg^{-1}), Mg (4.3cmol/kg^{-1}), base saturation (88.17%) and reduces total nitrogen (0.16%), Exch.Na (0.13cmol/kg^{-1}), K(0.26cmol/kg^{-1}) and ECEC (12.5cmol/kg^{-1}) relative to control. Chilli pepper responded positively to the application of abattoir effluent at allvarious rates but superior increases in plant height (75.33cm), number of leaves (34.67cm), stem girth (2.50cm), leaf area (164.00cm^2), numbers of fruits per plant (24.08), fruit width (9.0cm), fruit length (8.4cm) and fruit yield (2.5tons/ha)were obtained from plants treated with 50mls of abattoir effluent per 5 kg soil. Based on the findings of this research, it is observed that abattoir effluent is an important soil nutrient replenishing material and could therefore be used for pepper production in the study area.

Key words: Abattoir effluent, Chilli pepper, Ultisol, microbial population

INTRODUCTION

Soil fertility decline has been identified as one of the major problems affecting crop production in many parts of the tropics. The application of inorganic fertilizers has been used to improve soil nutrient and crop productivity. However, the use of mineral fertilizer among farmers is limited due to its high cost, increase soil acidity, and aggravates soil degradation and nutrient imbalance (Olayinka, 1990; Nwajiuba and Chimezie, 2000). The application of organic substances such as abattoir effluent can be an alternative to chemical fertilizers to improve soil fertility. Abattoir effluent is that residual material obtained from the abattoir after the slaughter of animals like cattle, sheep, goats, pigs etc. These wastes are highly organic. Studies have shown that the application of organic wastes such asabbatoir effluents, compost and sewage sludge to soil increase plant growth and development (Osemwuta, 2010). However, excessive application of effluent to the soils may inhibit any benefits that could have been derived from such materials or induce undesirable soil damage as well as food-water pollution (Isirimah,2002). Abattoir waste water has been reported to be a rich source of plant nutrients (Edieneet *al*., 2016; Iren and Uko, 2019). Similarly, Osemwuta (2010) reported that abattoir effluent has high residual capacity therefore has high tendency to supply nutrients even after several years of application. Thus, reduces high dependence on regular application of inorganic fertilizers. Gaur *et al.* (2002), Omole and Longe (2008), Yahaya*et al.* (2009), Rabah *et a..*(*2010),*Nebon*et a.,*(2013), Abhanzioya(2016),Chukwu and Anuchi(2016) reported significant increases in percent organic carbon, total nitrogen, available phosphorus and exchangeable calcium and sodium with a reduction in soils pH in soils amended with abattoir effluent. Similarly, Spakling*et a.,* (2006), Ayodele and Omotoso(2008), Osemwuta,(2010) and Castro *et al.*,(2011) observed increased in total herbage production, uptake of nitrogen and phosphorus and higher dry matter yield of maize in abattoir amended soils. According to Akinnibosun and Ayejuyoni, (2015), application of abattoir effluent on soil increased the microbial population of bacteria, fungi and coliform relative to the control soil.

Pepper (*Capsicum annum*.) is an important fruit vegetable which belongs to the family Solanaceae. Pepper is used in seasoning sauces, soup and other dishes. As a medicinal plant, pepper is used in the prevention and treatment of cold and fever (Udoh and Ndon,2016). Nigeria is known to be one of the major producers of pepper in the world accounting for about 50% of the African production (Idowu-Agida*et al.*, 2010). Although pepper is widely cultivated in Nigeria, the yields obtained are often very low due to low fertility of the soil (Adigun, 2001; Iren *et al.*, 2016; Ijah *et al.*, 2018). Therefore, this study was conducted to evaluate the effect of abattoir effluent on selected soil properties, microbial population and yield of chilli pepper in an acidic ultisol of AkwaIbom State.

MATERIALS AND METHODS

The Study Area

The experiment was conducted in the greenhouse of the Departments of Soil and Crop Science, Faculty of Agriculture, AkwaIbom State University, ObioAkpa Campus, OrukAnamL. G. A. The area is situated between latitude 4º 30¹ and 5º30¹N and longitude 7º 30¹ and 8º20¹E in the rainforest zone, with a mean annual rainfall of over 3000 mm. Temperature values are relatively high, with the mean annual temperature varying between 26 and 28^{o}C. (SLUS-AK, 1989) .

Research materials, soil sampling, experimental design and treatment

Pepper (*Capsicum annum L.)* seeds were obtained from the AkwaIbom State Agricultural Development Project (AKADEP) Office. Abattoir effluent was collected from a slaughter house in Abak market while composite surface soil samples (0-30cm) was randomly collected from Teaching and Research Farm of Faculty of Agriculture, AkwaIbom State University, ObioAkpa Campus. The samples were air dried, crushed and sieved using a 2mm mesh sieve and analyzed before the experiment using standard laboratory procedures (Udo *et al.*, 2009). The pepper seedlings were raised in nursery bed and transplanted at six weeks after planting. Five (5) kg of the 2mm sieved soil was weighed into perforated plastics buckets. There were five levels of treatments including control (0, 50, 100, 150 and 200ml) each replicated three times. The experiment was laid out in a completely randomized design (CRD).The different rates of abattoir effluent were added to specified soil in the bucketsexcept the control (0ml) which had no addition. After two weeks of application, young seedlings of pepper were transplanted from the nursery and were sown at the rate of one seedling per pot. The seedlings were watered before transplanting. The buckets were irrigated on the day of application and at regular interval throughout the duration of the study. Plant data were collected from two weeks after transplanting and subsequently at two weeks interval.

Laboratory Studies

The abattoir effluent and soil samples collected were analyzed in the laboratory using standard procedures as described by Udo *et al.* (2009): Particle size distribution was determined by the Bouyoucous hydrometer method. Soil pH was determined using a ratio of 1:2.5 in soil-water medium and read with a digital pH meter. Organic carbon content was determined by Walkley-Black dichromate oxidation method. Organic matter was obtained by multiplying total carbon by a factor of 1.724. Total nitrogen (N) was determined by the micro-kjeldahl method. Available phosphorus (P) was extracted by the Bray 1 extraction method, and the content of P was determined calorimetrically using a TechnicoAAIIauto-analyser (Technico, Oakland, Calif). Determination of exchangeable bases was by neutral ammonium acetate extraction and read with an atomic absorption spectrophotometer (AAS). Exchangeable acidity (H^+ + Al^{3+}) was determined by titration method. The effective cation exchange capacity (ECEC) was by summation of exchangeable bases and exchangeable acidity. Base saturation was calculated by dividing the sum of exchangeable bases by ECEC and multiplied by 100.Abbatoir effluent was analyzed for its chemical properties according to Rhoades (1982).

Isolation and identification of bacterial and fungal count

Distinct colonies of bacteria were purified by repeated subculture on the respective isolation media and preserved on slants at 4^0C as described by Olutiola*et al*., (1991). Morphological and biochemical tests to identify the isolates were carried out using the methods of (Fawole and Oso, 2001) and Bergeys manual of systematic bacteriology (Claus and Berkeley, 1986). Biochemical tests carried out in the conventional method include: Voges-Proskauer and Methyl-Red test, fermentation of carbohydrate, hydrolysis of starch, utilization of citrate, hydrolysis of casein, hydrolysis of gelatin. Fungal isolates were subculture using the same isolation media and were identified using macroscopic and microscopic fungal features. Fungal were identified using the cotton-blue in lactophenol method (Olutiola*et al*., 2001).

Statistical Analysis

Soil, microbial count and plant data collected were analyzed statistically and means were compared using Fishers Least Significant Difference (FLSD) at 0.05 probability level (Wahua, 1999).

RESULTS AND DISCUSSION

Physicochemical Properties of the Experimental Soil used

The soil used for the experiment was a loamy sandy soil with a pH of 5.8. The detailed chemical composition of the soil used for the experiment is shown in Table 1. The abattoir effluent used contained 2.1 % N, 1.60 K, 1.3% P, 4.2 % organic matter, 20.9 x 10^6 bacteria, 19.4 x10^3 fungi and 10.8 x10 ^{4} of coliform (Table 2).

Table 1: Physicochemical properties of the soil used for the experiment before treatment application.

Properties	values
Particle size distribution	
Sand (g/kg)	87.60
Silt (g/kg)	3.88
Clay (g/kg)	8.52
Textural class	Loamy sand
Soil pH 1.2.5 (H_2O)	5.8
Total nitrogen (%)	0.07
Organic matter (%)	1.80
EC (dS/m)	0.09
Available P (mgkg^{-1})	6.03
Exch. Ca (cmol/kg^{-1})	3.20
Exch. Mg (cmol/kg^{-1})	1.60
Exch. K (cmol/kg^{-1})	0.10
Exch Na (cmol/kg^{-1})	0.05
EA (cmol/kg^{-1})	1.0
ECEC (cmol/kg^{-1})	5.95
Base Saturation (cmol/kg^{-1})	83.19

LS – loamy sand, EC – Electrical conductivity, OM – Organic matter, TN – Total nitrogen, Exch. Ca= Exchangeable calcium, Exch. Mg= Exchangeable Magnesium, Exch. K= Exchangeable Potassium, Exch. Na= Exchangeable sodium, EA – Exchangeableacidity, ECEC =Effective cation exchangeable capacity.

Table 2: Chemical properties and microbial count of the abattoir effluent used for the study

Properties.	**Values**
Total nitrogen (%)	2.1
Potassium (cmol/kg)	1.60
Phosphorus(mg/kg^{-1})	1.3
Total organic matter (%).	4.2
Bacteria (cfu/g)	20.9
Fungi (cfu/g)	19.4
Coliform (cfu/g)	10.8

Effects of different rates of Abattoir Effluent rates on selected soil Properties

The effects of different rates of abattoir effluent on selected soil properties are shown in Table 3. Particle size analysis (Table 3) indicated that the soils were loamy sand in texture with very high sand fractions. The sand content ranged from 82.06 to 87.88, silt from 3.91 to 7.79, and clay from 7.31 to 10.15. The soil pH and the electrical conductivity of the treated soils were significantly ($P<0.05$) affected by the different rates of abattoir effluent (Table 3). However, the highest pH value of 7.47 was obtained from soil treated with 150mls followed by soil treated with 200 mls (7.42) while the least value was obtained from the control soil (5.80). The result obtained from this study is in line with that of Chukwu and Anuchi (2016) who reported a significant increase in soil pH in abattoir contaminated soil.

The highest value of 0.60 dS/m for electrical conductivity was obtained from soil treated with 50mls of abattoir effluent while the least was obtained from the control (0.09 dS/m) soil. The low electrical conductivity observed in this study is an indication of the fact that the abattoir effluent was non -saline and therefore would not contribute to soil salinity. Soil organic matter was significantly (P<0.05) increased in all the treated soils when compared with the control (Table 3). The highest soil organic matter value of 6.24% was obtained from soil treated with 100mls of abattoir effluent while the least was observed in the control soil (2.79%). Soil total nitrogen content was generally low in all the abattoir effluent treated soils according to the rating by Chude*et al* (2012). The highest value of 42.10 mg/kg^{-1} of available phosphorus was obtained in soil treated with 50mls of abattoir effluent while the least was obtained in soil treated with 200mls but was significantly (P<0.05) higher than the control (6.03 mg/kg^{-1}). Exchangeable calcium (7.20cmol/kg^{-1}) and magnesium (4.31cmol/kg^{-1}) were significantly increased in soils treated with 50mls and 100mls of abattoir effluent, respectively.

Table 3: Effects of abattoir effluent on some physicochemical properties of the soil

Soil Property	0 ml	50 mls	100mls	150mls	200mls	(LSD 0.05)
Sand (g/kg)	87.60	87.83	82.06	87.75	87.88	1.54
Silt (g/kg)	3.88	4.11	7.79	3.91	4.80	0.15
Clay (g/kg)	8.52	8.06	10.15	8.34	7.31	1.54
Texture	LS	LSLSLS	LS			
Soil pH	5.80	7.39	7.17	7.47	7.42	0.09
EC (dS/m^{-1})	0.09	0.60	0.33	0.23	0.46	0.01
OM (%)	2.79	3.25	6.24	5.95	5.12	0.02
TN (%)	0.07	0.08	0.16	0.15	0.13	0.00
Avail. P (mg/kg^{-1})	6.03	42.10	36.14	31.12	28.09	2.35
Ca (cmol/kg^{-1})	3.20	7.20	6.00	4.80	3.40	0.02
Mg (cmol/kg^{-1})	1.60	3.21	4.31	2.80	2.81	0.03
Na (cmol/kg^{-1})	0.05	0.13	0.09	0.12	0.10	. 0.02
K (cmol/kg^{-1})	0.10	0.24	0.18	0.26	0.24	0.02
EA (cmol/kg^{-1})	1.00	1.73	1,69	1.89	1.59	0.08
ECEC (cmol/kg^{-1})	5.95	12.51	12.27	9.87	8.14	0.12
BS (%)	81.66	88.17	86.22	80.85	80.46	1.07

LS – loamy sand, EC – electrical conductivity, OM – organic matter, TN – total nitrogen, EA – exchange acidity, BS – base saturation

Effect of abattoir effluent on soil microbial population

The effect of abattoir effluent on microbial population (Table 4) showed that 50 ml concentration of the abattoir effluent was higher than other levels of concentration with 14.6 x10^{6}, 11.0 x 10^{3} and 12.9 x 10^{6} cfu/g for bacteria, fungi and coliform respectively. Increased in concentration of abattoir effluent reduced the isolates. The trend of occurrence of isolates was in the order of bacteria > coliform > fungi. This could be because the effluents may contain microorganisms which enhanced mineralization of nutrients. All the different concentrations of the effluent on soil microbial population were higher than the control.

Effect of different rates of abattoir effluent on growth parameters of chilli pepper

The effects of different rates of abattoir effluent on plant height, numbers of leaves, stem girth and leaf area at 2, 4 6 and 8 weeks after transplanting (WAP) are shown in Figures 1, 2, 3 and 4. The plant treated with 50mls of abattoir effluent produced the tallest plant height (75.32cm), number of leaves (34.67 cm), stem girth (2.50 cm) and leaf area (164.00 cm) relative to the control. Production of taller plants and higher number of leaves, stem girth and leaf area in treated soils compared to the control could be attributed to mineralization of the amendment and fast release of nutrients for plant use Ijah *et al*, (2021). Positive increase in plant height, number of leaves, stem girth and leaf area have also been reported by Castro *et al.* (2011).

Table 4: Effect of abattoir effluent on soil microbial population

Conc. (mls/5kg)	Bacteria Population		Fungi Population		Coliform Population	
0	*Micrococcus luteus*	$14x10^6$	Aspergillus niger	$10x10^3$	Enterobacter cloacae	$15x10^6$
	Bacillus subtilis	$21x10^6$	Penicilliumcrustosum	$8x10^3$		
50	Bacillus subtilis	$29x10^6$	Fusarium species	$15x10^3$	Escherichiacoli	$18x10^6$
	Micrococcus luteus	$19x10^6$	Aspergillus niger	$16x10^3$	Enterobacter cloacae	$22x10^6$
	Pseudomonas aeruginosa	$17x10^6$	Penicilliumcrustosum	$14x10^3$	Klebsiella species	$17x10^6$
100	*Pseudomonas* aeruginosa	$14x10^6$	Penicilliumcrustosum	$10x10^3$	Enterobacter cloacae	$16x10^6$
	Bacillus Subtilis	$10x10^6$	Aspergillus niger		Escherichia coli	$14x10^6$
			Fusarium species	$12x10^3$		
150	Bacillus Subtilis	$9x10^6$	Penicilliumcrustosum	$9x10^3$	Enterobacter cloacae	$11x10^6$
	Pseudomonas aeruginosa	$7x10^6$	Fusarium species	$10x10^3$	Escherichia coli	$10x10^6$
200	Bacillus Subtilis	$6x10^6$	Penicilliumcrustosum	$6x10^3$	Escherichia coli	$8x10^6$
	Mean	**$14.6x10^6$**		**$11x10^3$**		**$12.9x10^6$**

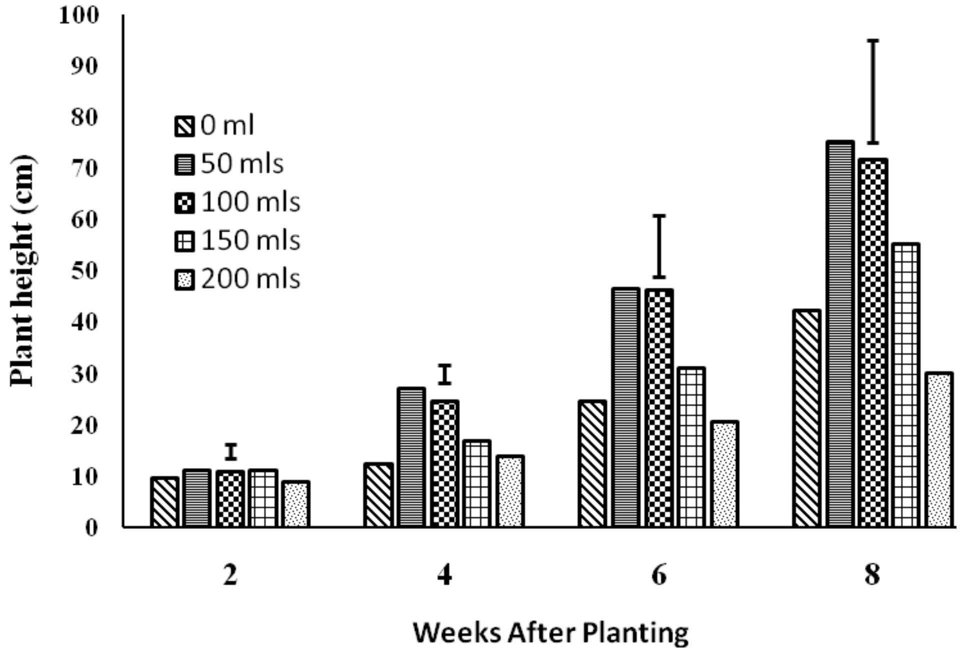

Figure 1: Plant height (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

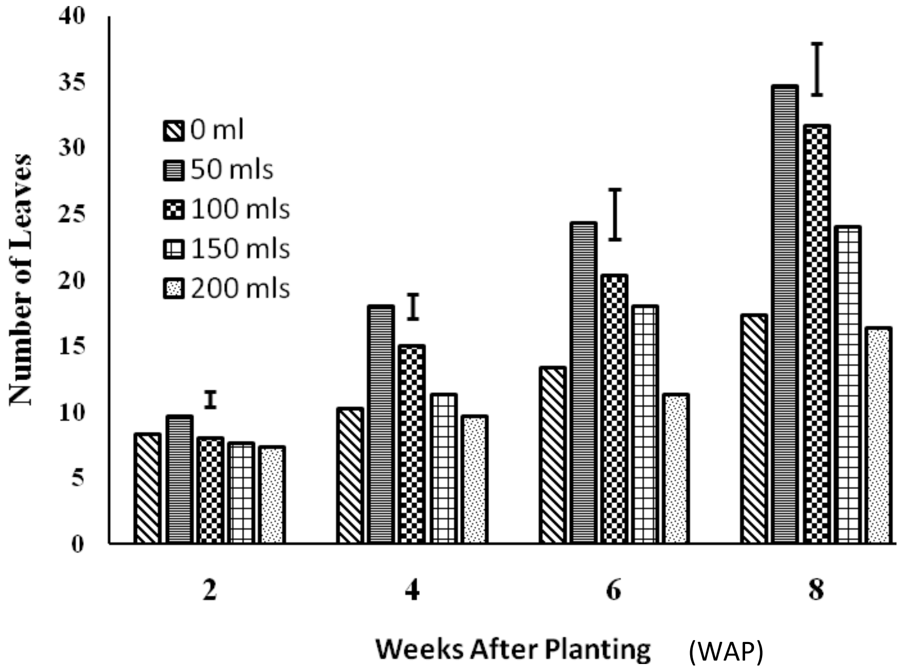

Figure 2: Number of leaves (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

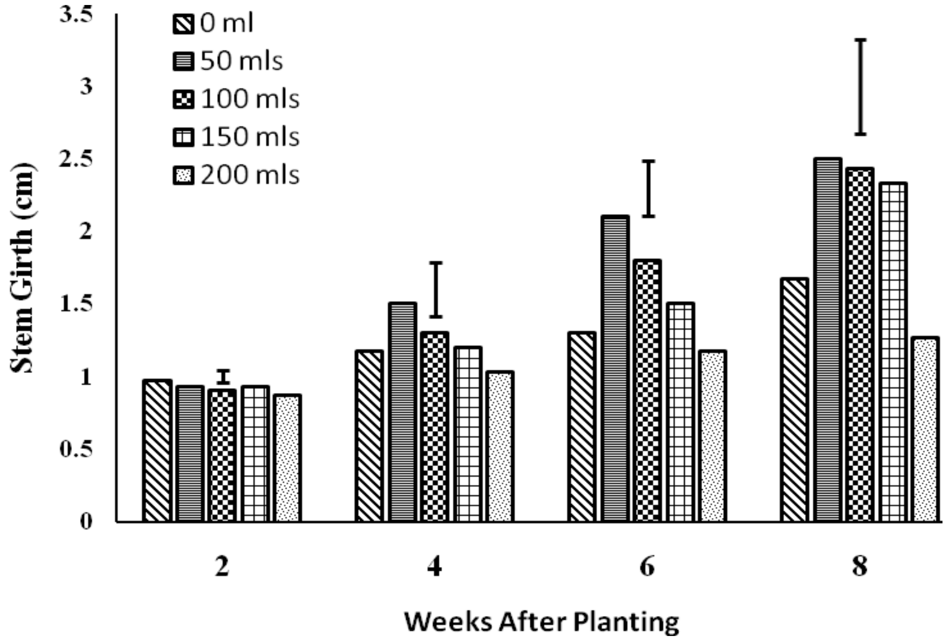

Figure 3: Stem girth (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

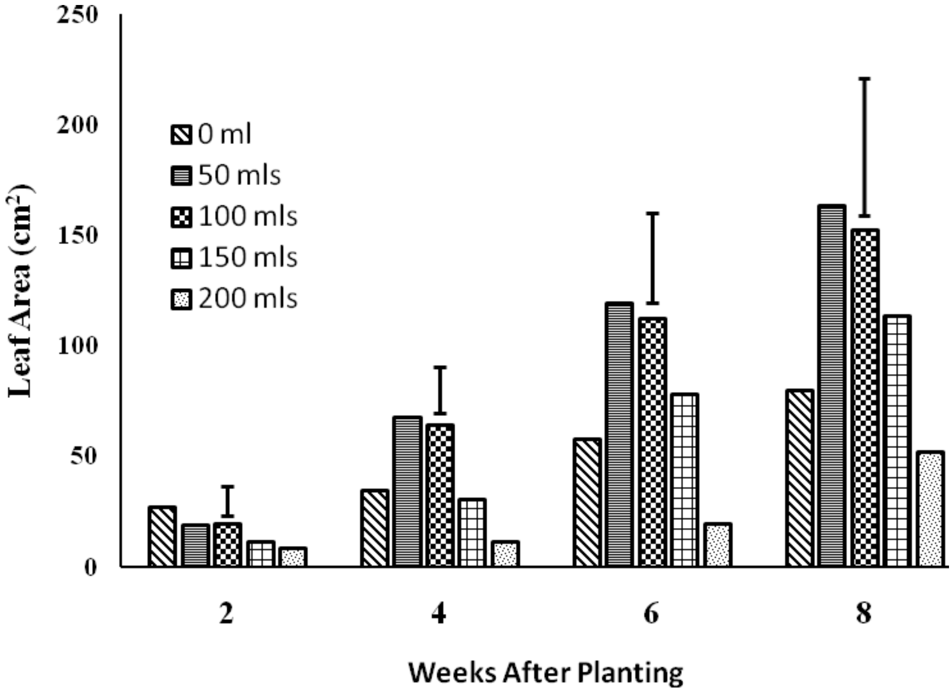

Figure 4: Leaf area (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

Effects of abattoir effluent on number of fruits per plant, fruit length and yield

The effects of abattoir effluent on number of fruits per plant, fruit length, and yield of chilli pepper are shown in Figures 5,6, 7 and 8. Application of different rates of abattoir effluent significantly ($p < 0.05$) increased number of fruits per plant (24.08 cm), fruit length (8.83 cm), fruit width (9.00cm) and fruit yield (2.5 tons/ha) when treated with 50mls of abattoir effluent compared with the control soil. There was no significant difference ($P > 0.05$) in fruit length of chilli pepper between plants treated with 50mls and 100mls of abattoir effluent but were significantly higher than the control. Positive increases in crop yield as a result of the application of abattoir effluent have been documented in several studies (Sparing *et al.,* 2006; Ayodele and Omotoso, 2008; Osemwota, 2010; Matheyarasu, 2016; Abhanzioya, 2016).

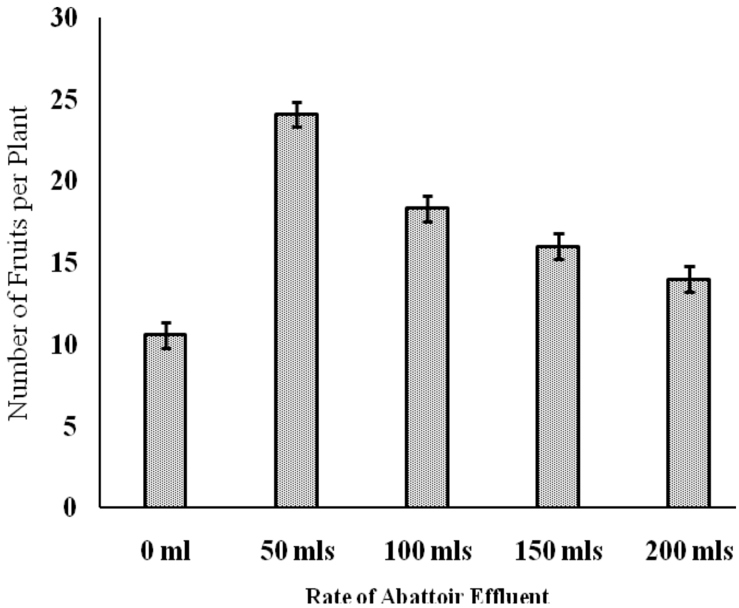

Figure 5: Number of fruits per plant of pepper (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

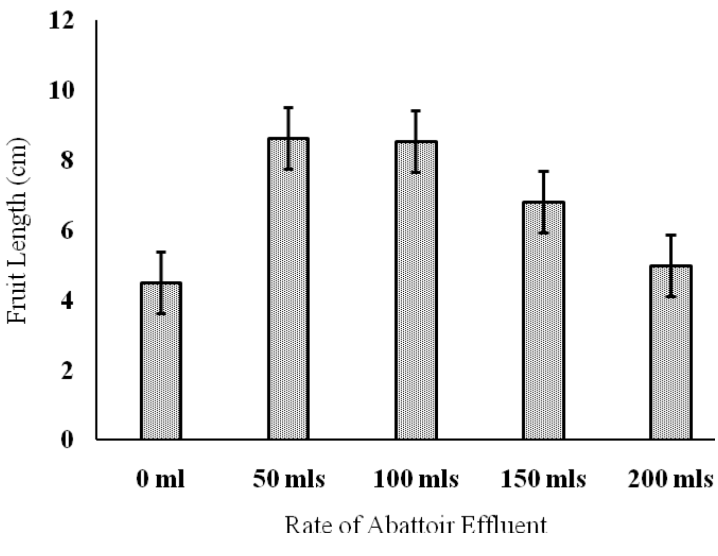

Figure 6: Fruit length of pepper (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

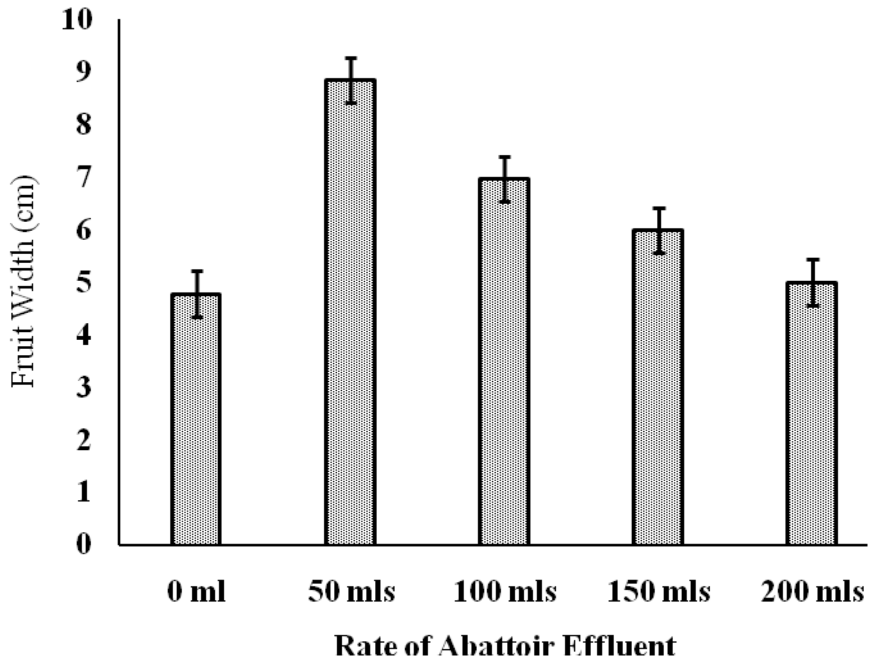

Figure 7: Fruit width of pepper (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

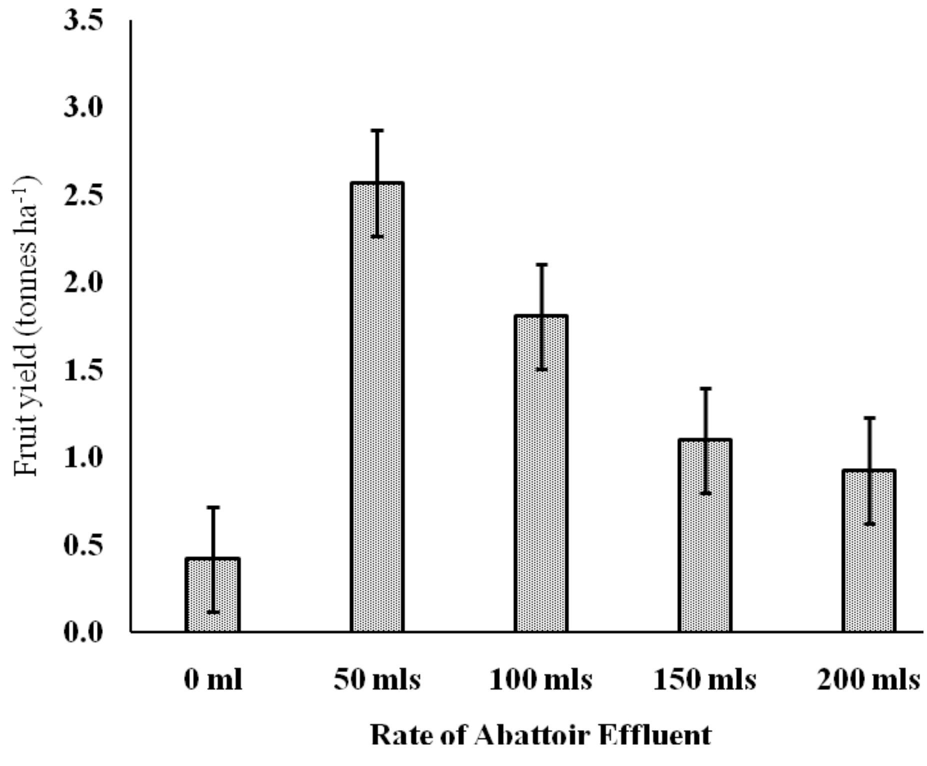

Figure 8: Fruit yield (ton ha^{-1}) of pepper (with $LSD_{0.05}$ bars) as affected by rates of abattoir effluent

CONCLUSION

The result of this study shows that the application of different rates of abattoir effluent significantly increased soil pH, organic matter, available phosphorus, exchangeable Ca, Mg, ECEC, base saturation and microbial populationrelative to the control. Chilli pepper responded positively to the application of abattoir effluent at all rates but superior increases in fruit number, fruit length, fruit width, and fruit yield were obtained from plants treated with 50mls of abattoir effluent. Based on the findings of this research, it could be concluded that the abattoir effluent is an important soil nutrient replenishing material and could be used for pepper production in the study area.

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Comparative Evaluation of Some Selected Soil Physical Properties Under Two Forest Plantations at Forestry Research Institute of Nigeria (Frin) Arboretum

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ABSTRACT

The different features of soil greatly affect the flora and vegetative diversity of a forest. The comparison of selected physical properties of soils under two forest plantations at Forestry Research Institute of Nigeria (FRIN) arboretum were evaluated to assess the productivity status of the soils. Soil samples was collected at 0 - 15 cm depth randomly from two forest plantations (i.e. mixed and *Nauclea didderrichii* forest plantation) with soil auger. Samples were collected into air tight poly bags to prevent the loss of soil moisture content. The following parameters were determined: bulk density, total porosity, soil gravimetric moisture content, particle size distribution, saturated hydraulic conductivity, plant available water (PAW), soil penetration resistance (PR), water stable aggregate, Infiltration rate. The study shows that bulk density, field capacity, microporosity, saturation, permanent wilting point and total porosity differs significantly ($P \leq 0.05$) under the two-forest plantation. Bulk density ranges from 1.18 kg\cm^3 under mixed forest plantation to 1.43 kg/cm^3 under *Nauclear diderrichii* forest plantation while total porosity ranges from 38.6% under mixed forest plantation to 50.7% under N*auclea diderrichii* forest plantation. It can be recommended that management practices be improved especially on mixed forest plantation in order to enhance the soil composition for the purpose of environmental sustainability.

Key words: Physical properties, Chemical properties, N*auclea diderrichii* and Mixed Forest Plantation

INTRODUCTION

The major ecological role of soils in forest and natural environment cannot be overemphasized. Soils are significantly affected by geologic and geomorphologic factors (water, wind, temperature change, gravity chemical interaction. topography, vegetation, living organism and pressure differences) (Boul, 1990). Soils are made up of four basic components: minerals, air, water, and organic matter. In most soils, minerals represent around 45% of the total volume, water and air about 25% each, and from 2% to 5% organic matter. Different characteristics of soil such as depth, consistency, temperature, nutrient contents, moisture content, permeability, porosity etc., can greatly influence the nature of vegetation that grows on them (Boyle and Powers, 2013). Forest soils in comparison to other soils are characterized by the presence of litter with an associated unique micro flora and fauna, higher porosity, higher permeability, more stable soil aggregates and greater water holding capacity (Ivonin and Zasoba, 2003).

The physical, chemical and biological processes sustained by soil make it a dynamic zone, consisting of inorganic (rocks) and organic particles (plant and animals remains), liquid (water and chemicals in solution) and gaseous substances. The relationship between trees and soil is of importance since they are dependent on each other and on the environment as a whole (FAO, 2015). The support, nutrients and water needed by trees to grow is provided by soil; while trees and other plants are important factors in the formation and enrichment of soil (FAO, 2015). The biological nitrogen fixation, phosphorus solubilization and decomposition of organic matter in rhizosphere and non-rhizosphere zones of plants increases soil organic matter, improve soil structure and nutrient cycling of soils (Voroney, 2007; Schoenholtz *et al*., 2000). Likewise, the gathering of nutrients by different tree species as well as their potential to return these nutrients into the soils can cause variations in soil properties (Rawat, 2005). The regular removal of vegetation through deforestation for farming and other human activities decreases the vegetation cover thereby leading to soil degradation by erosion processes especially in areas with hilly topography (Amonum *et al*., 2019). It may also result into water logging which may in turn cause leaching of nutrients under the plant's root zone and volatilization, making the soil deficient in some nutrients (Olujobi, 2016).

Trees may play a major role in increasing soil fertility through the ecological and physicochemical changes they induce in soil (Singh *et al*., 2002). Litter fall is the main path for the return of dead organic matter and nutrients to the soil and humus formation in tropical forest systems (Spain, 1984). Soil physical properties have long been considered to exert great influence on the distribution, growth and development of trees. Tree cover in turn, influences the improvement of physical properties of soil (Rathod and Devar, 2003).

Nauclea diderrichii is a forest species which can reach 35 - 40 m of height. Member of Rubiaceae family, this species is mainly found in African rain forest (Wagenfuhr, 2000). In Nigeria this overexploitation and lack of its reforestation leads to its disappearance, as a result this species is classified on the list of the rare species (UNEP, 2010). Its regeneration in-situ is laborious because of the dormancy of its seeds (Hawthorne, 1995). According to Onyekwelu *et al.*, (2003), because of the risk of extinction of this species, its artificial regeneration becomes necessary. Sustainability of natural forest and environment depend largely on consistent monitoring of soil quality. Therefore, the objective of this study was to investigate some selected physical properties of soils under two forest plantations at Forestry Research Institute of Nigeria (FRIN) arboretum.

MATERIALS AND METHODS

DESCRIPTION OF THE STUDY AREA

This experiment was carried out at Forestry Research Institute of Nigeria (FRIN) arboretum, Ibadan. The Research Institute is situated at Jericho Hill, Ibadan North West area of Oyo state. The area lies between latitude 8^o 23^1 N and longitude 3^o 15^1 E. The climatic condition of the area is tropically dominated by rainfall pattern from 1400 mm – 1500 mm. The average temperature is about 33^o C, average relative humidity of 85 – 90 % with two distinct seasons, dry season from November to March and rainy season from April to October (FRIN, 2020).

SOIL SAMPLING, PREPARATION AND LABORATORY ROUTINE ANALYSIS

Random soil samples were collected at 0 - 15 cm depth from two forest plantations (i.e. mixed forest and Nauclea didderchii forest plantations) with the aid of soil auger and core sampler during dry season. The soil samples were collected into properly labelled poly-bag, tied before taking to the laboratory for some selected physical properties determination. Soil samples collected were firstly sieved through 2mm mesh sieve to remove gravel, small stones and coarse roots.

Determination of Soil Physical Properties

Soil bulk density was determined using core method as described by Blake and Hartage (1986). Total porosity (TP) was determined from the relationship between the bulk density and the particle density. Gravimetric moisture content as described by Gardener (1986) was determined. Available water content was determined by tension plate apparatus similar to that of Topp and Zebchuk (1979). Particle size analysis was carried out using the Bouyoucos hydrometer method (Bouyoucos, 1962, Oshunsanya, 2016). Saturated hydraulic conductivity was determined using undisturbed core samples collected from the experimental field. (Soil Science Society of America, 2002; Oshunsanya, 2016). Soil penetration resistance (PR) was determine using cone i.e. (penetration test) for soil strength with a digital penetrologger (Eijkelkamp, Giesbeek, Netherlands) from 0 - 60 cm depth as described by (Soil Science Society of America, 2002). Water stable aggregate >250 µm (WSA >250 µm) was determined using a modified Kemper and Rosenau wet sieving method as described by Nimmo and Perkins (2002) on disturbed soils collected at 0 – 15 cm depth. Infiltration and near saturation hydraulic conductivity were determined using a tension Infiltrometer. This apparatus allows for the measurement of water movement into the soil in-situ.

DATA ANALYSIS

Data collected was analysed using Genstat statistical software package. Means were separated using least significantly difference (LSD) at 5% level of significance.

RESULT AND DISCUSSION

Comparison of some selected physical properties of soil under two forest plantations is as presented in Table 1. Available water content, saturated hydraulic conductivity, aggregate stability and macroporosity did not differ significantly. Available water content ranges from 0.25 under mixed forest plantation to 0.32 under *Nauclea diderrichii* forest plantation. This agrees with the findings of Williamson and Neilsen, 2000. In accordance with Mudgal *et al*., (2010), saturated hydraulic conductivity content ranges from 59.00 cm min^{-1} under N*auclea diderrichii* forest plantation to 116.00 cm min^{-1} under mixed forest plantation. In lieu of the observation of Messing *et al*., 1997, Aggregate stability range from 59.00 % under *Nauclea diderrichii* to 116.00 % under mixed forest plantation. Macro porosity ranges from 29.70 % under mixed forest plantation to 36.30 % under N*auclea diderrichii.*

Bulk density, field capacity, microporosity, saturation level permanent wilting point and total porosity differs significantly (P≤ 0.05) under the two-forest plantation. Bulk density ranges from 1.18 kg\cm^3 under mixed forest plantation to 1.43 kg\cm^3 under *Nauclear diderrichii* forest plantations. Therefore, the bulk density ranges from fine texture soil to medium texture soil. These findings support earlier work done by Shittu and Amusan, 2015, reported inverse relationships between BD and porosity of soils under two forest plantations.

Field capacity content ranges from 0.34 under mixed forest plantation to 0.47

under *Nauclea diderrichii* forest plantation. Microporosity ranges from 8.85% under mixed forest plantation to 14.38% under *nauclea diderrichii* forest plantation. Saturation level range from 0.39% under mixed forest plantation to 0.51% under *nauclear diderrichii* forest plantation. Permanent wilting point range from 0.09% under mixed forest to 0.14% under *nauclea diderrichii* forest plantation, total porosity range from 38.6% under mixed forest plantation to 50.7% under *nauclea diderrichii* forest plantation which may affect the infilteration of water in the mixed forest. This is in line with Lambers, *et al*., 2008 who reported that the soil physical properties can be altered over time by the management practices and nature of vegetative cover. The wilting point refers to the moisture content of soil where the absorptive capacity of the root is less than the demand of the plant.

Table 1: Comparison of some	***Nauclear diderrichii***	**Mixed Forest Plantation**	**LSD(P≤0.05)**
Aggregate Stability %	50.0	59.5	9.81 ns
Available Water	0.32	0.25	0.09 ns
Bulk Density kg\cm^3	1.43	1.18	0.17**
Field Capacity	0.47	0.34	0.09*
K. Sat cm min^{-1}	59.00	161.00	78.5 ns
Macro Porosity %	36.30	29.70	9.29 ns
Micro Porosity %	14.38	8.85	4.14*
Saturation level	0.15	0.39	0.092*
PWP	0.14	0.09	0.04*
Total Porosity %	50.7	38.6	9.23*

Table 2: Comparison of Penetration Resistance of the volumetric moisture content under two forest plantation.

Description	***Nauclear*** **(cm)**	**Mixed Forest (cm)**	**LSD (P≤0.05)**
Vol	13.80	10.00	5.13 ns
0 – 10 cm	0.24	0.19	0.17 ns
10 – 20 cm	0.64	0.80	0.41 ns
20-30 cm	0.88	1.99	0.54 **
30-40 cm	1.20	2.71	1.08 *
40-50 cm	1.65	3.42	1.27 *
50-60 cm	2.42	2.58	2.21ns

Comparison of Penetration Resistance of the volumetric moisture content under two forest plantations is as presented in Table 2. The penetration resistance of the volumetric moisture content, 0-10cm, 10-20cm, 50-60cm did not differ (P≤0.05) significantly under the two forest plantation. In line with the findings of Powers *et al*., 1990, volumetric moisture content range from 10 cm under mixed forest plantation to 13.8 cm under *Nauclea Diderichii*. At 0-10 cm, penetration resistance range from 0.19 cm under mixed forest plantation to 0.24 cm under *Nauclear Diderrichii* forest plantation, penetration resistance at 10-20 cm range from 0.64 cm under *Nauclea Diderrichii* forest plantation to 0.80 cm under mixed forest plantation. Penetration resistance at 50-60 cm range from 2.42 cm under *Nauclea Diderrichii* forest plantation to 2.58 cm under forest plantation. The penetration resistance at 20-30 cm, 30-40 cm and 40-50 cm differs significantly (P≤

0.05) under the two forest plantation. At 20-30 cm, penetration resistance range from 0.88cm under *Nauclea Diderrichii* forest plantation to 1.99 cm under mixed forest plantation, penetration resistance at 30-40 cm range from 1.20 cm under *Nauclear Diderrichii* forest plantation to 2.71 cm under mixed forest plantation, penetration resistance at 40-50 cm range from 1.65 cm under *Nauclea Diderrichii* forest plantation to 3.42 cm under mixed forest plantation. Therefore, penetration resistance above or greather than 2 cm implies that roots of plants will not be able to penetrate in which it resolves to compaction.

Table 3:- Comparison of particle size distribution soil under the two forest plantation

Textural Class	***Nauclaer***	**Mixed Forest**	**LSD**
SAND %	79.80	78.30	4.33*
SILT %	14.00	14.70	2.09ns
CLAY %	6.20	7.00	3.92ns
TEXTURAL	Loamy sand	Loamy sand	

Comparison of particle size distribution of soils under the two-forest plantation is as presented in Table 3. Sand differ significantly (p≤0.05) while Silt and Clay did not differ significantly under the two forest plantations. *Nauclea diderrichii* Sand content range from 78.30 % under mixed forest plantation to 79.80% under *Nauclea diderrichii* Plantations. Silt content range from 14.00% under to 14.70% under mixed forest plantaion to 7.00% under mixed forest plantation. While clay content ranges from 6.20% under *nauclea diderrichii* to 7. 00% under mixed forest plantation.

CONCLUSION AND RECOMMENDATION

The result showed that some selected physical properties such as bulk density, total porosity, field capacity, micro porosity, permanent wilting point and saturation differs significantly, while aggregate stability, availability of water, and saturated hydraulic conductivity did not differ significantly.

Therefore, It can be concluded that the soils under *Nauclea diderrichii* plantations is better used for planting because of its high porosity level at 50% easing the penetration or infiltration of water into the soils unlike the mixed forest with low level of porosity in which soil is compacted (not allowing easy penetration or infiltration of water into the soil) resulting from frequent traffic of people benefiting from the diverse species of forest products found on the plantation. Also, it can be recommended that management practices be improved especially on mixed forest plantation in order to enhance the soil composition for the purpose of environmental sustainability.

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Responses of Two Carbon Enzymes, Soil Respiration and Microbial Biomass Carbon to Land-Use at Varying Soil Depth in Two Contrasting Soil

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ABSTRACT

To determine the interaction effects between different land use types, soil depths and soil types on soil carbon enzymes. Soil samples were collected from two locations (Teaching and Research Farm of The Federal University of Technology, Akure and Esedo Comprehensive High school, Iwaroka, Akoko) both in southwestern Nigeria with each location representing two different soil order in the region, the two land uses selected in both soil order were; oil plantation that has been in place for more than 10 years and arable land occupied with maize (ploughed with tractor yearly). Two experiments comprising of randomized complete block design arrangement for the field determination and completely randomized design (CRD) laboratory incubation experiment was carried out to determine soil bio-chemical properties and the response of two carbon enzymes to land use and varying soil depth in two contrasting soil type (Alfisol and Ultisol) respectively. Soil respiration and microbial biomass carbon activities for the period of incubation, carbon enzymes (Invertase and Cellulase) activity, soil pH, organic Carbon, Nitrogen and Phosphorous were determined. Results revealed significant variations among the treatment combination as determined in carbon enzymes (invertase and cellulase) and soil types (Alfisols and Ultisols). Alfisols exhibited higher cellulase and invertase activity than Ultisols in both surface and subsurface soil (soil depth). Moreover, land use practices exerted a substantial influence in cellulase activity in arable land use.

Key words: Carbon enzymes, microbial biomass carbon, soil pH, soil respiration.

1.0 INTRODUCTION

Land use refers to the cyclic or permanent utilization of a vacant or developed land for a clear purpose such as cropland and forestland at a given time (Balasubramanian, 2015) and changes in land use is associated with changes in vegetation type and management practices. The changes in vegetation can alter above-ground biomass, soil organic matter content, soil microbial communities, and the plant growth microenvironment, and thus affect soil respiration and temperature fluctuations (Han *et al.,* 2014). Land use change is known to have a significant impact on soil carbon dynamics, as it alters the quantity and quality of plant litter inputs to soil and modifies the microbial community composition. Previous studies have reported changes in soil carbon storage and microbial biomass in response to land use changes such as agricultural intensification, afforestation, and urbanization (Lal, 2004; Guo and Gifford, 2002; Zhou et al., 2006). However, the effects of land use on soil carbon-degrading enzymes, such as invertase and cellulase, remain poorly understood. Moreover, the distribution of soil carbon and the microbial community varies with soil depth due to differences in physical, chemical, and biological properties. Recent studies have shown that the activity of carbon-cycling enzymes in soil also varies with soil depth (Sun et al.,2017; Gong et al., 2018).

Carbon enzymes are a group of enzymes involved in the carbon cycle, which is the process of carbon transfer between the atmosphere, oceans, and the terrestrial biosphere. Carbon enzymes play a crucial role in the decomposition of organic matter, releasing carbon and nutrients into the soil. Cellulase and invertase are essential enzymes involved in the degradation and metabolism of carbohydrates. Cellulase breaks down cellulose, a complex polysaccharide found in plant cell walls, into simpler sugar molecules, while invertase hydrolyzes sucrose into glucose and fructose. These enzymes play crucial roles in various biological processes, including plant cell wall degradation, nutrient cycling, and industrial applications (Kuhad *et al*., 2011; Santos *et al*., 2012). However, few studies have investigated the combined effects of land use and soil depth on soil carbon-cycling enzymes. Therefore, the objective of this study is to investigate the responses of invertase and cellulase activities to land use at varying soil depths in two contrasting soil types.

2.0 Materials and Methods

The experiment was a field and laboratory experiments. The laboratory experiment was carried out in the laboratory of Crop, Soil and Pest Management, Federal University of Technology, Akure, Ondo state located in the rain forest zone of Nigeria.

2.1 Experimental Site

2.1.1 Land use selection

The two locations where the research was carried out were selected because they distinctly represent two different soil order in the region where the research was carried out and the two land uses selected in both soil order were; oil plantation that has been in place for more than 10 years, Arable land occupied with maize and ploughed yearly.

2.2 Soil Sample Collection

Soil samples were collected at the Teaching and Research farm of Federal university of technology, Akure (FUTA) and Esedo comprehensive high school, Iwaroka Akoko, Ondo state both in southwestern Nigeria. The Teaching and Research farm of Federal university of technology, Akure (FUTA) has a land area of about 2303 km^2 and is situated in the western upland area within the humid region of Nigeria.

The general elevation is 300 - 700 m above mean sea level. Local peaks rise to 1000 m; other hill-like structures which are less prominent rise only a few hundred meters above the general elevations. The pattern of rainfall is bimodal, the first peak occurring in June and July, and the second in September, with a little dry spell in August. The mean annual rainfall ranges from 1300 mm to1500 mm (Odubanjo *et al*., 2013). The soils of the site are light textured and predominantly sandy clay loam and belong to the alfisol (Soil Survey Staff. Soil Taxonomy, 1999). The soil is moderately well supplied by organic matter and nutrients. Moisture holding capacity is moderately good (Fasinmirin, Adesigbin, 2010). The soil generally becomes dry during the dry seasons which fall within November and March.

Oka is the 4th largest city in Ondo state, this area is moderately populated and it is surrounded by settlement such as Ifira Akoko, Arigidi Akoko etc. Esedo Comprehensive high school is located in, Iwaroka-oka Akoko area in Ondo state, the landscape is a mix of savannah and lowland forest. Annual rainfall ranges between 8cm-150cm per year with an average temperature of 28-35ºC with annual rainfall of about 1,270mm. Humidity is relatively high for a good part of the year.

2.2.1 Sampling techniques

In each soil order, soil samples were collected at random from the two different forms of land use type. Each land-use type was approximately 0.5 hectares in size. Four soil samples were taken at depths of 0 -15 cm and 15 -30 cm from each land use category. Due to the homogeneity of the study area, each land use was treated as a unit. Soil samples were obtained at random from each of the two soil depths from various land use types, the soil sample was air dried, passed through a 2 mm sieve, and stored in plastic bags for laboratory analysis. A portion of each soil sample was placed in a container and it was frozen, this soil samples were used for the enzymes assay. Table 1 presents experimental sites and their coordinates.

Table 1: Experimental sites and their coordinates

Experimental sites	**Alfisol (FUTA)**		**Ultisol (Iwaro Oka Akoko)**	
	Longitude	**Latitude**	**Longitude**	**Latitude**
Maize farm(Arable)	E 5° 7' 49"	N 7° 18' 80"	E 5° 45' 88"	N 7° 26' 62"
Oil palm(Plantation)	E 5° 7' 98"	N 7° 18' 82"	E 5° 45' 12"	N 5° 45' 88"

2.3 Experimental Design

This research involved two different experiments. The field data collection was arranged in 2x2x2 factorial in RCBD while the incubation experiment was CRD

2.4 Determination of Physico-Chemical Properties of Soil

Soil texture, pH, Organic matter and soil nutrient status of the air-dried soil sample were determined following standard methods (AOAC, 1990). The soil samples were analyzed for total N using Kjeldahl digestion and distillation method. Available phosphorus was by the Bray 1 method, soil pH (1:2 soil-water) was determined by pH meter, while organic matter (OM) was determined by dichromate oxidation method.

2.5 Measurement of Soil Basal Respiration (SBR)

Basal respiration (µg CO_2 -C g^{-1} soil) was determined by the alkali sorption and titration method described by Anderson and Domsch (1990). A day prior to sampling, a 10 mL solution of 0.5M NaOH was dispensed into a 50mL beaker and placed inside the glass jars containing the treated soil to trap CO_2 evolved from the soil. On the second day, 5mL of 0.5M $BaCl_2$ was added to the NaOH solutions from the jars to precipitate carbonate (as $BaCO_3$), thus facilitating the determination of CO_2 evolution (as µg CO_2-C g-1 soil) from the treated soil. The evolved CO_2-C was then determined by titration. NaOH in solution was titrated against 0.5 M HCl using phenolphthalein indicator. Blank (without soil) was prepared along the samples to assess the amount of CO_2 trapped without respiratory activity.

2.6 Determination of Soil Microbial Biomass Carbon (Cmic)

Soil microbial biomass C (Cmic) was determined by the fumigation and extraction method described by (*Vance et al. 1987*). 10g of non-fumigated soil was extracted with 50 mL of 0.5 M K_2SO_4 by shaking for 45 min with a rotary shaker at 180 rpm, and the suspension filtered using a Whatman No. 2 filter paper. A separate portion was fumigated by placing it in a 50-mL beaker inside a desiccator alongside with another beaker containing ethanol-free chloroform. The desiccator was covered and evacuated with a vacuum pump until the chloroform boiled vigorously for 5 min. The evacuation was repeated three times at intervals of 15 min, letting air pass back into the desiccator to facilitate the distribution of the chloroform throughout the soil. The desiccator was evacuated a fourth time until the chloroform boils vigorously for 2 min. 24 hours later, the $CHCl_3$ was removed by vacuum extraction and the fumigated sample was extracted as above. Organic carbon in the extract was determined by the wet combustion method of Walkley and Black. MBC was calculated by the differences between the fumigated and non-fumigated samples divided by the K_2SO4 extract efficiency factor (Kc = 0.35) (Sparling *et al.*, 1990).

2.7 Incubation experiment for Assay of carbon cycling enzymes

2.7.1 Cellulase determination

Five (:-5)grams of soil was weighed into a 100ml Erlenmeyer flask, 1 ml of toluene was added and 10 ml of acetate buffer. 10 ml of carboxyl methyl cellulose (CMC) @ 1% was added and was incubated for 24hrs, the reaction was stopped by the addition of 3,5-dinitrosalicylic acid (DNS) reagent. 5ml of Sodium carbonate (Na_2CO_3) was added and the soil suspension was filtered and 1 ml of the filtrate was pipetted. Glucose solution was prepared for standard to determine the reducing sugar using spectrophotometer.

2.7.2 Invertase determination

Five (:-5) grams of soil was weighed into a 100 ml of Erlenmeyer flask, 1 ml of toluene was added, 6 ml of buffer solution and 1 ml of sucrose solution and left to incubate for 24hrs, the reaction was stopped by the addition of 3,5-dinitrosalicylic acid (DNS) reagent.. 5 ml of Sodium acetate buffer solution was added and the suspension was mixed and filtered. Glucose solution was prepared at different concentration 1 ml of the filtrate was pipetted and measured using spectrophotometer.

2.8 Chemicals

All the solvents and other chemicals used were analytical grades and obtained from Pascal Chemical Company Ltd. (Akure, Nigeria).

2.9 Data Analysis

All data collected were subjected to the analysis of variance (ANOVA) using Minitab software statistical package and mean separation was done using Tukey's test at 5% level of probability. **RESULTS**

3.1 Interaction effects of land use, soil depth and soil type on soil chemical properties

Significant variabilities were not observed among the treatment combination regarding their influence on pH although arable ultisol simile has the highest value at 15-30cm depth, Also, significant difference were observed across the table with respect to the treatment combination influencing organic C, P and N.

In summary, the table demonstrates that soil type, land use, and soil depth influenced soil chemical properties.

Table 2: Interaction effects land use, soil depth and soil type on soil chemical properties

Soil Type	**Land Use**	**Depth**	pH 1:2	Organic Carbon (%)	Phosphorus (mg/kg)	Nitrogen (%)
Alfisol	Arable	0-15 cm	7.13a	1.59bc	15.74d	0.14b
		15-30 cm	6.90a	1.29cd	26.43ab	0.41a
	Plantation	0-15 cm	6.83a	1.83ab	15.31d	0.47a
		15-30 cm	7.06a	1.64bc	28.42a	0.44a
Ultisol	Arable	0-15 cm	7.23a	1.00d	24.93b	0.36a
		15-30 cm	7.36a	0.64e	27.99ab	0.37a
Ultisol	Plantation	0-15 cm	7.06a	1.21d	16.39d	0.36a
		15-30 cm	7.06a	2.11a	21.30c	0.43a

Mean in a column that do not share the same letter(s) are significantly different according to Tukey Test(P<0.05).

3.2 Interaction effects of land use, depth and soil type interactions on soil basal respiration

Significant variations were observed among the treatment combination regarding their influence on soil respiration because across the weeks there were no consistent trend in the way treatment combination affected SBR. However, on day 7 the highest volume of CO_2-C was recorded in ultisol arable at 0-15cm depth and was strictly followed by ultisol plantation at the same depth. Whereas alfisol arable at 0-15cm recorded the lowest volume of CO_2-C collected in jars.

Table 3: Interaction effects of Land use, Soil depth and Soil type on soil basal respiration(mg-Ckg^{-1}day^{1})

	Days after incubation				
FACTORS	1	2	3	7	14
Soil type x Land use x Depth					
Alfisol Arable 0-15cm	13.2a	6.4c	14.8a	17.0bc	13.23abc
Alfisol Arable 15-30cm	10.2abc	9.0ab	14.2ab	11.80d	13.46ab
Alfisol Plantation 0-15cm	12.1ab	9.2ab	12.4abc	12.70cd	12.30abc
Alfisol Plantation 15-30cm	10.6abc	11.4a	14.5ab	9.60d	15.23a
Ultisol Arable 0-15cm	12.70a	10.6a	12.10abc	22.30a	11.93bc
Ultisol Arable 15-30cm	6.90c	11.4a	10.70bc	12.70cd	10.60c
Ultisol plantation 0-15cm	11.2abc	11.0a	12.30abc	17.80ab	11.93bc
Ultisol Plantation1 5-30cm	8.00bc	9.50ab	10.20c	13.10cd	14.10ab

Mean in a colmn that do not share the same letter(s) are significantly different according to Tukey Test(P<0.05)*3.3 Interaction effects of soil type-land use-soil depth on soil biomass carbon (Cmic)*

Results showing the combined effects of Soil type, Land use and Soil depth on biomass carbon (Cmic) are presented in Table 4. Significant variations were observed across the table regarding the influence of treatment combinations on biomass carbon. At day 1, alfisol arable and ultisol arable at 0-15cm depth respectively recorded the highest value which was strictly followed by ultisol arable at 0-15cm in day 2. However, at the end of incubation the lowest activity was recorded in alfisol plantation on day 14 at 15-30cm depth.

Table 4: Interaction effects of soil type-land use-soil depth on soil biomass carbon(Cmic)

	Days after incubation				
FACTORS	1	2	3	7	14
Soil type x Land use x Depth					
Alfisol Arable 0-15cm	11.16cd	11.16cd	14.80ab	16.23ab	15.90a
Alfisol Arable 15-30cm	20.40a	17.20ab	16.80a	14.70abc	16.50a
Alfisol Plantation 0-15cm	12.20c	12.20c	18.10a	15.30abc	7.00cd
Alfisol plantation 15-30cm	8.60d	8.60d	15.80a	12.63bc	6.03d
Ultisol Arable 0-15cm	16.30b	16.30bc	11.30bc	17.60a	15.90a
Ultisol Arable 15-30cm	20.40a	20.40a	8.00cd	12.70bc	13.70ab
Ultisol Plantation 0-15cm	8.00d	8.00d	10.80c	11.70c	11.60b

Mean in a column that do not share the same letter(s) are significantly different according to Tukey Test(P<0.05).

3.4 Interaction effects of land use and soil type and depth on soil invertase and cellulase activity

Cellulase and Invertase activity was found to be higher in ultisol arable at a soil depth of 0-15cm and ultisol plantation at 15-30cm depth. However, in ultisol plantation cellulse activity was lower at 15-30cm soil depth while alfisol plantation at 0-15cm recorded the lowest invertase activity. Hence, there was a consistent trend in the way treatment combination affected cellulase and invertase activity.

Table 5: Interaction effects of land use and soil type and depth on soil invertase and cellulase activity

	Carbon enzymes	
FACTORS		
Soil type x Land use x Depth	Cellulase activity	Invertase activity
Alfisol Arable 0-15cm	1.32b	0.41bc
Alfisol Arable 15-30cm	2.67ab	0.70ab
Alfisol Plantation 0-15cm	1.99ab	0.19c
Alfisol Plantation 15-30cm	0.62bc	0.75ab
Ultisol Arable 0-15cm	3.49a	0.30c
Ultisol Arable 15-30cm	0.79b	0.41bc
Ultisol plantation 0-15cm	1.89ab	0.18c
Ultisol Plantation 15-30cm	0.58bc	0.94a

Mean in a column that do not share the same letter(s) are significantly different according to Tukey Test(P<0.05).

DISCUSSION

Soil basal respiration is the rate at which microorganisms decompose soil organic matter and release CO_2 into the atmosphere. The interaction effects of land use, soil type and soil depth on soil respiration suggests that for all factors and levels, there is a general trend of decreasing soil basal respiration with increasing soil depth with land use and soil depth having significant effects on soil basal respiration. The complex interactions among soil types, land use, and depths in influencing soil basal respiration shows that soil type can have a significant effect on soil basal respiration. Different soil types have different physical and chemical properties that can affect the amount of carbon and other nutrients available for microbial activity. For example, soils with high organic matter content generally have higher basal respiration rates than those with low organic matter content (Xie *et al.,* 2021). Research studies have shown that basal respiration rates are generally higher in Alfisols than in Ultisols due to the differences in organic matter content and nutrient availability. Studies by Franzluebbers *et al.,* (2000) found that Alfisols had significantly higher basal respiration rates compared to Ultisols. Land use is another factor that can influence soil basal respiration rates. Other land use practices that can affect soil properties, includes soil moisture, organic matter content, and nutrient availability, which in turn can have impact on both microbial activity and basal respiration rates. For example, agricultural land use practices, such as tillage and crop rotation, can increase basal respiration rates by increasing the availability of carbon and other nutrients (Laville *et a*l., 2019). Conversely, land use practices that reduce vegetation cover, such as deforestation or urbanization, can reduce basal respiration rates by decreasing the amount of organic matter available for microbial activity (Brewer *et al*., 2020). Soil depth is another factor that can affect basal respiration rates. Soil properties, such as organic matter content and nutrient availability, can vary with depth, which can impact microbial activity and basal respiration rates. For example, deeper soils generally have lower basal respiration rates than surface soils due to lower nutrient availability and microbial biomass (Bianchi *et al*., 2018).

The impact of soil type on soil microbial biomass carbon, shows that the microbial activity was significantly higher in ultisol compared to alfisol which could be as a result of the differences in soil organic matter content. Ultisol soils are typically formed in areas with high rainfall and high temperatures, which can lead to higher rates of organic matter decomposition and turnover compared to alfisol soils, which are typically formed in areas with more moderate climates (Liu *et al*., 2018). Higher soil organic matter content can provide a greater pool of substrates for microbial growth and activity, leading to higher MBC rates. Another reason why MBC may be higher in ultisol soil type compared to alfisol soil type is due to differences in soil microbial community composition. Studies have shown that ultisol soils may have a greater abundance of microorganisms that are adapted to nutrient-poor and acidic environments compared to alfisol soils (Zhang *et al.*, 2018). These microorganisms may be better adapted to efficiently utilize substrates, leading to higher MBC rates in ultisol soils. Furthermore, ultisol soils are typically more weathered and have lower cation exchange capacity (CEC) compared to alfisol soils, which can result in lower nutrient availability and lower microbial biomass (Yang *et al.*, 2020). However, this can also lead to a more selective microbial community, which may be more efficient in utilizing substrates, hence a higher MBC rates.

The activities of cellulase and invertase enzymes are very high in alfisol compared to ultisol, and this could be as a result of the higher clay content and organic matter that provides a favourable environment for microbial activity. Cellulose-producing microorganisms thrive in these conditions, leading to increased cellulose activity. The presence of cellulose enzymes allows for the efficient decomposition of cellulose, a major components of plant residues, into simple sugars that can be utilized by plants. Also, the higher organic matter content in alfisol soil provides an abundant source of carbon for microorganisms which enhances the production of invertase enzymes. Invertase breaks down sucrose to glucose and fructose, making these sugars available for plant uptake. Arable land use involves the cultivation of annual crops which is characterized typically for regular tillage, incorporation of organic matter such as crop residues or manure, and crop rotation. These practices can contribute to higher organic matter in the topsoil, providing a favorable environment for microbial activity. The presence of crop residues and organic amendments provides a continuous source of carbon, promoting the growth and activity of microorganisms involved in the production of these enzymes.

CONCLUSION

The present study improved our understanding of how land use and soil depth responded to carbon enzymes in two contrasting soils. Land use and soil depth significantly affected soil nutrients and the structure of soil microbial community, with clear correlations found. Total nitrogen, biomass carbon, organic carbon, pH are the key factors driving the variation in soil cellulase and invertase activity in arable and plantation land use. Moreover, soil depth plays a crucial role in shaping soil enzymes, as different soil layers exhibit distinct physical and chemical properties that directly influence enzymatic activities. The results highlighted the different responses of two carbon enzymes to soil depth and land use type, and shed further light on microbial biodiversity and its ecological role. This provides a theoretical basis for the rational use of limited land in two contrasting soils. Selecting an appropriate land use type according to the structure of soil microbial communities in two contrasting soil type is of important practical significance.

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Effects of Biopesticides on Soil Bacterial Population and Diversity Associated with Bell Pepper (*Capsicum annuum*) Cultivation

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ABSTRACT

Bell pepper *(Capsicum annuum)* is affected by biotic factors during growth, and these have negative effects on the production and quality of its fruits. Control measures are necessary to avoid economic losses that occur during its cultivation, which makes it difficult to manage populations of Capsicum, hence the use of bio-pesticides to eliminate soil- borne insect pests and diseases associated with the crops. The aim of this study was to determine the effect of bio-pesticide on bacterial population and diversity in a bell pepper cultivated soil. This study was carried out at the Rivers State University Teaching and Research farm using a Randomized complete block design (RCBD) replicated three times. Two bio-pesticides; Effective microorganisms (EM-5) and Hot leaves (HL) were prepared and used. Each treatment was applied on the cultivated soil at two (2) weeks before planting and four (4) weeks after planting. A total of 18 soil samples were collected for analysis from the treated plots and the control plots. Bacteria were isolated after culturing using ten-fold serial dilution for population count whereas molecular techniques were used to identify bacterial diversity. Results showed EM5 increased beneficial bacterial diversity and population after planting. Population count went from 26 x 10^9cfu/g before planting to 27.00 x10^9cfu/g after planting. HLreduced from 25.67a x10^9cfu/g before planting to 3.00 x 10^9cfu/gafter planting. Bacteria at the control plot increased from 26 x 10^9cfu/g before planting to 27.33x 109cfu/g after planting. Molecular identification revealed the presence of fifteen (15) bacteria in all treatment plots which include the following; *Proteus mirabilis, Staphylococcus aureus knock down, Staphylococcus aureus sub specie aureusnewman, Streptococcus anginosus, Sphingobacteria bacterium, Bacteroidesdorei*. Eight were pathogenic and seven were beneficial. The control plots after planting revealed higher bacterial population and diversity than the plots with the bio-pesticides after planting which suggests that the bio-pesticides reduced the bacterial population of plot both treatment plots but increased beneficial bacterial diversity in the plots with the EM-5. Molecular identification helped evaluate prominent plant growth promoting Rhizobacteria (PGPR) which are very important in biogeochemical cycles and prevention of the deleterious effects of phytopathogenic organisms.

Keywords: Bacteria, Bio-pesticides, Diversity, Control plot

INTRODUCTION

Bio-pesticides are substances that naturally occurring from living organisms (natural enemies) or their products (microbial products, phytochemicals) or their by-products (semiochemicals) that can control pest by nontoxic mechanisms (Salma and Jogen, 2011).

Microbial communities in soil ecosystems provide various important functions like decomposition of organic material, recycling of nutrients, nitrogen and carbon cycle, storage and release of nutrients, plant growth promotion and providing a major food source at the base of food webs(Gupta,*et al.,* 2013). . Microbes are also capable of degrading soil-associated organic pollutants and can thus contribute to remediation of contaminated ecosystems which reduces the effect of pollution. Thus, many microbial functions are critical to crop production,soil sustainability,

andenvironmental quality. Therefore the impact of pesticides on the diversity of soil microbial communities and enzymatic activities become vital (Gupta,*et al*., 2013). Non target organism exposure and offsite mobility of the applied pesticides have become a major concern in respect to keeping the environment contaminants free; (Hafez and Theimann, 2003). The adverse effect of pesticides may also affect soil fertility,continuous use of synthetic pesticides leads to development of resistant plant pathogen strains leading to their resurgence as observed by (Schuster and Schroder 1990). Also,Synthetic pesticides kill non-target beneficial organisms such as pollinators, predators and antagonists thereby disrupting biodiversity (Schuster and Schroder 1990).
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An ideal pesticide should be biodegradable and toxic to only the target organisms. Based on the nature and origin of the active ingredients, bio--pesticides fall into several categories such as botanicals, antagonists, compost teas, growth promoters, predators and pheromones.(FAO 2015) Peppers are mostly prone to attack caused by pests and microbial organisms such as fungi, bacterial and nematodes that are pathogenic (Ademoh,*et al.*, 2015). Due to attack by pathogenic microbial organisms, pepper fruit usually get rot before they get to consumers, as a result, millions of naira is being lost by both the farmers and sellers of this farm produce. These fruit rot microbial organisms could be introduced into the crop through the seed itself, during crop growth in the field, during harvesting and post-harvest handling, or during storage distribution (Barth,*et al.*,2009). Among the disease that affects Capsicum, soil-borne diseases caused by pathogens of the genus *Phytophthora*, *Fusarium*, *Pythium* and *Rhizoctonia* are especially significant. For the control of these biotic agents, chemical synthesized pesticides have been traditionally used, which have generated several controversies due to their toxicity in humans and animals, and their damaging effects to the environment(Barra-Bucarei and Ortiz, 2020).Bio-pesticides exhibit different modes of action against pathogens and are reported to have various management success on different pest and diseases.

In traditional and modern agricultural field, crop damage due to these microbial infestationsis always encountered by farmers. There are harmful effects associated with the use of synthetic pesticides such as toxicity and poisoning. Therefore, this study aims at investigating the effects of bio-pesticide on population and diversity of bacteria associating in a bell pepper cultivated soil using molecular techniques.

MATERIALS AND METHODS

The experiment was conducted at the Rivers State University Teaching and Research Farm, Nkpolu-Oroworukwo. Port Harcourt, Nigeria, which lies between latitude 4° 48 14.1" and longitude E6°58 34.8", with an elevation of 8 km above sea level. This islocated within the humid rainforest region of the southern Nigeria with mean annual rainfall that ranged between 2,000mm - 3,000mm per annum. The average annual temperature ranges between 23°C and 29°C.(Ikati and Peter, 2019)

BIOPESTICIDES PREPARATION

HotLeafpreparationandapplication

One hundred (100) g of pepper,(100)g of ginger, (100)g of garlic and (100)g of Neem leaves were grinded and mixed with 4L of water and filtered to obtain the extract allowing it to ferment for three days. The extract was sprayed on the soil two (2) weeks before planting and four (4) weeks after planting) on the leaves and soil using knap sack sprayer.

EM-5 PREPARATION AND APPLICATION

The EM-5 was prepared from water 60%, molasses 10%, EM-1 10%, vinegar 10%, alcohol 10%, 15% of hot leaves. And total volume was produced in a 5L Keg and stored for 14 days before usage. EM-5 (2L) was added into 1L of water and sprayed on the soil and plants (two weeks before planting and 4 weeks after planting respectively.

Preparation of Beds

The research was an open field experiment where beds were raised. The plot had subplots (beds 4m×4m) and seedlings were planted in 2m x2 m beds. Spacing within and between rows was 2m apart. The bell pepper seedlings were transplanted one per hole. Each bed had 4 plants giving a total of 36 plants in 10 m x 10 m plot size.

SAMPLECOLLECTION

Soil samples were collected randomly from the various plots using hand trowel from 0-20 cm depths within the study plots and put in well labeled sterile bottles which were carefully taken to the laboratory for analysis.

LABORATORY ANALYSIS

The samples were subjected to most appropriate analysis in the laboratory which include; serial dilution, Plate pouring method of inoculation which was used for the isolation of the bacteria contained in the samples. A sterile pipette was used to take 1ml each of the serial dilution prepared samples into the corresponding labeled petri dishes. Nine (9) milliliters of molten prepared nutrient agar (NA) was dispensed into the petri dishes. The petri dishes were inoculated under room temperature for 24hrs.

Determination of Bacterial Load

The samples were determined visibly by counting the colony forming units after 24 hours. The bacterial load/ml was determined by the formula of Cheesbrough (2004) as:

Count/ml = No of colonies on plate x 1

Amount plated (dilution factor)

Bacterial DNA Extraction

Molecular identification of bacterial isolates was done by extracting the various bacterial DNA using bacterial DNA extraction kit from soil samples (ABM Ontario Canada).

Workflow of Library Preparation for Next Generation SequencingDNAShearing:

The input DNA was sonicated (exposed to hydrodynamic shearing) into small fragment

With a mean fragment size of 165bp and a fragment size range of 150 to 180bp (before adaptor ligation) using a covaris™ S2 system.

DNA P1 and P2 adaptors were ligated to the ends of the end-repair DNA. The ligated, purified DNA was run on a solid™library size selection gel. The correctly sized ligation products (200 to 23bp) were electrophoresed to the collection wells of the size selection gel. The elute from the solidlibrary size selection gel went through nick translation and subsequently amplification using library PCR primers 1and 2 and platinum® PCR amplification mix. After amplification, PCR samples were purified with the SOLID™ library column purification kit. Quantitative PCR (qPCR) was performed. Then contents of the tube was mixed and centrifuged briefly. The tube was incubated in a thermal cycler at 94ºc for 3mins to completely denature the template. The samples can be stored at -20ºc until used and amplification products were analyzed by agarose gel electrophoresis and visualize by ethidium bromide or safe view by (cat. No G18) staining. If 2x pcrtaq plus master mix with dye was used, the samples will be loaded directly without additional loading dye. Molecular weight standard was used appropriately.

BioinformaticsAnalysisofNucleotideSequencing

The nucleotide sequences obtained from the various bacterial isolates were analyzed by searching and comparing with the National Center for Biotechnology Information (NCBI) Website and a blast search was conducted on all the nucleotide sequences and the identities of the isolates were revealed.

RESULTS

Bacterial Population of Soils Treated with Hot Leafs (HL), Effective Microorganisms (Em-5) and the controlbefore and After Planting.

Results of the Bacterial Population of Soils treated with Hot Leafs [HL], Effective Microorganisms [Em-5) and the control before and After Planting are presented on table 1. Results shows that after application of treatments was done 2 weeks before planting and four (4) weeks after planting, there was a reduction in colony forming unit (cfu/g) from 25.67 x 10^9before planting to 3.00 x 10^9 after planting .EM5 increased bacteria population from 26.00 x10^9 before planting to 27.00 x10^9after planting and the control increased from 26.00 x10^9 before planting to 27.33 x109 after planting. There was no significant difference among the treatments before and after planting at (P<0.05). The plot treated with Hot Leaf (HL) had a mean value of 25.67x10^9 before planting and decreased significantly to 3.00x10^9 with the application after planting which is also the least value recorded among the treatment plots.

Table 1: Bacterial Population of Soils Treated with Hot Leaf (HL)Effective Microorganisms [Em-5) and the control before and After Planting.

Treatment	Sampling time Before/After planting	Cfu/g soil
Control	Before	26.00a x10^9
Control	After	27.33a x10^9
EM5	Before	26.00a x10^9
EM5	After	27.00a x10^9
HL	Before	25.67a x10^9
HL	After	3.00b x10^9
L.S.D (P<0.05)		67.83

Means followed by the same letter(s) in the same column are not significantlydifferent from one another at 5% level of probability using least significant different (L.S.D)

Molecular Identification of Bacteria Isolates from the Study Plots

Fifteen species of bacterial were identified in the study plots treated with hot leaf, Effective microorganisms (EM-5) and the Control plot (without treatment). Among the bacterial diversity identified are; *staphylococcus epidemidis, staphylococcus aureus, Bacillus lichenfomis, Proteus mirabilis, Streptococcus anginosus, Sphingobacteria bacterium, Streptococcus mutans, Bacteroidesdorei, Zymomonamobilis, Streptococcus mutans HACO4 strain, Uncultured spingobacteria bacterium whole geno, Staphylococcus aureus knock down, Escherichia coli, Uncultured sphingobacteria bacterium, uncultured bacteria.* Eight were pathogenic and seven were beneficial. At the plottreatedwith the hot leaf (HL) diversity also decreased while beneficial microbes increased at the plot treated with EM-5. Microbial diversity did not change at the control plot.

Table 2: Molecular Identification of Bacterial Isolated from the Treatment plot and controlbefore and afterplanting.

Treatment		Isolates	Beneficial/PathogenReferences
Hot Leaf(HL)	Before	*Staphylococcus aureus(subspp aureus newman)*	PathogenicPrithiviraj,*et al*,*(2005)*
		Streptococcus anginosus	PathogenicBudziaszek,*et al*,(2023)
		Staphylococcus aureus	PathogenicGerken,*et al*,(2022)
		Bacillus lichenfomis	BeneficialAkhtar,*et al*,(2020)
		Proteus mirabilis	BeneficialAmaresan,*et al*,(2021)
	After	*Staphylococcus epidemidis*	BeneficialChaudh and Pati*(2016)*
		Sphingobacteria bacterium	BeneficialWang, *et al*,(2022)
Effective microbes(EM-5)	Before	*Sphingobacteriabacterium*	Beneficial*Wang, et al,(2022)*
		Streptococcus mutans	PathogenicGledhill and Casida(1969)
		Bacteroidesdorei	BeneficialLarsbrink and McKee (2020)
		Staphylococcus aureus	PathogenicPrithiviraj,*et al*,(2005)
		Streptococcus sp	PathogenicZhao,*et al*,(2015)
	After	*Sphingobacteria bacterium*	BeneficialWang,*et al*,(2022)
		Bacillus lichenfomis	BeneficialAkhtar, *et al*,(2020)
		Zymonomamobilis	BeneficialMartien,*et al*,(2021)
		Proteus mirabilis	BeneficialDrzewiecka (2016)
Control	Before	*Bacteroidesdorei*	PathogenicLarsbrink and McKee (2020)
		Streptococcus anginosus	PathogenicBudziaszek,*et al*,(2023)
		Spingobacteriaspp	BeneficialWang,*et al*,(2022)
		Staphylococcus aureus(knock down)	PathogenicZhao,*et al*,(2017)
		Streptococcus mutants	Pathogenic Gledhill and Casida(1969)

	Escherichia coli	BeneficialHabteselassie,*et al*,(2008)
	Staphylococcus epidemidis	Beneficial *Chaudh and Pati(2016)*
After	*Bacteroidesdorei*	PathogenicLarsbrink and McKee (2020)
	Streptococcus anginosus	Pathogenic*Budziaszek, et al, (2023)*
	Spingobacteriaspp	BeneficialWang,*et al*,(2022)
	Staphylococcus aureus(knock down)	PathogenicZhao,*et al*,(2017)
	Streptococcus mutants	PathogenicGledhill and Casida(1969)
	Escherichia coli	Beneficial Habteselassie,*et al*, (2008)
	Staphylococcus epidemidis	Beneficial Chaudh and Pati (2016)

DISCUSSION

The plot treated with Hot Leaf (HL) had a mean value of $25.67x10^9$ before planting and decreased significantly to $3.00x10^9$ with the application of treatment after planting. According to Elazouni,*et al.,* (2019), several mechanisms are known to be responsible for suppressing the growth of a microorganism by biological control agents and these include the production of antagonistic metabolites, hydrogen cyanide or siderophores, competition for nutrients and space, parasitism, and induced systemic resistance such as phenolicsand polyphenols (flavonoids, Quinone, tannins, coumarins), terpenoids, alkaloids, lectins and polypeptides which are antimicrobial.The antimicrobial action of plant extracts depends on the chemical composition of the extract and the microbial targets. Despite the antimicrobial action of plant extracts, their use as food preservatives is limited by their stability under processing or storage conditions. Okur, *et al.,* (2010) discovered a decrease in microbial and enzymatic activity when plants extracts were used as pesticides. Kurma, *et al.,* (2019) also observed that plant extract bio- pesticides also negatively affected soil microorganisms by limiting their biological services in the production of certain plant growth-promoting traits. The increase in the microbial population after the application of EM-5 after planting conforms to the findings of Han and Lee (2006). They observed that by maintaining healthy soil ecology, that harmful microorganisms that cause plants diseases can be suppressed. They further emphasized, that there is a balanced interaction in the soil system between harmful microbes and billions of beneficial microbes working together to provide protection. Schnürer and Magnusson (2005) observed that the EM introduces and increases the population soil microorganisms. According toOngena and Jacques (2008) the bacteria could be one of the major sources of potential microbial bio-pesticides because it retains several valuable traits. Beneficial microbes in soil promote healthy plant growth, which leads to increased crop yields and better crop quality. When beneficial bacteria are introduced to soils and plants by EM, pests are controlled or managed. Inoculants containing microorganisms compete with pests and diseases and are used naturally to decrease or manage pests Singh *et al.,* (2003).

CONCLUSION

This study emphasizes on the soil Bacterial population and diversity in bell pepper cultivated soils from plots treated with EM-5, Hot leaf (HL) and control (without treatment). Study revealed that EM-5 increased beneficial bacterial population while (HL) reduced beneficial bacterial population and at the control plot, there was no significant difference in population and diversity when compared with the treated plots. Bacteria could be a major source of potential microbial bio pesticide as seen with the EM-5.

EM-5 could be used by farmers as a bio-pesticide and large scale farmers. And as part of the monitoring activities of farmers, soil microbial analysis should be done regularly to evaluate prominent members of the microbial communities in their farmland. Farmers should adopt the use of bio pesticides because they are effective in very small quantities and often decompose quickly, resulting in lower exposures and largely avoiding the pollution problems caused by conventional inorganic pesticides. Molecular identification helped evaluate prominent plant growth promoting Rhizobacteria (PGPR) which is very important in biogeochemical cycles and prevention of the deleterious effects of phyto-pathogenic organisms.

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SECTION THREE: SOIL PHYSICS, CONSERVATION AND HYDROLOGY, SOIL BIOTECHNOLOGY AND ENVIRONMENTAL POLLUTION MANAGEMENT

Physicochemical Properties and Heavy Metal Concentrations of Soils Using Pollution Load Index and Contamination Factor in Southern Nigeria

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ABSTRACT
Parent material from which the soil is developed determines the soil's nutrient supply capacity and weathering of metal-bearing parent material can be an important source of heavy metals soils. This study evaluated the physicochemical properties of soils, pollution loads, and the degree of contamination of heavy metals in soils formed from sandstone and shalestone parent materials in Ogoja. Soil samples were collected at a depth of 0-20 cm from soil developed on basaltic and sandstone parent materials, air-dried, and sieve through 2 mm mesh sieve for physico-chemical and heavy metals analysis. Results showed that both sandstone and shalestone soils were low in heavy metal content (Pb, Cr, Al, Ni and Cd) and have high potential for crop production as they are high in base saturation, clay, moderate in exchangeable Ca and Mg, CEC, ECEC and suitable pH. These soils showed moderate contamination factor especially sandstone in Moniaya, Egbung and Emandack, and shalestone soils in Ekuaro, Wininba, Nkemero and Mbenkpen. The results of pollution load index showed that the values recorded for all the soils are below 1, indicating an unpolluted condition and practically uncontaminated as shown by geo accumulation index of <0 for the studied heavy metals in the soil. The soils in Ogoja generally are still in a safe state and can be utilized for cultivation of crops with continuous monitoring but attention has to be taken to control the moderate level of Cd contaminations because it may result in depletion of essential crop nutrients and reduced crop growth and yield.

Keywords: pollution load index, heavy metals, sandstone, shalestone, contamination factor.

Introduction

Despite the importance of parent materials to soil nutrients supply (Afu *et al.*, 2021), weathering of metal-bearing parent material can be an important source of heavy metals in soils (Kabatha-Pendias, 2001; Nikova *et al*., 2016; Althaus *et al.*, 2018; Afu *et al.*, 2020). Contamination of soils with heavy metals is a serious environmental problem in both developing and developed countries of the world. This contamination can be of natural or geologic sources such weathering and volcanic eruption, and/or by anthropogenic activities (Afu *et al*., 2020; Afu *et al.*, 2021). In tropical region, there seem to be high possibility for release of heavy metal into the soil during weathering as result of high rainfall, temperature and acidity in the tropic that facilitate mineral weathering. However, their concentration remains mostly below toxic level in natural undisturbed soil.

Heavy meals are commonly found in the soil at various concentrations, owing to the pedogenic process of weathering of the parent materials (Liu *et al.*, 2022). Alloway (1995) stated that the highest cadmium concentrations are found in sedimentary rocks and soil underlain by cadmium rich Monterey shales in coastal regions of California contain some of the highest natural cadmium concentrations in the world. Sandstone and shalestone are parts the major soil parent materials in Cross River State. Sandstone is a clastic sedimentary rock composed mainly of sand-sized (0.0625 to 2mm) mineral particles or rock fragments and comprised of about 20 to 25% sedimentary rock (Boggs, 2006); while shales are fine grained laminated or fissile classic sedimentary rocks with predominance of silt and clay components (Krumbein and Slows, 1963).

Few studies on the extent of contamination of soil developed on various parent material including sandstone and shalestone in Cross River State exist (Afu *et al*., 2021, Adie *et al*., 2022; Nzegbule *et al*., 2007). Afu *et al*. (2021) evaluated the heavy metal concentrations of basaltic and sandstone soils and reported higher levels of heavy metals in sandstone than shalestone soil in Cross River State, Nigeria. Heavy metals pose risks and hazards to humans and the ecosystem through direct ingestion or contact with contaminated soil, food chain, drinking of contaminated groundwater, reduction in food quality (safety and marketability) via phytotoxicity, reduction in land usability for agricultural production resulting to food insecurity (McLaughlin *et al*, 2000).

Excessive heavy metals in soil could accumulate in crops and leads to decline in crop quality (Ali *et al.,* 2020). Heavy metals can be absorbed through the root system then transported to the stem through the xylem for stronger (Jolly *et al.*, 2013). Long term exposure to high concentration of heavy metal through consumption of heavy metal enriched crops can advance long damage, prostrate disease, hypertension, weakening function of kidney digestive tract and liver (Rao *et al.*, 2022; Naseri *et al.*, 2021).

Consequently, to ensure safe crops and feed for human and animal consumption, information on the influence of parent materials on heavy metal loads of soils must be generated and given utmost publicity bearing in mind the enormity of the effect of heavy metal on human health and soil biomass. It is based on this background that this study assessed the pollution indices and physicochemical properties of sandstone and shalestone soils in Cross River state, Nigeria.

Materials and Methods

The Study Area

The study was conducted in Ogoja Local Government Area of Cross River State, Nigeria. The area lies between latitude 06^{O}41.818’N and longitude 008^{O}47.113’E of the equator (Fig. 1). The area is located in the rainforest belt with annual rainfall varying from 1750-2000 mm (Afu *et al*., 2022). Ogoja has an average temperature ranging from 27-29 ^{0}C with the warmest temperature in the month of March and the coldest in the month of September. The study area (Ogoja) is one of the areas that produce the highest food crops in Cross River State. Most of the crops cultivated in the area include yam, cassava, fluted pumpkin, pepper, oil palm tree, rice, mango, maize and coconut.

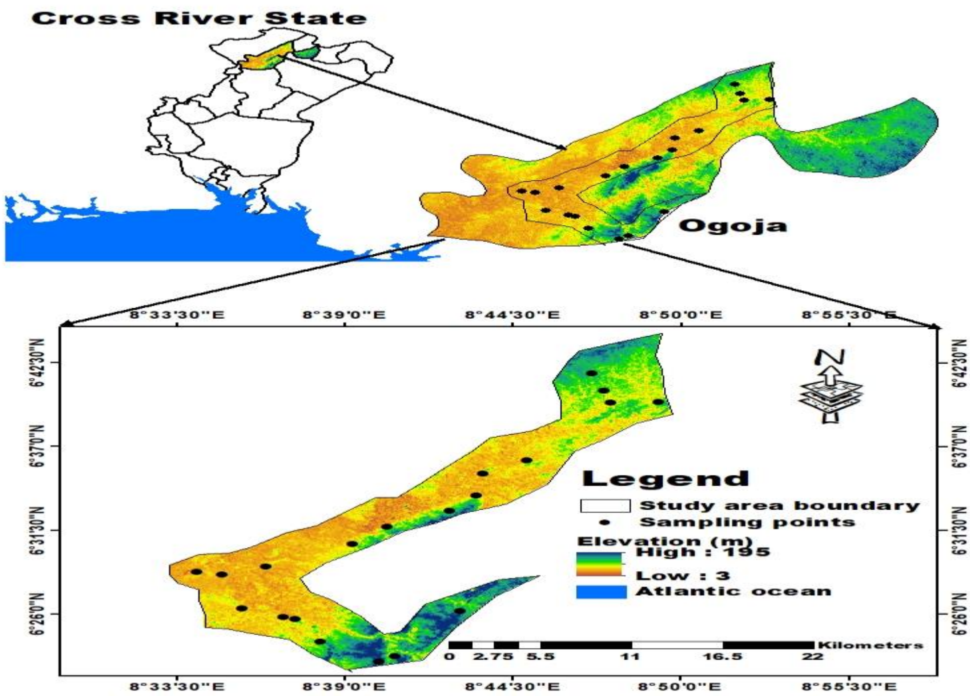


Fig 1: Map of Ogoja showing sampling location

Sample collection

A total of twenty (20) composite samples were collected from soils developed on sandstone and shalestone parent materials using stratified random sampling with the aid of soil auger at the depth of 0-30 cm. The samples collected were properly labeled in air tight and clean polythene bags and taken to the laboratory. In the laboratory, the soil samples were air dried for 10 days, crushed to powder using porcelain mortar and pestle, sieved with a 2 mm sieve to obtain uniform size fraction that was used for routine physicochemical and heavy metal analyses.

Digestion of soil samples

The soil samples were digested using the procedure reported by Afu *et al.* (2021). One (1) gram of dried soil sample was dissolved in a clean 200 ml flask followed by addition of 0.2 ml of concentrated HCl in small portions, 1 ml of concentrated NHO_3 and 5 ml of perchloric acid. The mixture was covered with glasses and heated to near boiling point for 3 hours on a hotplate. After cooling, 1 g of ammonium chloride and 20 ml of 0.5 N HCl were added. Samples were reheated for 1 hour and evaporated to approximately 10 ml. After cooling, the extracts were filtered into a 100 ml volumetric flask and stored in a high-density plastic bottle for heavy metal analysis.

Quality assurance

For accuracy and precision of the analytical results, the recovery study method was used for validation of the digestion method. This was achieved by determining the metals concentrations in triplicate samples of spiked and un-spiked soil samples. Spiking was done by adding 1 ml of different concentrations of metal standard solution to 0.5 g of soil sample that was later subjected to the digestion procedure. The formula for calculating the percent recoveries according to Javed *et al.*, (2010) is presented as:

Recovery (%) = X-Y/Zx100 (1)

Where:

S = Concentration of metal in the spike sample
Y = Concentration of metal in the un-spike sample
Z = Spiking concentration

Laboratory analysis

Soil particle size distribution was determined by boyoucous hydrometer method (Udo *et al*., 2009). Soil pH (H_20) was determined in a soil/water ratio of 1:2.5 using glass electrode pH meter as outlined by Udo *et al.* (2009) while organic carbon was determined by Walkley-Black wet oxidation method described by Udo *et al.* (2009). Total nitrogen was determined using modified micro-kjeldhal method (Udo *et al.*, 2009) while available phosphorus was determined using Bray P-1 described by Estefan *et al.* (2013). Exchangeable bases were determined by leaching the soil samples with 1ml neutral NH_4OAc as the extractant solution. Ca and Mg were determined by the EDTA complexometric titration method while K and Na were determined by flame photometry using procedure outlined by Udo *et al.* (2009). Exchangeable acidity was determined by titration method described by Estefan *et al.* (2013). Effective cation exchange capacity (ECEC) was obtained by summation method and base saturation obtained by expressing the exchangeable bases as percentage of the ECEC. The concentrations of the heavy metals in the soils were determined by Atomic Absorption Spectrophotometer (Perkin Elmer A Analyst 400 AAS). Percentage aluminum saturation was computed using the formula below:

$$\% Al \text{ saturation} = \frac{Exchangeable \text{ Aluminium}}{Effective\ Cation\ Exchange\ Capacity} \text{ x } 100$$

(2)

Statistical Analysis

The data collected were subjected to statistical analysis (mean, pollution indices and t-test) using SPSS software (version 25) and Microsoft Excel 2013 and Interpolation was done using inverse distance weighting utilizing ArcGIS 9.7. Various indices to assess the current pollution level were obtained using the models presented in Tables 1 and 2. The interpolation of selected soil pollution indices was done using the deterministic methods of inverse distance weighting (IDW). IDW assumes that the value of an attribute in an unsampled area is that of the weighted average of the known data points within a local neighborhood surrounding the unsampled location (Burrough and McDonnell 1998). Estimated values were interpolated based on the data from surrounding locations using the formula:

$$Z(xo) = \sum_{i-1}^{n} wiZ(xi)$$

(3)

Where Z(x0) is the estimated value, *wi* is the weight assigned to the value at each location *Z (χi)*, *n* is the number of close neighboring sampled data points used for estimation.

The weight was estimated using:

$$wi = \frac{1/d_i^p}{\sum_{i=1}^{n} 1/d_i^p}$$

(4)

Where *di* is the distance between the estimated point and the sample point, *p* is an exponent parameter.

Table 1: Single metal pollution and contamination indices

Pollution indices	Equation	Class/Values	Soil risk grade	References
Contamination Factor (Cf)	$C_f = \frac{C_{metal}}{C_{backgrund}}$	CF < 1	low contamination factor	Hakanson, 1980
		1 ≤ CF < 3	moderate contamination factor	
		3≤ CF < 6	considerable contamination factor	
		CF ≥ 6	very high contamination factor	
Geo-accumulation Index (I_{geo})	$I_{geo} = \log_2\left(\frac{C_n}{1.5 * B_n}\right)$	Class 0 = Igeo <0	practically uncontaminated	Muller, 1969
		Class 1= 0 < I_{geo}< 1	uncontaminated to moderately contaminated	
		Class 2 = 1 < I_{geo}< 2	moderately contaminated	
		Class 3 = 2 <$_{Igeo}$< 3	moderately to heavily contaminated	
		Class 4 = 3 < I_{geo}< 4	heavily contaminated	
		Class 5 = 4 < I_{geo}< 5	heavily to extremely contaminated	
		Class 6 = I_{geo}>5	extremely contaminated	

C_{metal} = measured concentration of the examined metal (n) in soil; $C_{background}$ = concentration of the examined metal (n) in the reference environment; Bn = the background concentration of the metal (n) in reference environment; Factor 1.5 = the background matrix correction factor due to lithogenic effects; T_r = metal toxic response factor for metals (Cr =2, Pb =5, Cd = 30, As =10) and Al does not have value for Tr.

Table 2: Integrated metal pollution and contamination indices

Pollution indices	Equation	Class	Soil risk grade	References
Degree of contamination (Cd)	$C_d = \sum_{i=1}^{n} C_f$	Cd<7	low degree of contamination	Hakanson, 1980
		7≤Cd<14	moderate degree of contamination	
+		14 ≤ Cd < 28	considerable degree of contamination	
		Cd ≥28	very high degree of contamination	
Pollution load index (PLI)	$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{1/n}$	PLI<1	No metal pollution	Tomlinson *et al.*, 1980
		PLI = 1	Baseline levels of pollutants	
		PLI >1	indicates a polluted condition	

Results and Discussion

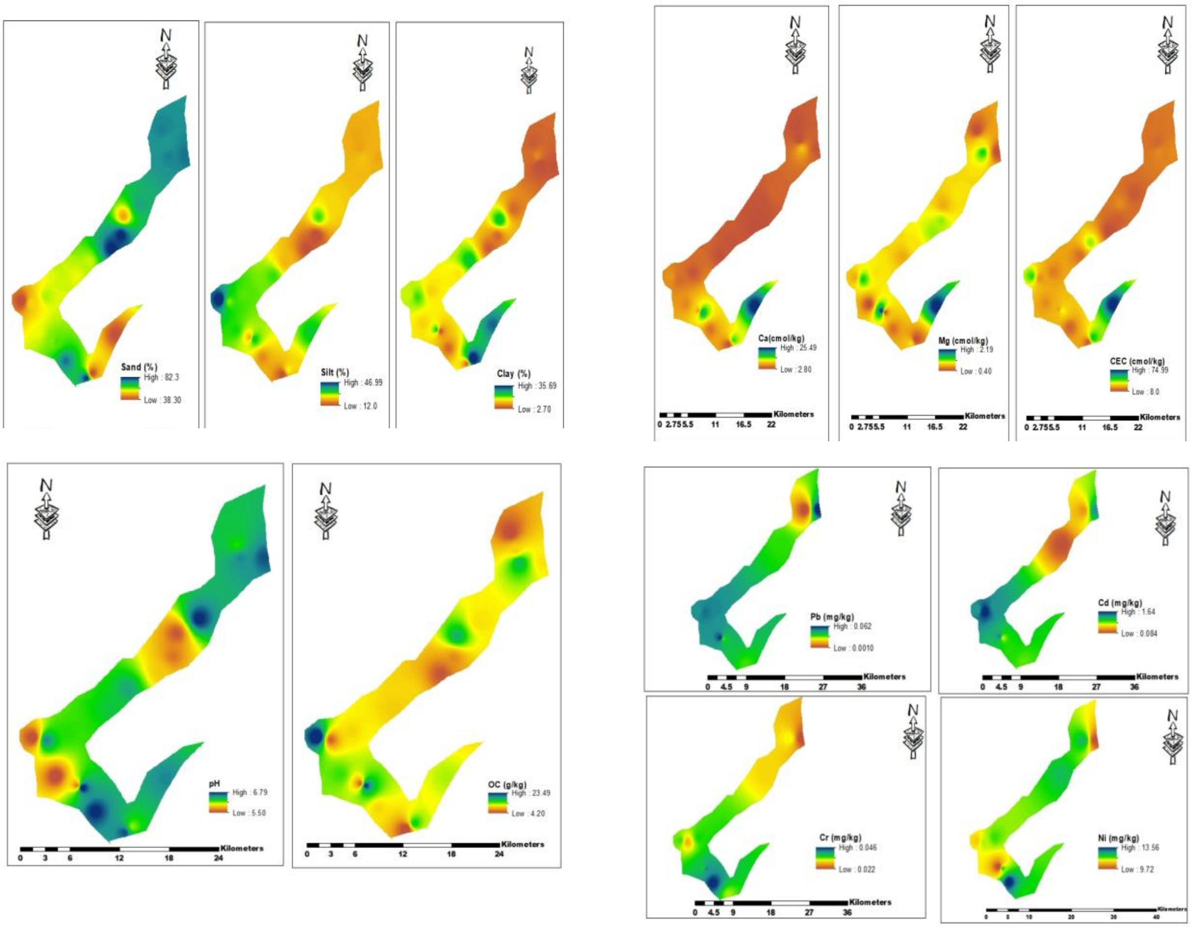
Physicochemical properties of sandstone and shalestone soils

The physicochemical properties of sandstone and shalestone soils of the study area are presented in Tables 3 and 4 respectively. The results of particle size distribution in sandstone soil revealed that sand, silt and clay had mean values of 724.4 g/kg, 190.69 g/kg and 67 g/kg respectively, having CV of 12.9%, 28.8% and 76.10% respectively while shalestone had mean values of 515.9g/kg (sand), 298g/kg (silt), and 186.1g/kg (clay), having CV of 19.2%, 25.6% and 51.1% respectively. The textural classes of sandstone soil were loamy sand and loam while those of shalestone were sandy loam, loam, and sandy clay loam. These observations are quite contrary to what was obtained by Afu *et al.* (2022).

Spatially, sand was higher in the northern and southern part of the study area and lower toward the west while silt contents were low in the northern and southern part of the study area and high in the west. Similarly, clay contents were low in the north and western part of the study area while it showed high values in some part of the south (Fig. 2). However, silt and clay fractions were higher in shalestone soil compared to sandstone soil suggest that shalestone soil will hold high quantity of exchangeable cations with positive implication in soil fertility.

The results of pH showed that both parent materials had moderately to slightly acid pH level and falls within the pH range of 5.5-6.5 for crop growth as categorized by Enwezor *et al*. (1989). The results obtained revealed that organic carbon content was higher in shalestone soil than sandstone soil. In sandstone soil, it ranged from 4.2 to 16.6g/kg with mean value of 9.88gkg, and CV of 43.6% while in shalestone it ranged from 6.4 to 23.5g/kg with mean value of 13.04g/kg and CV of 43.2%. The mean values obtained for both soils show that organic carbon content were low (Landon 1991). Afu *et al*. (2020) attributed low organic carbon content of soil to bush burning, leaching due to high rainfall and rapid mineralization of organic matter. The spatial distribution of organic carbon indicated low values across the entire study area apart from the western part while pH was high in all part of the study area except in the central and western parts (Fig. 2)

The total nitrogen was higher in shalestone soil than in sandstone soil and ranged from 0.3 to 1.40g/kg with mean value of 0.90g/kg and CV of 46.4% in sandstone. Similarly, in shalestone soils, it varied from 0.5-2.0g/kg with a mean value of 1.09 g/kg and CV of 46.3%. The total nitrogen content of both soils was low (1.0 - 2.0 g/kg) (Landon, 1991). These findings are in agreement with the report of Afu *et al* (2022) in soils of the area. Available P ranged from 1.0 to 29.37 mg/kg with mean values of 9.07mg/kg and C.V of 91.1% sandstone and ranged from 3.87-11.37 mg/kg with mean value of 6.72mg/kg and C.V of 31.4% in shalestone.



Sand (%)
High : 82.3
Low : 38.30
Silt (%)
High : 46.99
Low : 12.0
Clay (%)
High : 35.69
Low : 2.70
Ca(cmol/kg)
High : 25.49
Low : 2.80
Mg (cmol/kg)
High : 2.19
Low : 0.40
CEC (cmol/kg)
High : 74.99
Low : 8.0
Kilometers
pH
High : 6.79
Low : 5.50
OC (g/kg)
High : 23.49
Low : 4.20
Pb (mg/kg)
High : 0.062
Low : 0.0010
Cd (mg/kg)
High : 1.64
Low : 0.084
Cr (mg/kg)
High : 0.046
Low : 0.022
Ni (mg/kg)
High : 13.56
Low : 9.72

Table 3: Physicochemical properties of Sandstone in soils of Ogoja

Sample description Soil depth (cm)	Particle size Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Texture	pH (H_2O)	OC (g/kg)	TN (g/kg)	AV. P (mg/kg)	Exch. Cations Ca (cmol/kg)	Mg	K	Na	Exch. Acidity Al^{+3}	H^+	CEC	ECEC	BS %
Moniaya (0-30)	763	200	37	Loamy sand	6.6	11.0	0.9	1.0	3.6	0.4	0.14	0.1	0.2	0.56	20	5.0	85
Okuku Road (0-30)	727	196	77	Loamy sand	6.2	10.4	0.8	4.37	2.8	1.0	0.13	0.1	0.23	0.76	14	5.02	80
Ogoja Army Barrack (0-30)	753	200	47	Loamy sand	6.3	5.0	0.4	7.25	3.2	0.4	0.12	0.11	0.2	0.56	17	4.59	83
Igoli (0-30)	753	220	27	Loamy sand	6.5	16.4	1.4	29.37	9.2	1.4	0.13	0.1	0.32	0.84	20	11.99	90
Okunde (0-30)	713	230	57	Loamy sand	6.7	10.8	0.8	7.37	4.8	1.0	0.14	0.09	0.12	0.65	12	6.8	87
Ukpagada Aladim (0-30)	493	300	207	Loamy	5.6	16.6	1.4	5.37	3.4	0.8	0.1	0.09	1.64	0.68	20	6.71	65
Igodor (0-30)	823	120	57	Loamy sand	5.7	8.0	0.7	6.37	3	1.2	0.11	0.08	0.0	1.64	13	6.03	73
Ikandangha (0-30)	823	130	47	Loamy sand	5.9	5.8	0.5	5.0	3.2	1.2	0.12	0.1	0.42	1.16	8.0	6.2	75
Egbung (0-30)	763	180	57	Loamy sand	6.7	10.6	0.8	7.25	5.4	0.6	0.15	0.11	0.4	1.02	14	7.68	82
Emandack 2 (0-30)	813	130	57	Loamy sand	6.6	4.2	0.3	17.37	3.2	1.0	0.14	0.12	0.54	1.22	12	6.22	72
Min	493.0	120.0	27.0		5.600	4.2	0.30	1.00	2.80	0.40	0.10	0.08	0.00	0.56	8.0	4.59	65.0
Max	823.0	300.0	207.0		6.700	16.6	1.40	29.37	9.20	1.40	0.15	0.12	1.64	1.64	20.0	11.99	90.0
Mean	742.4	190.60	67		6.280	9.88	0.80	9.07	4.18	0.90	0.128	0.10	0.40	0.91	15.0	6.62	79.20
SD	95.66	54.80	50.99		0.42	4.305	0.371	8.27	1.95	0.34	0.015	0.012	0.46	0.35	4.11	2.11	7.77
CV (%)	12.9	28.8	76.10		6.6	43.6	46.4	91.1	46.6	38.1	12.1	11.5	113.2	38.4	27.4	31.8	9.8

OC = Organic carbon; TN = Total Nitrogen; AV. P = Available Phosphorus; BS = Base saturation; ECEC = Effective cation exchange cation exchange capacity

Table 4: Physico-chemical properties of Shalestonein soils of Ogoja

Sample description	Particle size			Texture	pH	OC	TN	AV. P	Exch. Cations				Exch. Acidity		CEC	ECEC	BS
Soil depth	Sand	Silt	Clay		(H_2O)			(mg/kg)	Ca	Mg	K	Na	Al^{+3}	H^+			%
(cm)	g/kg					(g/kg)	(g/kg)		cmol/kg								
Eshiaya (0-30)	583	210	207	Sandy loam	6.4	10.6	0.9	5.12	3.4	1.0	0.11	0.09	0.38	0.92	40	5.9	78
Mbenkpen (0-30)	573	300	127	Sandy loam	6.3	10.2	0.8	7.75	3.2	0.8	0.1	0.08	0.34	1.26	16	5.78	72
Mbenkpen (0-30)	593	290	117	Sandy loam	6.2	10.6	0.8	7.12	3.6	1.0	0.09	0.08	0.36	1.32	18	6.45	74
Ekuaro (0-30)	432	280	188	Loam	6.5	6.4	0.5	7.5	4.8	1.4	0.09	0.08	0.0	0.6	20	6.97	91
Nkemero (0-30)	383	470	147	Silty loam	5.5	23.5	2.0	5.0	7.0	0.8	0.08	0.07	0.48	1.48	46	9.91	80
Ntara (0-30)	573	310	117	Sandy loam	5.5	14	1.2	7.75	6.4	0.4	0.08	0.06	0.3	1.42	20	8.66	80
Winiba (0-30)	603	200	197	Sandy loam	5.7	6.4	0.5	3.87	7.5	2.2	0.11	0.09	0.4	1.6	23	11.8	83
Nkpakna 1 (0-30)	623	340	37	Sandy loam	6.8	20.9	1.8	11.37	20	0.4	0.14	0.11	0.0	1.2	35	21.85	95
Nkpakna 2 (0-30)	393	250	357	Sandy clay loam	6.1	15.2	1.3	5.37	15.2	0.4	0.13	0.1	0.84	1.76	51	18.43	86
Nkpakna 3 (0-30)	403	330	267	Sandy clay loam	6.5	12.6	1.1	6.37	25.5	2.1	0.14	0.11	0	1.14	75	28.99	96
Min	383	200	37		5.50	6.40	0.50	3.87	3.20	0.4	0.080	0.06	0.0	0.60	16.0	5.78	72.0
Max	623.	470	357		6.80	23.5	2.0	11.37	25.5	2.20	0.14	0.11	0.84	1.76	75.0	28.9	96.0
Mean	515.9	298	186.1		6.15	13.04	1.09	6.72	9.66	1.05	0.11	0.087	0.31	1.27	34.40	12.47	83.5
SD	99.2	76.42	89.418		0.44	5.63	0.50	2.1	7.83	0.66	0.023	0.016	0.26	0.33	18.9	7.97	8.36
CV (%)	19.2	25.6	51.1		7.3	43.2	46.3	31.4	81.1	63.1	21.6	18.8	84.3	26.4	55.2	63.9	10.0

OC = Organic carbon; TN = Total Nitrogen; AV. P = Available Phosphorus; BS = Base saturation; ECEC = Effective cation exchange capacity

Higher content of available phosphorous in sandstone soil than in shalestone is contrary with the findings of Afu *et al*. (2020) in similar parent material in Odukpani LGA of Cross River State and agrees with that of Osujieke (2017). In the same vein, exchangeable bases were higher in shalestone soil than in sandstone. The cations distributions were in the order of Ca>mg>k>Na for both soils developed of sandstone and shalestone.

Acidity of the soil was majorly caused by hydrogen ion. However, both hydrogen and aluminum were higher in sandstone than shalestone. Cation exchange capacity (CEC) had mean value of 15cmol/kg and 34.4cmol/kg with CV of 274% and of 55.2% in sandstone and shalestone soils accordingly. Effective Cation exchange capacity (ECEC) followed the same trend with CEC. The result of CEC in this study is similar to CEC values reported by Afu *et al*. (2015) in a related study in the area. CEC, Ca and Mg were low when assessed spatially across the entire study area except some part of the south (Fig 4). Base saturation was slightly higher in shalestone than sandstone soil but are rated high (> 50%) in both soils (Landon, 1991).

Heavy metal concentrations and their spatial distribution in the studied soils.

The concentrations of lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni) and aluminum (Al) in soils show that Pb, Cd and Cr were higher in shalestone soil than in sandstone soil while Ni and Al were more concentrated in sandstone than in shalestone (Table 5). Heavy metal content of soils is influenced by soil organic matter content, soil reaction and clay content (Adelekan and Alawode, 2011), as well as parent material and pedogenic processes (Lhendup and Duxbury, 2008). Lead, Cd and Cr had mean values of 0.034 mg/kg, 0.701 mg/kg and 0.033 mg/kg with CV of 63.5 %, 68 % and 26.5 % in soils developed on sandstone. Similarly, Pb, Cd and Cr had means of 0.048 mg/kg, 1.234 mg/kg and 0.035 mg/kg with CV of 21.2 %, 28.3 %, and 14.1% respectively in soils developed on shalestone. Nickel had average values of 12.166 mg/kg and 11.383 mg/kg with CV of 9.8 % and 8.8% in soils of sandstone and shalestone respectively. The concentration of heavy metals in soils of the two parent materials were not statistically different as shown by the t-test values of $t = -1.127$, $df = 4$, $p = 0.323$ for Pb, $t = -2.108$, $df = 4$, $p = 0.103$ for Cd, $t = -1.51$; $df = 4$, $p = 0.206$ for Cr and $t = 1.149$; $df = 4$, $p = 0.314$ for Ni.

The levels of Pb in both soils were far below the maximum permissible limit of 30 to 300 mg/kg and 300 mg/kg recommended by USEPA (1994) and Hong *et al*. (2014) respectively for agricultural soils which means that the soils are not contaminated with Pb. Low level of Pb and other heavy metals in soils of the study area means that the area has no anthropogenic input of these toxic metals. However, the abundance of lead in the continental crust according to Afu *et al*. (2021) is 14.8 mg/kg and that among sedimentary rocks; shale has higher abundance (22 mg/kg) than sandstone (10 mg/kg). This may be the reason for higher values of Pb obtained in shalestone than sandstone soils in this study. The values of Pb and Cd for sandstone in this study are lower than 43.34 mg/kg and 49.92 mg/kg recorded in sandstone in Ikom by Afu *et al*. (2021) but similar but slightly lower Cd values of 0.98 and 0.96 mg/kg have been reported in shale and sandstone soils by Sodango *et al*. (2021) in Fuzhou City of China. Similar result was also made by Liu *et al.* (2022) who recorded 0.13 mg/kg Cd in both soils in China. Cadmium level in both soils was far below the maximum permissible limit of 3 mg/kg by Hong *et al*.(2014).

Contrary to the results of this study, Liu *et al*., (2022) recorded higher content of Cr in sandstone (36 mg/kg) than in shalestone (28 mg/kg). They also reported higher values of Ni in shale (15 mg/kg) than in sandstone (10mg/kg). In both soils, Al was higher than Cd, Cr, Pb and Ni. Aluminum was slightly higher in sandstone soil. Higher concentration of Al may be due to the abundance of the element in the earth crust; the third most prevalent element in the earth crust only next oxygen and silicon (Foth, 2006). The values of Al obtained quite lower than the ones obtained by Afu *et al*. (2021) in sandstone and basalt in Ikom, Nigeria. Spatial distribution and source identification of heavy metals in soils are essentials for identification of hot spot areas of pollution and to assess potential sources of pollutants (Harri *et al*. 2014). Spatial distribution of metals shows Pb, Cr and Cd were lower in the northern part compared to other parts of the study area. Similarly, Ni was extremely low in northern part of the study area. The spatial variability results for heavy metals in the studied soils are presented in Fig 2.

Contamination indices

Contamination factor (CF), degree of contamination (Cd), geo-accumulation index (Igeo) and pollution load index (PLI) are the contamination indices that were used for the assessment of the soils. The calculated values of the pollution indices are presented in Tables 6 and 7.

Table 5: Heavy metal concentrations of the soils

Sandstone								Shalestone							
Sampling location (SP)	Coordinate		Pb	Cd	Cr	Ni	Al_{sat}	SP	Coordinate		Pb	Cd	Cr	Ni	Al_{sat}
	Latitude	Longitude			mg/kg				Latitude	Longitude			mg/kg		
Monaiya	06^{0}39.931N	008^{0}49.263E	0.062	1.284	0.022	10.282	400	Ekuaro	06^{0}20.596N	008^{0}35.298E	0.052	1.642	0.028	11.720	0.0
Igoli	06^{0}39.893N	008^{0}47.727E	0.001	0.360	0.032	12.480	2669	Winiba	06^{0}25.800N	008^{0}37.006E	0.060	1.360	0.036	9.720	3390
Egbung	06^{0}24.218N	008^{0}38.207E	0.040	0.920	0.046	13.560	5208	Nkpakna	06^{0}25.680N	008^{0}37.363E	0.032	0.682	0.042	12.246	0.0
Emandak	06^{0}22.903N	008^{0}40.125E	0.034	0.855	0.033	12.107	8682	Nkemero	06^{0}28.763N	008^{0}34.140E	0.048	1.228	0.035	11.229	4844
Okunde	06^{0}36.113N	008^{0}44.993E	0.035	0.084	0.030	12.400	1765	Mbenkpen	06^{0}30.603N	008^{0}39.242E	0.050	1.260	0.036	12.00	6441
Min			0.001	0.084	0.022	10.282	1765	Min			0.032	0.662	0.028	9.720	0.00
Max			0.062	1.284	0.046	13.560	8682	Max			0.060	1.642	0.042	12.246	6441
Mean			0.034	0.701	0.033	12.166	4464	Mean			0.048	1.234	0.035	11.383	2935
SD			0.022	0.477	0.009	1.188	2695.7	SD			0.010	0.349	0.005	1.004	2888.4
CV(%)			63.5	68	26.5	9.8	60.4	CV(%)			21.2	28.3	14.1	8.8	98.4
MPL			2-200	0.01-0.7	1-1000	1-50	10-300000								
BV			85	0.8	100	29	47200								

BV= World geochemical background value in average shale (Turekian & Wedepohl, 1961)

MPL= Maximum permissible limits (Lindsay,1979)

Contamination factor (Cf)

Contamination factor is used to interpret theextend of heavy metal impact on the contamination of any environment; water, sediment, soil and air (Edori and Kpee, 2017). Based on Hakanson (1980) classification scheme for contamination factor, the result of the study (Table 6) clearly indicated that the Cf values are less than unity (<1) for Pb, Cr, Ni and Al in both shale stone and sandstone soils. However, Cd showed some level of contamination ranging from low contamination to moderate contamination level. These results mean that the soils in Ogoja are low in Pb, Cr, Al and Ni. Nonetheless, Cd showed moderate level of contamination in soil developed on sandstone in Moniaya (1.605), Egbung (1.60) and Emandack (1.069) and sandstone soils contamination sites were Ekuaro (2.053), Winiba (2.053) Nkemero (1.53) and Mbenkpen (1.57). These values are in disagreement to those of Afu *et al*. (2021) who in a related study recorded moderate degree of contamination of Pb and very high contamination level of Cd in basalt and sanstone in Ikom, Nigeria. Soils contaminated with heavy metals can cause serious challenge to the ecosystem and human health due to various means of interaction (agriculture, livestock, etc.) where highly toxic heavy metals can enter the food chain (Yaradua *et al.,* 2019). Also, contrary to this study, Abou El-Anwar (2019) reported considerable contamination of Pb, Cd and Cr in soils and sediment in Egypt and had contamination factors of 1.04, 4.37 and 4.0 for Pb, Cr and Cd in some the soils studied. Similar to the findings by Afu *et al*., (2021) and Abou El-Anwar (2019), Muzerengi (2017) recorded Cf which indicated considerable contamination by Cd and As and moderate contamination by Pb in soils of Limpopo province of South Africa. Nevertheless, similar findings to this present study were made by Nwineewii *et al.* (2018).

Degree of contamination (C*d*)

The result for degree of contamination is also presented in Table 6. Soils developed on both sandstone and shalestone showed low degree of contamination of heavy metals. This is comparable with the findings of Jonah *et al.* (2014) who obtained 2.071 and 4.221 for rainy and dry seasons in Ohii Miri river in Abia State. Similarly, Afu *et al.* (2021) who obtained considerable (14<Cd<28) and very high (Cd>28) degrees of contamination for Pb, Cr, Fe,As and Al in basaltic and sanstone soils in Ikom, Cross River State. Contrarily, Mosses *et al.* (2015) reported least Cd value of 7.0 in Ekpene Ukpa within Qua Iboe River Estuary, South-South, Nigeria. The degree of contamination for all the studied heavy metals in this study is also not in agreement with the results of Kolawole *et al*.(2018) who obtained Cd varying from moderate to considerable and further stated that the soils can be described as severely polluted on the basis of pollution index (PI) and modified pollution index (MPI)

Pollution load index (PLI)

The results of the pollution load index (PLI) calculated for both soils according to the method of Tomlinson *et al.,* (1980) are presented in Table 6. The results showed that the values recorded for all the soils are below 1, indicating an unpolluted condition for the studied heavy metals. The results of this evaluation revealed that the soils in Ogoja are unpolluted by the assessed heavy metals even though there is moderate contamination factor for Cd. These findings are comparable with those of Andem *et al.* (2015) who studied the sediment of Okporku River, Nigeria and revealed that it is unpolluted by heavy metals but differ from those of Barakat *et al.* (2012) in Day River, Morocco whose values lie between 1.57-2.20, indicating that the concentration levels of the studied metals in most of the stations exceeded the background values. However, the low PLI obtained are not static, there may be tendency for an increase as a result of increased human activities input and hence there is a need for regular check. The results also vary from those of Sodango *et al*. (2021) whose pollution index were 7.29, 1.05, 0.59 and 0.65 for Cd, Pb, Cr and Ni, respectively, in soils of Fuzlou city of China. They stated that the area was heavily contaminated by Cd and has potential pollution for Pb, As, and Ni. In the same vein, study by Muzerengi (2017) in Limpopo City of South Africa found that the soils varied from uncontaminated, moderately to heavily contaminated, with PLI range of 0.97 to 2.63.

Geo-accumulation index (Igeo)

The Igeo of heavy metals in the soil had mean values of -12.662(Pb), -1.270(Cd), -12.208(Cr), -3.073(Ni) and -4.199(Al) for soil developed on sandstone while those on shalestone showed mean values of -11.393(Pb), -0.016(Cd), -12.061(Cr), -3.168(Ni) and -2.342(Al) (Table 7). From the result, it is evident that the Igeo values for all the heavy metals fell in class '0' indicating practically uncontaminated conditions in these locations. Zho *et al*. (2021) had similar values for Cr and Ni in their study except for Cd.

Table 6: Contamination factor, degree of contamination and pollution index of heavy metals in Ogoja

Stations	Parent materials	Cf-Pb	Cf-Cd	Cf-Cr	Cf-Ni	Cf-Al	*Cd	PLI
Moniaya	Sandstone	0.0007	1.605	0.00022	0.151	0.085	1.842	0.020
Igoli	Sandstone	0.0000	0.450	0.00032	0.184	0.057	0.690	0.007
Egbung	Sandstone	0.0005	1.150	0.00046	0.199	0.110	1.461	0.022
Emandack	Sandstone	0.0004	1.069	0.00033	0.178	0.184	1.431	0.022
Okunde	Sandstone	0.0004	0.105	0.0003	0.182	0.037	0.325	0.010
Mean		0.0004	0.876	0.0003	0.179	0.095	1.150	0.016
Ekuaro	Shalestone	0.0006	2.053	0.00028	0.172	0.000	2.226	0.000
Winiba	Shalestone	0.0007	1.700	0.00036	0.143	0.072	1.916	0.021
Nkpakna	Shalestone	0.0004	0.853	0.00042	0.180	0.000	1.033	0.000
Nkemero	Shalestone	0.0006	1.535	0.00035	0.165	0.103	1.804	0.022
Mbenkpen	Shalestone	0.0006	1.575	0.00036	0.176	0.136	1.889	0.024
Mean		0.0006	1.179	0.000	0.174	0.080	1.433	0.015

Cd = Cadmium, Cf = Contamination factor; *Cd = Degree of contamination; PLI = pollution load index

These Igeo values are comparable with those reported in previous studies (Rabee *et al.*, 2011; Bentum *et al.*, 2011; Barakat *et al.*, 2012; Jonah *et al.*, 2014; Andem *et al.*, 2015; Abou El-Anwar 2019). Consistent values of Igeo were also obtained by Sodango *et al*. (2021) for Cu, Pb As, Cr, and V except for Cd (3.29). In one of such studies, Akpan and Thompson (2013) obtained Igeo value of Cu of 2.92. Contrarily, Afu *et al*. (2021) recorded higher Igeo and stated that soils developed on basalt varied from heavily to extremely contaminated with Cd whereas those developed on sandstone were extremely contaminated with Cd.

Table 7: Geoaccumulation Index and enrichment factor in Ogoja

Sampling point	Parent materials	Igeo-Pb	Igeo – Cd	Igeo -Cr	Igeo-Ni	Igeo –Al
Moniaya	Sandstone	-11.006	0.098	-12.735	-3.310	-4.146
Igoli	Sandstone	-16.960	-1.737	-12.195	-3.031	-4.729
Egbung	Sandstone	-11.638	-0.383	-11.671	-2.911	-3.765
Emandack	Sandstone	-11.873	-0.489	-12.150	-3.075	-3.028
Okunde	Sandstone	-11.831	-3.837	-12.288	-3.040	-5.326
Mean		-12.662	-1.270	-12.208	-3.073	-4.199
Ekuaro	Shalestone	-11.260	0.452	-12.387	-3.122	0.000
Winiba	Shalestone	-11.053	0.181	-12.025	-3.391	-4.384
Nkpakna	Shalestone	-11.960	-0.815	-11.802	-3.058	0.000
Nkemero	Shalestone	-11.375	0.033	-12.065	-3.183	-3.869
Mbenkpen	Shalestone	-11.316	0.070	-12.025	-3.087	-3.458
Mean		-11.393	-0.016	-12.061	-3.168	-2.342

I-geo = Geoaccumulation index; *EF* = Enrichment factor

Conclusions

This study revealed that the soils of both sandstone and shalestone parent materials studied are good physical and chemical condition for crop growth and yield. The soils had moderate level of nitrogen, high base saturation with slightly higher values of fertility parameters obtained in shalestone than in sandstone soils. The soils had moderate levels of exchangeable bases, CEC and a favorable pH. The study also showed that soils of both parent materials were low in contamination factor for all the investigated heavy metals except Cd that had low to moderate contamination factor. Contamination factor was moderate for sandstone soils in Moniaya, Egbung and Emandack, and shalestone soils in Ekuaro, Wininba, Nkemero and Mbenkpen. The soils had low degree of contamination and not polluted as indicated by pollution load index (PLI <1) and practically uncontaminated as shown by geo accumulation index < 0 for the studied heavy metals. Soils in Ogoja were observed to be fertile and safe, therefore are recommended for crop production.

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Variations of Soil Water Retention Properties and Organic Matter across Four Different Land Uses in A Coastal Plain Soil

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ABSTRACT

This research investigated land use effects on soil water retention properties and organic matter across four land uses in Imo State, using a Randomized Complete Block design. The Mbagwu and Mbah (1998) model was used to estimate Field Capacity FC, permanent Wilting Point PFL and Available Water Capacity AWCC, PWP, and AWC Standard laboratory methods were used to estimate the organic matter, moisture, hydraulic conductivity, porosity, and pH. Statistical analysis via SPSS and Fisher's Least Significant Difference test LSD and organic matter's role in linear regression were applied. Results revealed Sand Mining SM with the highest clay content (24.5%) and Primary Forest Land PFL with the lowest (16.2%). Soil texture varied from SL in OPPL, CCL, and PFL to SCL in SM. Primary Forest PFL retained the most water at FC (28.7%), followed by Oil Palm Plantation Land OPPL (25.5%). % Field Capacity FC exhibited no significant differences across land uses and depths ($P \geq 0.05$). SM had the highest bulk density (1.71 g/cm³) and PFL had the lowest bulk density (1.49 g/cm³). Hydraulic conductivity significantly varied among land uses ($p<0.05$). Organic matter differed notably: CCL, OPPL, PFL, and SM reported 1.61%, 1.93%, 2.2%, and 1.13%, respectively. Promoting strategies like bush fallowing, forest restoration, and additive incorporation is vital for sustainable land use. Similarly organic matter differed significantly across land uses: CCL, OPPL, PFL, SM had values of 1.61%, 1.93%, 2.2%, and 1.13% respectively. Linear regression of organic matter with some water retention properties showed stronger fits for data in the OPPL and PFL. This underscores their interdependence on organic matter. To ensure sustainable land uses, strategies such as bush fallowing, forest restoration, and additive incorporation should be promoted and sustained.

Keywords: Sand Mining, Primary Forest, Continuously Cultivated Land, Oil Palm Plantation, Hydraulic Conductivity, Field Capacity, Permanent Wilting Point, Water retention properties, Porosity etc

1.0 INTRODUCTION

Water affects every aspect of soil development and behavior. Processes such as rock weathering, organic matter decomposition, plant growth, recharge of underground water as well as the pollution of nearby water bodies are some of the processes where water plays a major role (Brady and Weil, 1999). Water is also a necessary constituent of the soil environment in addition to other requirements namely, adequate nutrients supply, good aeration, optimum temperature, all of which jointly make the varied life forms in the soil possible.

Its importance also accounts for seed germination and development, plant nutrients uptake processes, translocation of these nutrients within the plant organs, various microbiological activities and temperature control within the plant systems by way of transpiration processes.

The soils ability to hold water is termed soil termed soil water retention. Having a knowledge of soil water retention and transmission is important and has practical implications in agriculture, environment and in hydrologic situations (Ali, 2014). Available soil water retention is influenced by the soil depth, organic matter content as well as the soils texture (Ahmed, 2006). Thus, restoring the soils organic matter will obviously enhance plant water availability, resilience against soil water losses as well as contributes to both climate change mitigation and adaptation (Lal, 2020; Paul *et al*., 2023). Similarly, the magnitude of land use management practices can cause soil organic matter depletion or additions, thus impacting on the soils water retention ability (Zhu *et al*., 2021). The disruption of the soil structure and the pore spaces as a result of land use changes often result in reduced water retention. Similarly, reduced water movement and the disruption of the soil structure due to land use not only increases run off but also reduce the transportation of dissolved plant nutrients to the root zones where they are needed. Conversely, land uses that result in creation of large macro pores can result in reduced water retention as well as the rapid transportation of dissolved chemicals to the ground water system (Thomas and Philips, 1979). The pattern of land use systems in Imo state have affected the water transmission, soil properties and productivity of agro ecosystems (Osuji *et al*., 2010). As a result of urbanization, fallowed lands are being cleared and converted to other marginal uses. It is common seeing forested lands being converted to plantations, rangelands, grassed or landscaped for aesthetics in Imo state. These changes from the original forest land to the current land use systems have affected water transmission in those soils resulting to low productivity as well as erosion witnessed in the state of recent (Emenyeonwu and Onweremmadu, 2011). Urbanization has been reported as one of the drivers fueling this unwholesome land use practices that result in the modification of the natural soil canopy. Bisong, (2001) observed that human activities like deforestation and urbanization negatively impact soil structure, degrade soil quality and reduce soil's ability to perform its ecological, agronomic and environmental functions. According to Kigne, (2009) urbanization is the most forceful of all the land uses that affect the hydrology of an area as it leads to the decline in the volume of water that is retained in the soil resulting in varied forms of land degradation. Therefore, land degradations in the form of soil erosion, increased destruction, and flooding as well as reduced productivity are some of the serious challenges faced by the inhabitants of the state (Emenyeowu and Onweremadu, 2011). Shepherd *et al*., (2006) corroborated this in their findings that land use systems in tropical ecosystems can cause significant modifications in soil properties such as reduced fertility and land degradations.

Despite the general recognition of the threats of degradations, low productivity as well as ecosystem instability and the need to ensure high precision agriculture and sustainable water use, it becomes necessary to ascertain the resulting variations of the water retention properties and organic matter across four different land use systems as establish a linear relationship between the soils organic matter and the soils water retention. This will help in generating qualitative information that will help in irrigation scheduling, appropriate land use changes, erosion prevention and control as well as rational use of organic and inorganic amendments.

2.0 Materials and methods

2.1 Description of the study area.

The study was conducted in Uloanondugba in Isu L.G.A of Imo state. Uloanondugba lies between Lat 005^{o}39'52''N to Lat 005^{0}41'51''N and Long 007^{0}02'52.9''E to Long 007^{0}02'45.4''E. The soils of the study area are derived from coastal plain sand. The area has a tropical humid climate with daily minimum and maximum temperatures of 20^{o}C and 30^{o}C respectively. The mean annual temperature of the area ranges from 27-28^{o}C with relative humidity ranging from 75-80% (IPEDC, 2006). The area is characterized by rainy and dry seasons. The rainy season starts in March/April with its peak in July and September, while the dry season starts in November and ends March. The vegetation type in the area is tropical rainforest with mean annual rainfall of 2000-2500 mm (IPEDC, 2006). Four land use systems namely a continuously cultivated land of 10 years (CCL).

2.2 Land description

An Oil palm plantation (OPPL) of about 35 years, 100 years old forest (PFL) and a Sand mining site (SM) served as the experimental treatment. Common tree species of the primary forest include iroko (*Chlorophora excelsa*), oil bean trees (*Pentacletha macrophyla*) African bread fruit (*Treculia Africana*) Gmelina (*Gmelina arborea*). The Continuously cultivated land (CCL) was a 10 years old land previously under continuous cultivations. The major crop grown during the course of this research was cassava. The Oil Palm Plantation (OPPL) has been in existence for over 30 years ago with little or no maintenance in the areas of clearing weeds and other shrubs. The fertility of the CCL is maintained by the use of mineral fertilizers, poultry droppings and household wastes. The weeds were cleared manually with specialized hoes. The land use is on a near level to gently undulating land with mean altitude of 159 m. Similarly, the sand mining site SM has been on seasonal use since 15 years now.

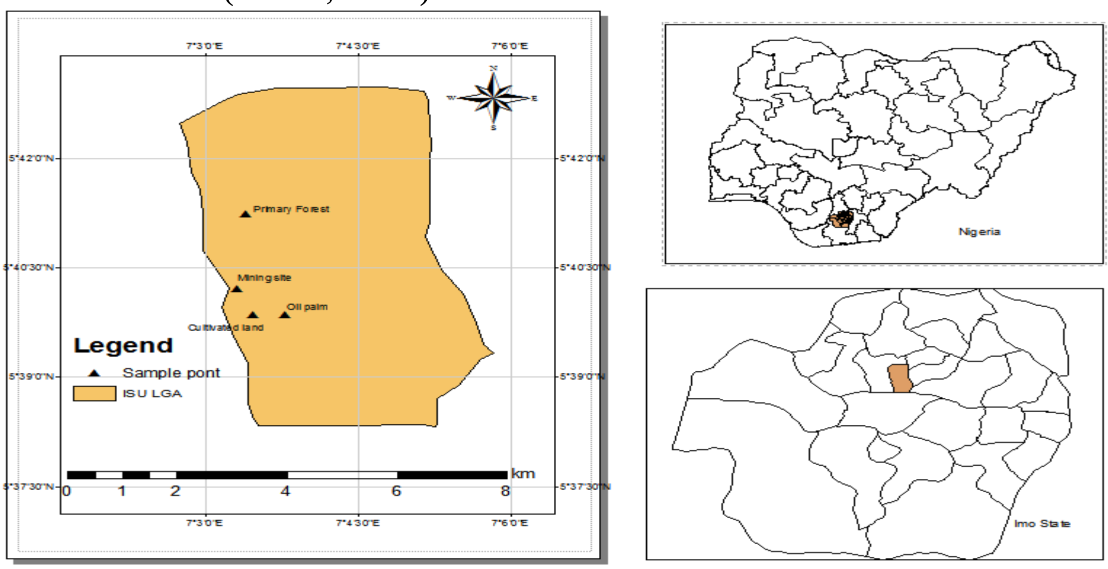

Figure 1: Map of the study area showing the various land uses

2.3 Sample collection and laboratory analysis:

In order to collect soil samples for laboratory analysis, profile pits were dug in each of the three replicates of the four land uses. Four Samples were collected at distinguished horizons from each of profile pits at both the rainy and dry seasons for two years. Collected samples were prepared using standard laboratory methods. The particle size distribution was determined by the hydrometer method (Gee and Or, 2002). Bulk density was determined by the core method as described by Gee and OR (2002). Saturated hydraulic conductivity was determined by the constant head permeameter method ((Klute and Dirksen, 1986). Soil moisture content was determined by the gravimetric method according to Gardner (1986). Soil pH was measured electrometrically by glass electrode in distilled water using a soil: water ratio of 1:2.5 (Hendershot *et al.*, 1993). The Organic carbon was determined using dichromate wet oxidation method of Walkley and Black as modified by Nelson and Sommers (1982) while the organic matter was calculated by multiplying the Organic carbon values by 1.724 (Van Bemmelens conversion factor). The soil water saturation percentage (SP) was determined using the saturation water percentage-based estimation models of Mbagwu and Mbah (1998). Available water was computed as the difference between the moisture retained at field capacity and permanent wilting point.

FC =0.79(SP)-6.22 ………………………………………equation 1

PWP=0.51(SP)-8.65……………………………………...equation 2

Where FC = field capacity percentage,

PWP = permanent wilting point percentage,

SP = saturation water percentage.

The SP was determined by soaking perforated crucibles of soils in a container with the water nearly 2/3 of the height of the crucibles containing samples of soils. The soil was soaked for about 2 days to get the soil pores completely saturated with water. The mass of the saturated soil and crucibles (M_{sa}) was obtained by weighing it on a sensitive weighing balance. The saturated soil was then placed in an oven at about 105^0C and allowed to stay for forty-eight hours to get it dried. It was then brought out and placed in a desiccator to cool. On cooling the mass of the oven dried soil and crucibles was obtained as (M_{so}). The saturation water percentage (SP) was calculated using,

$$SP = \frac{[Me + (Msa - Mso)]}{Mso}$$ ………………………. equation 3

$$Mso = \frac{100 \times [Msa]}{100 + er}$$ ……………………equation 4

Where ɵr = residual air dry moisture (%) ,$M_ɵ$ = Mass of H_20 absorbed (g), M_{sa} =Mass of air-dry soil (g), M_{so}= Mass of oven dried soil (g).

Soil properties among the different land use systems were compared using a two way analysis of variance and the least significant difference was used for mean separation at 0.05 level of separation

3.0 RESULTS AND DISCUSSIONS.

The results of the soils physical and some chemical properties are listed in table 1.0 and 1.1. Results indicates that the percentage sand, silt and clay were significantly different in all the land uses studied (p<0.05). In table 1.0, the percentage sand was 78.3% in the OPPL in the first rainy season while the SM recorded the lowest percentage sand (69.5%). The percentage clay varied significantly across the different land uses with the SM having the highest percentage of clay (24.5%) compared to the other land uses. The higher percentage clay recorded in the SM was as a result of increased clay translocation from the surface to the deeper depths during excavations as reported by Jaiyeoba (2003). Similarly, the texture of the soils ranged from SL in the OPPL, CCL, PFL to SCL in the SM. The high sand fractions in all the land uses according to Asawalam *et al* (2009), Chukwu (2012) was as a result of the soils been derived from unconsolidated sand deposits over a coastal plain soil. The bulk density values ranged from 1.58-1.71g/cm^3 across the land uses studied. They bulk density values were significantly different in all the land uses and were observed to increase with depths. The absence of vegetative covers and large scale use of machineries in the SM led to the increased bulk density in the SM land use. This corroborated with the findings of Musa (2013) and Onwuka 2019. Conversely, the dense vegetation's in the PFL may have led to the decreased bulk density values witnessed in the land use. Mulugeta (2004) corroborated same. Similarly the moisture content varied significantly across the land uses (p<0.05). The OPPL and PFL recorded the highest percentage moisture content of 24.6 and 24.2% respectively while CCL and SM had moisture of 22.2 and 21.4% respectively. The improved moisture content in the OPPL and PFL is premised on the extensive root network of the forest trees as well as on the protective canopy of the oil palm trees that helped to checkmate evapotranspiration. Generally, the moisture contents were low and this may not be unconnected to the high sand and low organic matter that impairs moisture retention and organic matter decomposition.

Table 1.0: Effect of land uses on soil physical properties

LAND USES	DEPTHS (cm)	%SAND	%SILT	%CLAY	T	BD g/cm^3	% P_o	%MC	K_{sat} cm/hr
OPPL	0-30	83.8	6.13	10.06	LS	1.47	43.2	19.7	21.1
	30-60	76.46	4.8	18.4	SL	1.65	37.4	21.4	14.2
	60-90	75.13	5.46	19.4	SL	1.75	33.2	28.6	8.8
	90-120	77.88	8.8	20.06	SL	1.7	31.7	28.83	2.8
Mean		78.32	6.30	16.98		1.6	36.4	24.63	11.7
LSD (P≤0.05)		0.04	0.84	2.04		0.01	0.01	0.20	4.29
PFL	0-30	82.13	6.46	11.4	LS	1.41	46.74	22.34	37.5
	30-60	77.86	6.13	16.06	SL	1.46	44.63	21.88	31.8
	60-90	75.13	7.15	17.7	SL	1.51	46.7	25.48	14.1

	90-120	74.46	5.46	19.7	SL	1.56	40.86	26.95	7.1
Mean		77.40	6.30	16.22		1.49	44.73	24.16	22.6
LSD		0.04	0.84	2.04		0.01	0.01	0.20	4.29
	0-30	80.86	6.13	13.06	LS	1.41	46.7	21.6	26.3
CCL	30-60	77.13	5.46	17.06	SL	1.67	36.7	22.4	19.7
	60-90	75.8	4.8	18.78	SL	1.58	40.3	21.4	9.1
	90-120	72.29	8.12	21.06	SCL	1.65	37.5	23.4	5.7
Mean		76.52	6.13	17.49		1.58	40.3	22.2	15.2
LSD		0.04	0.84	2.04		0.01	0.01	0.20	4.29
	0-30	72.44	7.8	19.73	SL	1.65	37.56	19.5	14.5
SM	30-60	70.8	4.8	24.46	SCL	1.71	35.43	20.2	7.5
	60-90	67.86	5.13	26.73	SCL	1.74	34.05	22.56	3.4
	90-120	67.13	5.8	27.06	SCL	1.71	33.03	23.3	7.6
Mean		69.56	5.88	24.50		1.71	35.02	21.4	8.3
LSD		0.04	0.84	2.04		0.01	0.01	0.20	4.29

The percentage porosity also varied significantly across land uses ($p<0.05$) with the PFL having the highest pore space of 42.3 against the 33.7% observed in the SM land use. The higher pore spaces in the forest land use are premised on the extensive root network of the trees that have created more pores. Hydraulic conductivity K_{sat} also varied significantly across the land uses with the PFL and CCL having the highest Ksat values 8.32cm/hr each. The lowest K_{sat} values of 4.9cm/hr which may not be unconnected to the high bulk density experienced in the site as well as the low organic matter present therein. Celik (2005); Li and Shao, (2006) observed similar trends when they studied on land use effects on organic matter and the physical properties of soils as well as changes on soil physical properties under long term natural vegetation respectively. The declined K_{sat} values in the SM were as a result of increased clay content down the depths in all the land uses. This was in line with the findings of Jarvis et al. (2002) that percentage increase in clay retards the soils hydraulic conductivity. In table 1.2, the soil pH showed a definite trend of increasing acidity with the depths. The mean soil pH ranged from extreme acidity to very strong acids in all the land uses. The PFL and CCL had a very strong acid condition of 4.1 each while the SM had extremely strong acid condition of 3.14. The higher acidity in the sand mining was probably as a result of excavations that have triggered erosion and has washed away the exchangeable bases. This result is consistent with the findings of Gabrekidan and Negasa, (2006).

Table 1.2 Effect of land use on some soil chemical properties

LAND USES	DEPTH	pH	%OM	%TN
OPPL	0-30	5.13	3.15	0.14
	30-60	4.46	2.06	0.08
	60-90	3.38	1.2	0.03
	90-120	3.43	0.49	6.3
Mean		4.10	1.73	1.64
LSD		0.42	0.12	1.92
PFL	0-30	5.03	3.71	0.23
	30-60	4.4	2.72	0.13
	60-90	3.8	1.56	0.06
	90-120	3.1	0.6	0.02
Mean		4.08	2.15	0.11
LSD		0.42	0.12	1.92
CCL	0-30	4.43	2.4	0.4
	30-60	4.12	1.74	0.07
	60-90	3.5	1.24	0.03
	90-120	3.3	0.96	0.04
Mean		3.84	1.59	0.14
LSD		0.42	0.12	1.92
SM	0-30	3.56	1.98	0.02
	30-60	3.06	1.33	0.02
	60-90	3	0.85	0.01
	90-120	2.93	0.23	0
Mean		3.14	1.10	0.01
LSD		0.42	0.12	1.92

3.1 Variations of water retention properties across land uses

The variations of water retention properties across the land uses are shown in table 1.3. According to the table, the OPPL retained the highest mean water at FC (29%) while the PFL retained the second highest amount of water at FC (27%). The CCL and SM retained 18.1% and 16.4% of water at FC respectively. The % FC did not show any significant difference across the four land uses and depths ($P \geq 0.05$). The percentage FC was was no significant difference in the PWP of the PFL and OPPL across the depths. Meanwhile, the AWC had its highest mean value of 14.9% in the PFL as against the 6.9%, 7.9% and 14.1% recorded in the SM, CCL and OPPL observed to increase with depth across the land uses. The highest percentage of water retained at FC was at the 90-120cm depth of the PFL and CCL while the least value occurred in the 0-30 depth of the SM. Similarly, the highest water retained at PWP was in the PFL with a percentage mean value of 13.7% while the SM, CCL and OPPL had a FC of 6.9, 7.9 and 11.6% respectively. There
respectively. There were significant differences in the 0-30 and 90-120cm ($P \leq 0.05$) depth of the PFL. Similar variations were observed in the 0-30 and 90-120cm

Table 1.3 Effect of land uses on the soil water retention properties

Land uses	DEPTHs (cm)	%FC	%PWP	%AWC
PFL	0-30	26.9	12.7	14.2
	30-60	29.5	14.4	15.1
	60-90	26.9	12.9	14.1
	90-120	31.6	15.2	16.4
	Mean	28.7	13.7	14.9
LSD		**4.8**	**3.0**	**1.9**
OPPL	0-30	24.8	11.2	13.3
	30-60	25.6	11.9	13.7
	60-90	24.5	12	13.3
	90-120	27.2	11.5	16.1
	Mean	25.5	11.6	14.1
LSD		**4.8**	**3.0**	**1.9**
CCL	0-30	21	9.0	12.1
	30-60	23	10.3	12.8
	60-90	16.4	5.8	10.4
	90-120	17.7	6.7	11
	Mean	19.6	7.9	11.6
LSD		**4.8**	**3**	**1.9**
SM	0-30	15.2	5.2	9.7
	30-60	17.4	6.6	10.8
	60-90	19.6	7.9	11.6
	90-120	19.2	7.8	11.4
	Mean	17.8	6.9	10.9
LSD		4.8	3	1.9

3.2. Simple linear regression of Organic matter and selected soil physico-chemical properties at the various land use types

Table 1.4 revealed that at CCL, OM had negative relationship with FC, PWP, K_{sat}, MC, total porosity, pH and TN, but positively related with BD. The values of the coefficients of determination (R^2) showed that OM contributed greatly in (40.6%), AWC (58), total porosity (32.5%, BD (31.9%), TN (70%) and pH (50.5%) influencing the saturated hydraulic conductivity of the soil with R^2 value of 99.7%. The percentage contribution of OM in influencing the other parameters is FC (40%), PWP

Table 1.4: Relationship between organic matter and selected soil parameters at continuously cultivated land (CCL)

Dependent	Independent	linear model	R^2
FC	OM	FC= -0.63 OM+131	40.3
PWP	OM	PWP = -0.63OM+80.6	40.6
AWC	OM	AWC=-0.61OM+66.9	58.0
K_{sat}	OM	Ksat = -0.99OM+49.9	99.7
MC	OM	MC = -0.14OM+25.2	20.0
P_O	OM	Po = -0.57OM+94.7	32.5
BD	OM	BD = 0.56OM+0.14	31.9
TN	OM	TN = -0.26OM+0.17	70.0
pH	OM	pH = -0.7OM+7.3	50.5

At OPPL (Table 1.5), OM was shown to relate negatively with FC, PWP, MC, K_{sat}, total porosity and TN, but had a positive relationship with BD and pH. The total variability in these parameters caused by OM (R^2) was shown to be BD (70.1%), PWP (40.6%), AWC (50.2), K_{sat} (99.7%), FC (99.6), total porosity (32.5%), TN (4.0%) and pH (63.0%).

Table 1.5: Relationship between organic matter and selected soil parameters at oil palm plantation land use (OPPL)

Dependent	Independent	linear model	R^2
FC	OM	FC = -0.99OM+42.1	99.6
AWC	OM	AWC=0.89OM+48.7	50.2
MC	OM	MC = -0.63OM+131	40.3
K_{Sat}	OM	K_{sat} = -0.99OM+49.9	99.7
P_O	OM	P_O = -0.57OM+94.7	32.5
PWP	OM	PWP = -0.63OM+80.6	40.6
TN	OM	TN =-0.06OM+0.16	4.00
pH	OM	pH =0.79OM+10.5	63.0
BD	OM	BD =0.87OM+0.68	70.1

At PFL in Table 1.6, OM was shown to relate positively with FC, PWP, AWC, Ksat, MC, total porosity and pH, but related negatively with BD and TN. The extent of influence of OM on the parameters given by the R^2 values was FC (68.5%), PWP (66.9%), AWC (66.9%), BD (99.2%), Ksat (8.3%), MC (99.2%), total porosity (99.5%), p^H (0.8%) and TN (86.99%).

It was also shown that at SM, OM had a positive linear relationship with all the parameters except with MC which related negatively with it. However, the R^2 values revealed that OM influenced changes in the soil parameters having contributed 81.8% change in K_{sat}, 37.4% (FC), 37.8% (PWP), 31.9% (AWC), 85.2% (MC), 5.70% (porosity) and 60.7% (TN). The negative relationship of OM with water retention characteristics at CCL and OPPL could be attributed to the possible hydrophobic nature of certain organic compounds contained in the OM. Hence, the repulsion of water molecules from the surfaces of the organic materials decreased the capacity of the OM to retain water within the soils. On the contrary, the positive linear relationship of OM with the water retention characteristics at PFL and SM could be inferred on the ability of the OM to bond with the water molecules via the large charged surfaces of the organic materials. In sandy soils, OM plays a significant role in retaining soil water at varying pressures (Ahmed, 2006), while at soils with considerable amount of clay particles, OM tends to weaken the water holding capacity of the soil by increasing he dispersion of clay particles which would have served in water retention (Azian *et al*., 2012).

Table 1.6: Relationship between organic matter and selected soil parameters at primary forest land use (PFL)

Dependent	Independent	linear model	R^2
FC	OM	FC = 0.82OM-61.9	68.5
PWP	OM	PWP = 0.81OM-44.5	66.9
AWC	OM	AWC =0.82OM-17.1	66.9
BD	OM	BD = -0.99OM+2.61	99.2
K_{Sat}	OM	K_{sat} = 0.28OM+9.03	8.3
MC	OM	MC = 0.99OM-3.56	99.2
P_O	OM	P_O = 0.991OM+2.16	99.5
pH	OM	pH = 0.89OM+5.88	0.8
TN	OM	TN = -0.93OM+57	86.9

The negative relationship of OM with K_{sat} and total porosity at CCL and OPPL may be associated with the sealing of soil pores resulting from the dispersion of clay by the OM. Hence, the higher the OM, the higher the dispersion of clay particles and subsequent sealing of soil pores. The sealing of soil pores decreases the total porosity (pore volume) which consequently decreases the saturated hydraulic conductivity (K_{sat}) of the soil (Rawls *et al*., 1993). Conversely, the positive relationship of OM with total porosity and K_{sat} at SM and PFL may be due to the improved soil structure by the OM. Improved soil structure via good aggregation increased the total pore volume (porosity) and water transmission via soil column (Lee and Foster, 1991).It could also be predicted that the positive relationship of OM with BD at CCL and OPPL was due to the decrease in pore volume caused by the sealing of soil pores with dispersed clay particles brought about by the OM. At SM, the increase in BD with OM could be predicted on the aggregation of sand particles into massive and weighty aggregates by the OM which resulted in large mass per unit volume of the soil (BD) (Gupta, 2004). On the contrary, the negative relationship of OM with BD at PFL could be attributed to the considerable accumulation of organic materials in the soil relative to the mineral component of the soil solids. Organic matters are relatively light with large surface area (bulky) compared to the solid mineral component. Hence, increased OM content decreased the soil BD due to its small mass per unit volume (Onyegbule *et al*., 2018).

The negative relationship of OM with TN at CCL, OPPL and PFL was possibly the resultant effect of the increased microbial population caused by the increased OM content. Increase in microbial population decreases the nitrogen content of the soil due to the intake of the nitrogen by the organisms. Also, when OM content of the soil is increased, it improves the soil fertility which promotes the growth of plants. However, as these plants grow, they take up nitrogen via mineral nutrition hence the amount of nitrogen in the soil diminishes (Cresswell *et al.*, 1992). Conversely, the positive relationship of OM with TN at SM (Table 1.7) was possibly a result of the limited microbial population and reduced plant population which otherwise reduced the depletion of nitrogen released from the OM decomposition. Aminu *et al.*, (2013) inferred that sand lacks the effectiveness of supporting plant growth and microbial activities, hence nutrients removal by plants uptake and microbial nutrition is minimal.

It could be inferred that the positive relationship of OM with pH at OPPL, PFL and SM could possibly be due to reduced loss of basic cations (Ca, Mg and K) released from the OM into the soils. At OPPL and PFL, loss of basic cations via leaching was possibly reduced by the adequate ground covering which reduced the velocity of water flow both vertically and laterally. Hence, as OM increased, soil pH increased following accumulation of basic cations in line with the report of Bronick and Lal, (2005). At SM, this positive relationship was probably a consequence of limited plant growth which reduced the loss of basic cations by plants' uptake. Hence, the availability of the basic cations from the OM decomposition increased as OM content increased leading to increase in pH, and vice versa. In contrast, at CCL, due to the continuous cultivation of the soil, OM is easily decomposed releasing basic cations which were readily absorbed by the crops and some lost by leaching, hence, the soil pH decreased (acidity) due to the possible accumulation of acidic radicals released from the OM decomposition as reported by Celik, (2005).

Table 1.7: Relationship between organic matter and selected soil parameters at Sand mining Land use (SM)

Dependent	Independent	Linear model	R^2
FC	OM	FC = 0.50OM+5.1	25
PWP	OM	PWP = 0.43OM-4.0	18.5
AWC	OM	AWC = 0.64OM+5.5	41.0
K_{sat}	OM	K_{sat} = 0.93OM-9.2	88.1
MC	OM	MC = -0.92OM+30.9	84.7
Po	OM	Po = 0.96OM+24.8	93.0
BD	OM	BD = -0.94OM+1.98	89.3
TN	OM	TN = 1.0 OM-0.37	99.0

It was also revealed in table 1.7 that at SM, the OM had a positive relationship with FC, PWP, AWC, Ksat, total porosity and TN, but related negatively with BD and MC. The contribution of OM in influencing the changes in the parameters was 25% (FC), 18.5% (PWP), 41% (AWC), 88.1%

3.3 Conclusions

The dominance of sand across all land uses indicates the coastal nature of the area. Sand excavations that exposed subsoil contributed to the higher clay content in SM, which increased bulk density and lowered porosity, moisture, and organic matter. The four land uses studied had significantly different bulk density values ($p<0.05$). PFL and OPPL showed better water retention and transmission compared to SM and CCL, aided by higher saturated hydraulic conductivity (Ksat) and lower bulk density. Organic matter (OM) positively correlated with water retention in OPPL, PFL, and SM, as indicated by high R^2 values. The negative relationship between OM and bulk density suggests increased pore volume decreases soil mass per unit volume. Despite improved porosity by OM, its negative relationship with Ksat in OPPL and PFL might be due to increased osmotic forces from dissolved organic materials, reducing water flow. At CCL and OPPL, the negative correlation of OM with moisture retention may result from OM's adverse effects on clay, reducing water retention capacity. Conversely, at PFL and SM, OM's positive relationship with water retention is due to its ability to attract and hold water molecules, enhancing soil moisture.

3.4 Recommendations

(a). Appropriate land use practices such as conservative tillage, as well as constant mulching are necessary in other to restore the productive potentials of the soil. Mulching apart from preventing excessive loss of water from the soil surface can as well add to the organic matter of the soils, this can also provide a substrate for growth and multiplication of beneficial microorganisms.

(b). The application of mineral fertilizer such as N.P.K is recommended as a soil management practice for the continuously cultivated soils to immediately resuscitate their fertility and productivity within short period considering their continuous loss of nutrients by crop uptake, crop removal, leaching and overland flow.

(c). Liming of the soils to reduce the inherent acidity in the land uses should be initiated immediately as the soils were extremely acidic.

(d). As a result of the higher and rapid infiltration rates observed in the land uses, farmers and other policy makers are advised to adopt the overhead type of irrigation so as to conserve water. This will invariably reduce the amount of water and nutrients that are leached down the profiles.

(e). The farmers and other land users should as a matter of fact convert most of the Continuously Cultivated land and Sand mining sites in the area into a forest or plantations. This will help in restoring most of the soils productive potentials; improve organic matter build up as well as reduce runoff that causes erosion.

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Effect of Land Use Types on Some Selected Soil Physical and Chemical Properties in Itakpe, Kogi State

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ABSTRACT

Information about effects of land use types on selected soil physical and chemical properties is essential in sustainable utilization of soil resources. Therefore, this study was conducted to evaluate the effect of land use types on some selected soil physical and chemical properties in Itakpe, Kogi State, Nigeria. Three land use types namely; arable, fallow and agro-forestry land were evaluated in this study. On each land use type, 3 profile pits were dug and soil samples (30) were collected from arable land, agro-forestry land, and fallow land at 0 – 30 cm soil depth, bulked in to 10 composite samples for each land use practice and replicated three times. The one-way analysis of variance was used to test mean difference of the soil physical and chemical properties. The highest mean value of sand was obtained under fallow land. Arable land and agro-forestry had statistically similar amounts of silt which were higher than that of the fallow land. Clay particles were not significantly different for all the three land uses meaning that land use did not affect this soil fraction. The pH in water ranged from 5.87 – 5.93 and pH KCl ranged from 5.30 – 5.33 while the mean values of Organic carbon and Organic matter ranged from 1.71 – 2.16 %. However, the mean value of total nitrogen ranged from 0.05 – 0.06 %. The mean value of available phosphorus ranged from 3.15 – 4.53 g/kg, which implies low p and hence deficiency of available phosphorus in the study area. The exchangeable basic cations and CEC values were within very low to low ranges in all land use practices. The soil properties determined showed that soil nutrients under Agro-forestry were significantly higher than those of fallow and arable land. Research findings lends credence to the fact that land use practices which improves soil nutrient/fertility such as Agro-forestry should be adopted so as to boost the productivity capacity of the land and ensure sustainability of agricultural production. To improve the soil pH (which is slightly acid), use of liming materials ($CaCO_3$) should be encouraged. Growing of leguminous trees and crops such as *Tamarindus indica*, forage crops and cover crops to enhance soil fertility and crop productivity is recommended in the study area. Animal husbandry is also recommended as an alternative utilization of the land to boost the soils nutrient status for sustainable farming.

Keywords: Land use, Fallow land, Arable land, Agro-forestry land, Physical and Chemical properties, Itakpe.

1.0 INTRODUCTION

Environmental degradation as a result of inappropriate land use has become a global problem that attracted attention in sustainable agricultural production systems. Land degradation is one of the major threats to food security and conservation of natural resources as well as the environment. Given the intense pressure on the ecosystem and the continuous decline especially in soil fertility due to population explosion demanding more lands for food production, such information becomes necessary for appropriate soil planning and management (Wilson *et al., 2008*). Land is put into agricultural and non – agricultural uses as several activities are carried out on land. The purpose for which a portion of land is used makes up its land use (Ufot *et al*., 2016; Eneje and Eke, 2012; Anon, 2005).

Land use and management practices influence physical, chemical, and biological properties of soils (Lawal *et al.* 2020; Zajicova, 2019; Deng *et al.* 2016; Jamala and Oke, 2013). Lands are largely put to agricultural practices in the study area which spans from arable (continuous cultivation), crop rotation, fallow, and agro-forestry. Agricultural practice however requires basic knowledge of sustainable use of the land (Takele *et al*., 2014). This is because, agricultural practices have enormous consequences for soils (Zajicova, 2019), as tillage affects the amounts of carbon/organic matter content which is usually lower in arable lands than forests and natural grasslands (Lawal *et al.* 2013; Jamala and Oke, 2013). Addition of pesticides and mineral fertilizers in large quantities also contribute to the depletion of soil quality (Salifu, 2022; Zajicova, 2019).

Soils of Itakpe are formed from basement complex rocks which ranged from very shallow to deep soils (Akpa, 2008). Predominantly, soils that originate from basement complex rocks of itakpe have impervious subsurface horizons due to plinthization process (Odunze and Kureh, 2009). Plinthization is a threat to agriculture as it affects vertical flow of water by limiting it and ensuring horizontal flow of water in the soils (Jimoh *et al.* 2018); hence, this phenomenon called plinthization could affect the distribution of soils and distortion of its properties. There is scarcity or rather dearth of information regarding current status of soil properties in Itakpe. There is need therefore to gather facts relating to soil conditions, their current status, changes due to land uses and management practices (Paul *et al.* 2019). This is because successful agriculture requires the sustainable use of soil resources, as soil can easily lose its quality and quantity within a short period of time for different reasons such as intensive cultivation, leaching and soil erosion (Kiflu and Beyene, 2013).

It is essential to study the impact of land use types and management practices on physicochemical properties which can be of great help to policy makers and other stakeholders (farmers, landowners, and other land users) to have proper land use planning aiming at improving and replenishing soil fertility, protecting the environment from erosion hazards, and also restoring degraded ecosystem. This will also help in mitigating climate change effects; improve the socio-economic conditions and ecosystem of Itakpe, to encourage stakeholders and decision makers. This research will propose steps and recommendations that can be helpful for future (posterity) sustainable planning and production. Evaluating soil properties is a step toward land use sustainability and prevention of degradation which destroys soil quality and consequently productivity.

Therefore, the aim of this study is to evaluate the effects of land use types on selected soil physical and chemical properties in Itakpe, Kogi State.

2.0 MATERIALS AND METHODS

2.1 Description of the Study area:

The experiment was carried out in the School of Agricultural Technology students' research farm, Kogi State Polytechnic, Itakpe campus, Southern Guinea Savanna of Nigeria. The study design was a field survey to take inventory of the soil properties. The study location lies between Latitude 7° 39' 20" N and Longitude 6° 21' 40" E with an elevation of 169 m above the sea level in the Southern Guinea Savanna ecological zone of Nigeria (Wakawa *et al.*, 2016). The climate is humid tropical, supporting guinea savanna vegetation (Adenle *et al*., 2020). The mean annual rainfall is between 1,100 mm and 1,300 mm. The rainy season last from April to October each year, while the dry season last from November to March (Ogunwale *et al.,* 1999). Temperature is uniformly high and ranges between 25 °C and 30 °C in the wet season; throughout the season except between July and August when clouding of the sky prevents direct insolation. Dry season temperature ranges between 33°C to 34°C. Relative humidity in the wet season is between 75 to 80% while in the dry season it is about 65 % (NBS, 2009). The climate supports tall grasses interspersed with short, scattered trees. It also favours the cultivation of arable crops such as millet, cassava, yam, cowpea, maize, and rice (Salifu *et al.* 2023).

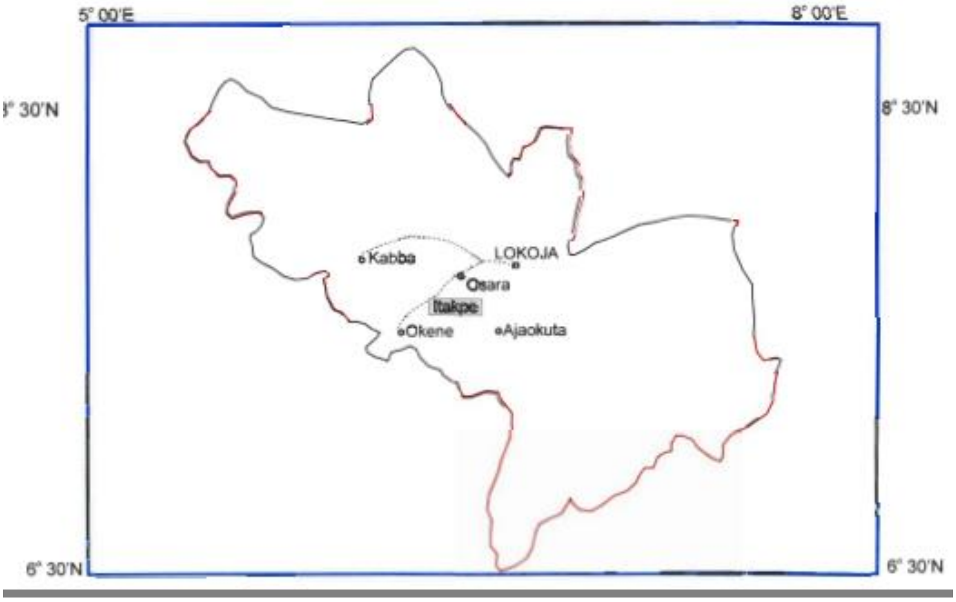

Figure 1: Map of Study Area and environs (Itakpe, Kogi State)

Table 1: Description of Land Use Types and Characteristics of Sampling Sites

S/No	Land use type	Vegetation	Coverage on hectare basis	Features/Description
1	Arable land	Maize, Cassava and Rice	2 ha	Continuously cultivated land for cassava, maize, for more than 20 years, frequent use of inorganic or chemical fertilizers
2	Agro-forestry	Trees, shrubs, Cassava, Maize, and vegetables	3 ha	Average height of trees was 1.36 m and the average age was about 5 years. The land is also planted to shrubs and crops such as cowpea, groundnut, soyabean, cassava for more than 15 years
3	Fallow land	Shrubs and grasses	Vast land of about 6 ha	Land is fallowed for about three (3) years having grasses and shrubs, although scanty soil cover

Table 2: GPS and altitude information about sampling sites

Sampling Site	Slope Aspect	GPS Coordination (Decimal)		Altitude (m.a.s.l.)
		Latitude	Longitude	
1 Arable land	N	6.359113	7.660664	150.2 m
2 Agro-forestry	NW	6.359116	7.660122	162.4 m
3 Fallow land	N	6.358839	7.660934	170.1 m

m.a.s.l. – meter above sea level

2.2 Soil Sample Collection and Preparation

A stratified random sampling method was adopted to collect soil samples by hypothetically dividing each land use type in to three (3) subdivisions representing three (3) replications since land use types' plot were not replicated and land/plot sizes were very large. Three (3) profile pits were dug 150 m apart on each land use type, namely, arable, agro-forestry, and fallow land. In each replication, composite samples at ten (10) different points were taken and then bulked. A total of 30 soil samples were collected from each land use type using a soil auger at 0 – 30 cm depth at 50 m intervals along a transverse (in transect), and carefully labeled for ease of identification. The soil samples were air-dried and sieved using a 2 mm wire mesh sieve before routine laboratory analysis.

2.3 Laboratory Analysis

The air-dried 2 mm sieved soil samples were used for the analysis of soil pH in 1:2.5 soil/water suspensions and in KCl by employing the use of a glass electrode pH meter (Maclean, 1982). Particle size distribution was determined by the hydrometer method and sodium hexametaphosphate as dispersant (Gee and Bauder, 1986; Bouyoucos, 1962). For the determination of soil organic matter/carbon, the Walkey – Black wet oxidation method was adopted (Nelson and Sommers, 1982; Walkey – Black, 1934). The Kjeldahl digestion method as described by Bremner and Malvaney (1982) was used to determine total nitrogen (TN) of the soil. Available phosphorus (Avail. P) was determined using Bray 1 extraction method (Bray and Kurtz, 1945) and colorimetrically by the ascorbic acid as described by Murphy and Riley (1962). Exchangeable cations/bases were extracted in neutral normal (1N) ammonium acetate solution (pH 7.0). Exchangeable calcium ($Ca2^+$) and magnesium (Mg^{2+}) in the solution were determined using the Atomic Absorption Spectrophotometer (using Acetylene flame and lithium salt) while exchangeable potassium (K^+) and sodium (Na^+) were determined with the flame emission photometer (Thomas, 1982). Exchangeable acidity (E.A) was determined by the phenolphthalein indicator after titration with HCl as described by Thomas (1992). Effective cation exchange capacity was determined by the procedure described by Carter (1993) by the summation of exchangeable bases and acidity.

2.4 Statistical Analysis.

To determine the influence of land use types on the selected measured soil properties (physicochemical properties), the one-way analysis of variance (ANOVA) was used. Differences among land use types were tested/separated using the Duncan Multiple Range Test (DMRT) and means separated and ranked using the standard error (SE) at 5 % level of significance. All analyses were performed with the use of Jamovi v1.8.4 computer software package.

3.0 RESULTS AND DISCUSSION

3.1 Effect of Land Use Types on Soil Physical Properties (Particle Size Distribution)

Table 3 shows the results of the effect of land use types on the soil physical properties (particle size distribution) at 0 – 30 cm depth. There was significant land use effect on sand and silt fractions while clay particles showed no significant difference across the three (3) land use types. Fallow land had higher sand content than those of arable and agro-forestry land; which were statistically the same. Agro-forestry and arable land had higher amounts of silt particles than fallow who had the least amount of silt. Arable land and agro-forestry were adjudged or ascribed a sandy loam textural class while fallow land had a loam sand texture.

Particle size distribution results depicted consistently higher sand contents than silt and clay across all land use types. This implies that basic cation could easily be leached as soil texture is known to influence the capacity of soils to retain basic cation (Salifu, 2022; Wapa *et al.* 2013).

Table 3: Effect of land use on soil physical properties (particles distribution) 0 – 30 cm soil depth

TREATMENT LAND USE	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	Textural class
Arable land	60.45^b	126.97^a	192.58	Sandy loam
Agro-forestry land	681.45^b	127.97^a	191.92	Sandy loam
Fallow land	779.78^a	69.30^b	150.92	Loam sand
SE ±	98.001	46.333	51.667	

SE ± = Standard error Means followed by the same letter(s) within the same column are not significant at 5% level of probability. means with no alphabets are statistically the same, hence no need for ranking with alphabets.

3.2 Effect of Land Use Types on Selected Sol Chemical Properties

The effect of land use practices on some selected chemical properties at 0 – 30 cm soil depth is presented in Table 4. Generally, the land use types did not significantly influence all the soil chemical properties determined in this study. Soil pH in water and KCl, total nitrogen (TN), electrical conductivity (EC) were not significantly influenced by land use practices. However, land use types significantly influenced soil organic matter, carbon and available phosphorus (Avail. P). The soil pH of the soils was slightly acid and are within range for most plants (Jamala and Oke, 2013).

Agro-forestry consistently had higher organic carbon/matter and available phosphorus than arable and fallow land. The higher organic matter observed under agro-forestry land could be as a result of greater accumulation of plant residues, vegetative cover, and root activity which exudes organic materials high in nutrients (carbon) which soil microbes utilize thereby improving the soil aggregation and carbon storage capacity (Salifu, 2022). The low organic carbon observed in arable land could be attributed to tillage; there is depletion of organic carbon through cultivation (Adaikwu and Ali, 2013, Lawal *et al.* 2020).

Table 4: Effect of land use on soil chemical properties at 0 – 30 cm depth

TREATMENT	**pH**	**pH**	**O.C**	**O.M**	**TN**	**Avail. P**	**EC**
LAND USE	**(water)**	**(KCl)**	**%**	**%**	**%**	mgkg-^{1}	dsm-^{1}
Arable land	5.93	5.33	0.99^{b}	1.71^{b}	0.05	4.53^{a}	0.46
Agro-forestry land	5.83	5.17	1.25^{a}	2.16^{a}	0.06	3.75^{b}	0.49
Fallow land	5.87	5.30	1.00^{b}	1.71^{b}	0.05	3.18^{c}	0.51
SE ±	0.338	0.353	0.203	0.351	0.010	0.342	0.078

O.C = Organic carbon, O.M = Organic matter, TN = Total nitrogen, Avail. P = Available Phosphorus, EC = Electrical conductivity, SE ± = Standard error, Means followed by the same letter(s) within the sam column are not significant at 5% level of probability and means with no alphabets are also not statistically significant or different.

3.3 Effect of Land Use Types on Soil Exchangeable Bases, Exchangeable Acidity (E.A) and Effective Cation Exchange Capacity (ECEC)

The influence of land use types on soil exchangeable bases, exchangeable acidity (E.A) and effective cation exchange capacity (ECEC) at 0 – 30 cm depth is presented in Table 5. There was significant treatment difference in soil exchangeable bases, exchangeable acidity, and effective cation exchange capacity across the three (3) land use types. Agro-forestry consistently had higher amount of exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and effective cation exchange capacity (ECEC) than arable and fallow land. While arable land had the least exchangeable bases and ECEC. The higher amounts of exchangeable bases and ECEC recorded in agro-forestry could be accrued to the higher deposition and accumulation of leaf litter and minimal soil disturbance as soils are not pulverized hence organic matter is built up. Tillage activities such as continuous cultivation as observed under arable land pulverizes the soil and organic matter are lost through intense microbial oxidation. And most times farmers slash and burn plant residues without incorporating them back into the soil which causes soil carbon loss. This result is in tandem with the reports of Salifu, (2022) and Lawal *et al.* (2020).

Table 5: Effect of land use on soil Exchangeable Bases, Acidity and Effective Cation Exchange Capacity at 0 – 30 cm soil depth

TREATMENT LAND USE	Ca^{2+} cmolkg^{-1}	Mg^{2+} cmolkg^{-1}	K^{+}	Na^{+}	EA	ECEC
Arable land	3.54^{b}	1.70^{b}	1.55^{b}	0.47^{a}	1.89^{a}	8.65^{b}
Agro-forestry	3.96^{a}	2.06^{a}	1.93^{a}	0.42^{b}	1.18^{a}	9.54^{a}
Fallow land	3.50^{b}	1.64^{b}	1.48^{b}	0.48^{a}	1.39^{b}	8.49^{b}
SE ±	0.28^{3}	0.254	0.246	0.044	0.129	0.618

EA = Exchangeable acidity, ECEC = Effective cation exchange capacity, SE ± = Standard error, Means followed by the same letter (s) within the same column are not significant at 5% level of probability.

3.4 Soil Nutrient Status as Affected by Land Use Types

Table 6 and Table 7 shows the results of the nutrient status of Itakpe soils as affected by land use types at 0 – 30 cm depth. Land use type significantly influenced organic carbon, available phosphorus, exchangeable bases, and effective cation exchange capacity (ECEC) content. Soil pH range from 5.83 – 5.93 and is rated moderately acid. Soil organic carbon was significantly influenced by land use. Agro-forestry consistency had higher organic carbon (1.25 %) higher than those of arable land and fallow land. The higher organic carbon found under agro-forestry can be attributed to higher leaf litter and vegetative cover which culminate into organic matter. Fallow land had a scanty vegetative cover as at the time of sampling. Bush burning could be the reason for the lower organic carbon observed under fallow land The lower organic carbon observed under arable land could be attributed to cultivation which exposes organic matter to rapid microbial decomposition, hence, loss of organic carbon and consequently decline in soil fertility and quality.

Furthermore, the higher content of carbon under agro-forestry could be due to high distribution of plant root, deposition of leaf litter by forest trees and minimum soil disturbance which facilitate the high accumulation of organic carbon (Lawal 2012 and Hamza 2018). Total nitrogen was not significantly affected by land use and are rated very low to low in the soil (Amacher *et al.*, 2012). Although

Nitrogen is one of soil quality indicator and a key nutrient in plant and it is useful for soil micro-organism in the soil (Agbede 2009). The very low nitrogen content of arable land could be attributed to microbial immobilization of mineralize nitrogen due to low quality organic matter content in soil. Nitrogen fixing plants such as cowpea, soyabean were not planted in the agro-forestry. Plant uptake of nitrogen was higher than that which was available. Land use significantly affected available phosphorus with arable land consistently having higher phosphorus than other land use types, this could be because of the frequent supply of phosphorus fertilizer. Available phosphorus was rated low for the three land uses (Enweazor *et al*., 1989).

Exchangeable cations were significantly influenced by land use types and they were ranked in the order; agro-forestry > arable = fallow. They were rated low. The low status of Ca^{2+} in cultivated soil (arable) and fallow land could be attributed to leaching. However, depletion of Ca^{2+} in soil is majorly due to cultivation and erosion as a result of low organic carbon content. Mg^{2+} was observed to be significantly higher in Agro-forestry (2.06 cmolkg-1) higher than those under arable and fallow. Arable and fallow has statistically the same Mg^{2+}. Mg^{2+} is rated moderate across all land uses evaluated. This research finding is in line with the reports of Salifu (2022) and Lawal (2012).

Land use had very significant influence on exchangeable potassium (K^+) as treatment means were different across all land use types. Soil under agro-forestry was observed to have higher K^+ than all other land uses and rated very high. This could be as a result of the kind of parent material from which the soil emanates or originates from. Exchangeable sodium (Na^+) was not significantly influenced by land use.

Effective cation exchange capacity (ECEC) was significantly affected by land use type. The highest ECEC (9.54) was observed under agro-forestry which was statistically different from those of the arable and fallow land. Arable (8.66) and fallow land (8.49) had statistically similar ECEC. The ECEC was rated low for all land use type according to the rating of FAO, (2006) The low ECEC observed across the three land uses may be ascribed to low organic matter content (Ekebafe *et al.*, 2013; Jamala and Oke, 2013). Salifu (2022) and Lawal *et al* (2009) reported significant positive influence of organic matter on the soil pH and Cation exchange capacity of soil stating that for most low activity clays of the typical soils, organic matter is the principal exchange site for the basic cation in the soils, hence land use with high organic matter will improve the ECEC of the soil.

Table 6: Soil Nutrient status as affected by land use at 0 – 30 cm soil depth

LAND USE	pH in H_2O (1:2.5)	OC %	TN %	Av. P gkg-1	Ca^{2+}	Mg^{2+} cmolkg-1	K^+	Na^+	TEB	ECEC dsm-1	ECe
Arable land	5.93	0.99[b]	0.05	4.53[a]	3.54[b]	1.70[b]	1.55[b]	0.47[a]	7.27[b]	8.66[b]	0.46
Agro-forestry land	5.83	1.25[a]	0.06	3.75[b]	3.96[a]	2.06[a]	1.93[a]	0.42[b]	8.36[a]	9.54[a]	0.49
Fallow land	5.87	1.00[b]	0.05	3.18[c]	3.50[b]	1.64[b]	1.48[b]	0.48[a]	7.10[b]	8.49[b]	0.51
SE ±	0.338	0.203	0.010	0.342	0.283	0.254	0.246	0.044	0.746	0.618	0.078

OC = Organic carbon, TN = Total nitrogen, Av. P = Available phosphorus, **Ca2+ = Exchangeable calcium,** Mg2+ = **Exchangeable magnesium, K+ = Exchangeable** Potassium, **Na+ = Exchangeable sodium, TEB = Total exchangeable** bases, ECEC = Effective cation exchange capacity, Ece = Electrical conductivity, SE ± = Standard error, Means followed by the same letter(s) within the sam column are not significant at 5% level of probability.

Table 7: Nutrient status rating of soil in Itakpe

Land Use	Rating							
	TN	P	K^+	Ca^{2+}	Mg^{2+}	TEB	ECEC	pH
Arable Land	Very Low	Low	Very High	Low	Moderate	Low	Low	Moderate Acid
Agro-Forestry	Low	Low	Very High	Low	Moderate	Low	Low	Moderate Acid
Fallow Land	Very Low	Low	Very High	Low	Moderate	Low	Low	Moderate Acid

TEB = Total Exchangeable Bases, **ECEC =** Effective cation exchange capacity, **pH =** Soil reaction

4.0 SUMMARY AND CONCLUSION

Studies were conducted to determine the soil physicochemical properties of three (3) land use types, namely, Arable land, Agroforestry, and fallow land. Soil physicochemical properties were measured routinely, and the effect of land use was determined using analysis of variance (ANOVA). Generally, the soil nutrient indicators showed that soils have low nutrient status which could be as a result of the parent material, soil amendments will be needed to improve the nutrient status of these sols especially the adoption of the use of animal manure.

Soils of Itakpe showed considerable variations in their physicochemical properties which in turn will impact on the production potentials. The knowledge of the soil properties is essential in soil management and productivity. In this study, results obtained betokened that physicochemical status of soils of Itakpe was at risk of degradation or deterioration under the arable land use based on management practices observed.

The results of this research also showed that soil organic carbon, cation exchange capacity were higher under agro-forestry and is attributed to the higher leaf litter continuously deposited and accumulated on the forest floors. The study indicated that land use and management practices have great impact on soil physicochemical properties. This study also suggested that Agro-forestry had better influence on the soil properties due to the low/minimal soil disturbance and greater microbial activity because of tree root activity which exudes chemical substances that soil microbes relish. Land use type that increases organic carbon storage like agroforestry should be encouraged among farmers to help improve soil quality and boost agricultural production as well as improve the quality of the environment.

4.1 RECOMMENDATIONS

Practices that will improve soil organic matter content should be encouraged amongst farmers engaging in arable farming (continuous cultivation) for sustainable agricultural production. Since the soil pH tends towards acidity (slightly acid), liming with gypsum and adding organic manure to the soil will buffer the soil reaction and maintain an optimum pH range for crops in the study area. Specifically, growing leguminous trees and crops such as *Gliricidia sepium*, *Tamarindus indica*, *Mucuna pruence*, forage crops, and cover crops is recommended for building up the soil organic matter content of the arable and fallow land thereby improving the soil nutrient and quality. We also recommend that farmers be encouraged to practice organic farming in the study area so as to boost the soil fertility. Alternative land use is recommended for animal husbandry.

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Effect of Variety and Supplemental Irrigation on Water Use Efficiency of Potato (*Solanum tuberosum* L.) in Kuru, Jos, Nigeria

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ABSTRACT

Effect of variety and supplemental irrigation (SI) on water use efficiency (WUE) of potato (Solanum tuberosum L.) was conducted in the 2017 and 2018 cropping seasons at the Research Farm of the National Root Crops Research Institute (NRCRI) Kuru, Jos in Plateau State, Nigeria. The treatments consisted of two varieties of potato (V_1 = improved variety, nDaimat; $V_{2} =$ local variety, variety commonly used in the study area) and four levels of water application (W_1 = Control – no supplemental irrigation, W_2 = SI of 200 m^3 W_3= SI of 400 m^3, W_4 = SI of 600 m^3). The factors were combined to give 8 treatment combinations that were laid out in a 2×4 split plot arrangement in a Randomized Complete Block Design (RCBD) and replicated three times. WUE of potato was computed using formulae. WUE data collected were subjected to analysis of variance (ANOVA). Variety had no significant effect on WUE of potato in both planting seasons. SI had significant ($p \leq 0.05$) effect on WUE of potato in both planting seasons.SI of 400 m^3 had the highest WUE of 4.66 kgm^{-3} and 4.83 kgm^{-3} in 2017 and 2018 respectively followed by SI of 600 m^3 with WUE of 3.25 kgm-^{3} and 3.51 kgm-^{3} in 2017 and 2018 respectively. The least WUE of 0.52 and 0.49 kgm^{-3-}obtained in 2017 and 2018 respectively was gotten under the no – SI. There was no significant interactive effect of local variety and SI on WUE efficiency of potato in both seasons. Significant ($p \leq 0.05$) interactive effect occurred between Diamat variety and SI in both seasons. Variety Diamat x SI of 400 m^3 gave the highest WUE of 5.38 and 5.31 kgm. $^{-3}$ in 2017 and 2018 respectively. The least WUE of potato was obtained under variety Daimat x no –SI which gave 0.79 and0.76 kgm^{-3} in 2017 respectively. It is hereby recommended that Variety Daimat bx SI of 400 m^3 be planted by farmers for efficient use of water.

Key words: Potato, Water use efficiency, Variety, Supplemental irrigation

INTRODUCTION

Potato is the most fruitful and efficient tuber crop in the world in terms of tuber yield and days to maturity. It matures in about 60-90 days (2-3 months) as compared to 9 and 12 months of yam and cassava respectively (Kudi. Akpoko. And Yada, 2008, Muthoni. Shimelis., Mbiri and Elmar, 2021).

Potato was introduced in Nigeria during the 1920s by way of Germans living in the Cameroons and by other Europeans involved in Missionary and Tin mining activities on the Jos Plateau, where production was limited to small garden plots (Mosely. Vales., Memoran and Yilma, 2000). Nigeria is the fourth biggest producer of potato in sub-Saharan Africa. It has almost much land under potato cultivation as Germany (GIiz, 2016). The main potato growing area is Jos Plateau State; where altitudes ranging from 1200 to 1400 m and a temperature that rarely exceed 35 ^{0}C make for temperate climate well suited to potato production. However, productivity is constrained by a lack of suitable varieties.

Average potato yield in Nigeria is little over 3.1 tons per hectare (Giz, 2016, Nowacki, 2018), a far cry from the global average yield of 40 tons per hectare.Supplemental irrigation is a temporal intervention, designed to influence when water is made available to augment natural evapotranspiration. Eearly season drought is now a serious limiting factor in agricultural production in northern Nigeria either by delaying planting or causing serious moisture stress in young seedling (Nowacki, 2018). Climatic data of the study area in the last ten years (2006-2016) also shows the erratic nature of rainfall in the area (NRCRI, 2015). Table 1 further buttresses this fact.

In view of the above concern, potato growers are in great dilemma because early planting may correspond with early season drought (dry spell) and potato is very sensitive to moisture stress.

The way out to the farmer may be supplemental irrigation where he may plant earlier and supplement the rainfall in the event of dry spell.

When potato program established at Kuru, Jos by N. R. C. R. I. Umudike in 1976, production steadily rise from 473, 420 metric tons in 1991 to 742, 870 metric tons in 1996. However, production has gradually reduced to about 470, 000 metric tons in 2000 (PADP, 2002). It is said that the drop-in production is due to poor and erratic rainfall among other factors (Waaswa. Oywaya. Mwangi and Ngeno, 2021).

Rain-fed agriculture has to be supplemented with irrigation to obtain the potential of our soils and hence high yield in potato production.

The major aim of this study is to determine the effect of variety and supplemental irrigation on WUE of potato.

The specific objectives were to:

(i) Evaluate the effect of variety on WUE of potato

(ii) Determine the effect of different rates of SI on WUE of potato

(iii) Determine the interactive effect of variety and SI on WUE of potato

MATERIALS AND METHODS

Site Description and Characteristics

The field experiment was located at the Research Farm of the Potato Program, National Root Crops Research Institute, Kuru ($09^0 44^l$ N,$08^0 47^l$E, elevation 1,236.3 m a.m.s.l.) Jos, Plateau State. Mean rainfall is about 1500 mm received in 130-150 days from May to September (Danbaba and Fogah, 2013). It has a maximum temperature of 27 ^{0}C and a minimum temperature of 10 ^{0}C.

The climate is characterized by two distinct wet and dry seasons. The wet season starts from late April and end in October while the dry season starts from November to mid-April. It is located within the northern guinea savanna agro-ecological zone of Nigeria (Daggash, 2018). The map of Plateau State and map of the study area are presented in figure 1 and 2 respectively.

Experimental Treatments and Design

The treatments consisted of two varieties of potato: V_1 (Daimat; improved variety), andV_2 (Local variety) and four levels of water application: W_1 (control; No Supplemental irrigation), W_2 (supplemental irrigation of 200 m^3-W_3 (Supplemental irrigation 400 m^3) and W_4 (supplemental irrigation of 600 m^3). The factors where combined to give a total of 8 treatment combinations as follows;

$T_1 = V_1W_1$

$T_5 = V_2W_1$

$T_2 = V_1W_2$

T6 = V_2W

$T_3 = V_1W_3$

$T_7 = V_2W_3$

$T_4 = V_1W_4$

$T_8 = V_2W_4$

Treatments were laid out in a 2x4 split plot arrangement in a randomized complete block design (R C B D) and replicated three (3)

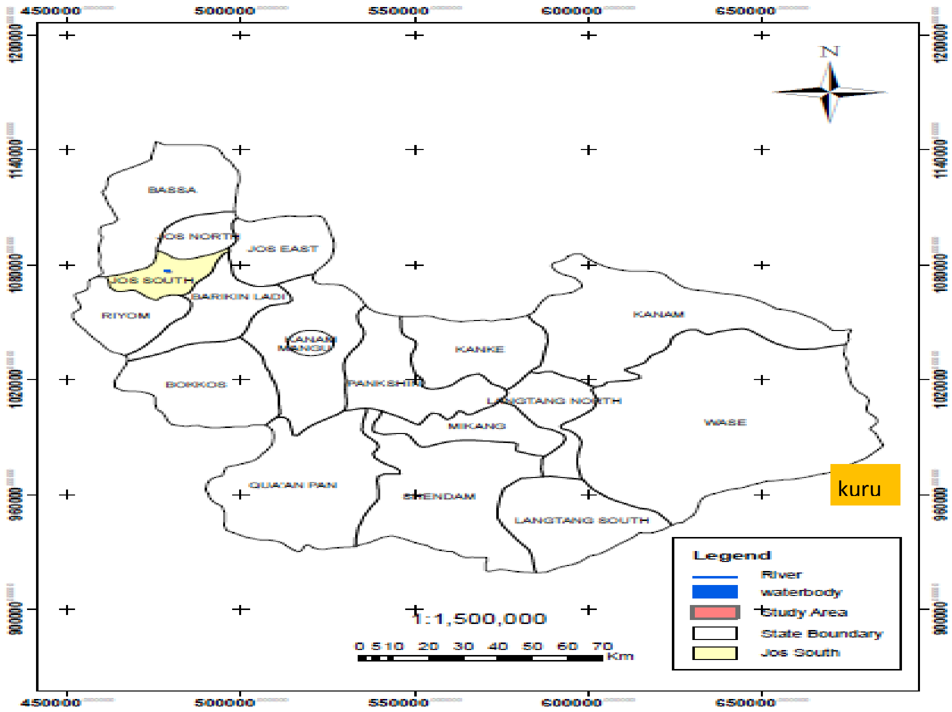

Figure 1: Map of Plateau state showing Kuru, Jos (Source: NCRS, 2017)

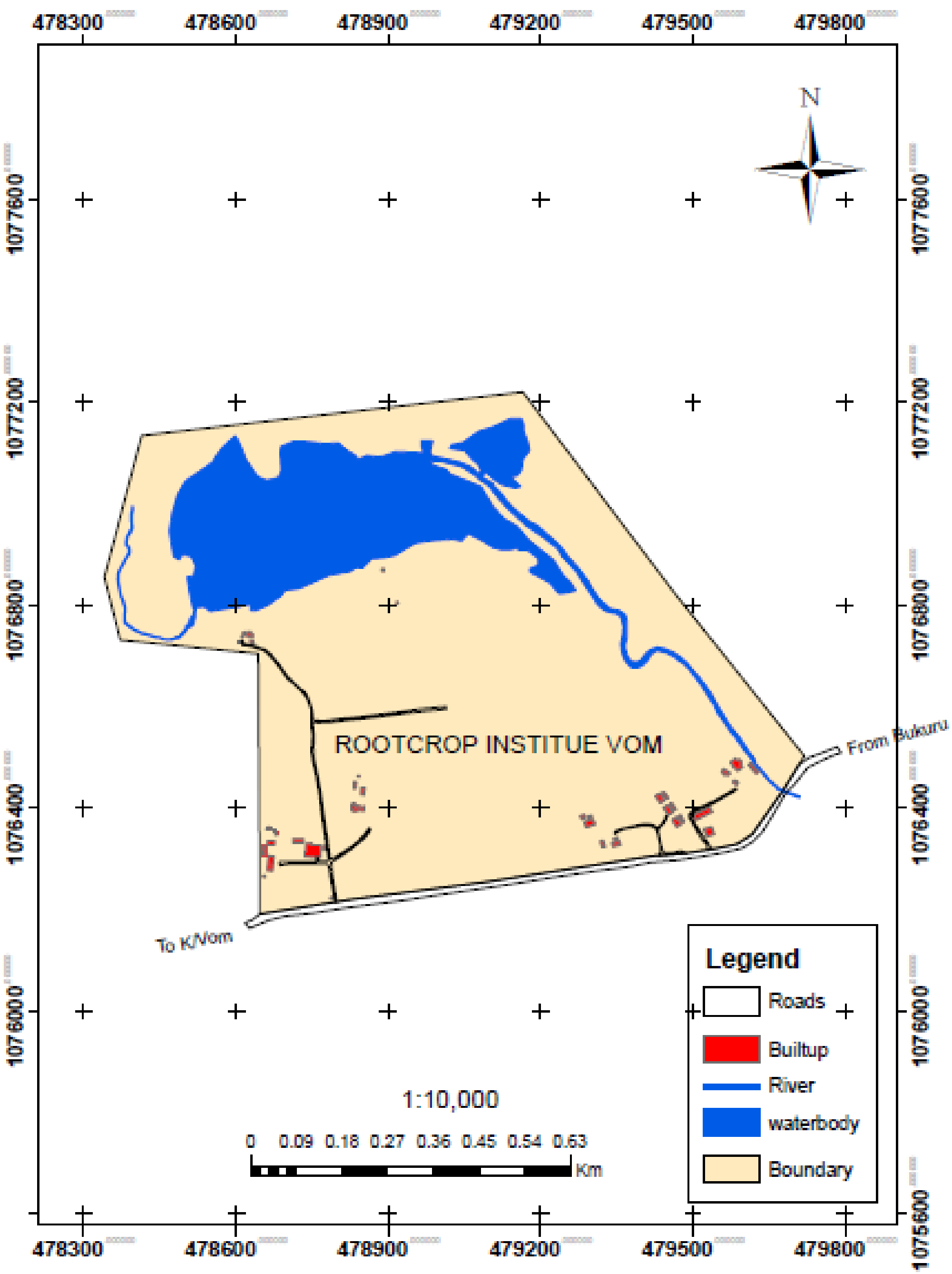

Figure 2: Map of the Study Area (Source: NCRS, 2017

Application of supplemental irrigation

SI application was achieved by monitoring of soil moisture content. Level furrows were created between rows to ensure uniform distribution of water in irrigated plots. Furrows were closed to prevent runoff and a flow The soil water content by weight was measured at field capacity (under 0.3 bar) and wilting point (under 15 bar) (Klute and Dirksen, 1986). Available water capacity was calculated using equation 1 – 3.

Total available water capacity (TAWC)

TAWC= (FC- WPT) x B.D x 100 x DRZ (mm $^{-1}$) …………. ………………1

Where

FC= field capacity

WPT= wilting point

B. D= Bulk density

D R Z=Depth of root zone (main root zone at the time of peak demand for water (60 cm for potato at tuber bulking)

DNWR =TAWC x MAD…………………………………………………………………………… 2

DNWR= Design net water requirement

MAD = management allowable water depletion (lowest soil water content that is allowed before next irrigation so that undesirable crop stress does not occur – taken as 50 % of available soil moisture content for soil.

Hence

DNWR = (FC-PWPT) x B.D. x 100 x DRZ x MAD (%)……………………….3

meter was used to measure the amount of water applied to each plot. Furrows not used for irrigation were dammed and at least one dammed furrow was created between two irrigated ones. Aavailable water was determined by multiplying the appropriate water values by 50 %.

Tensiometers were installed in the field to monitor the available moisture range. Supplemental irrigation levels of 0, 200, 400 and 600 m^3 were applied to the respective plots when the available moisture content were below their expected range

Data Collection

Climatic data

Meteorological data were obtained from the Meteorological Station of National Root Crops Research Institute (NRCRI) Vom.

Water use

All parameters in equations 1 - 3 were expressed in equivalent depth of water in millimeter over a period of time. The sum of periodical crop water uses for the whole maturity, estimate of the seasonal crop water use and in essence an estimate of the total crop water requirement.

Statistical Analysis

. WUE of potato was computed using formulae. WUE data collected were subjected to analysis of variance (ANOVA) using GenStat. Means that were statistically significant were separated using Least Significant Difference (LSD) according to Steel and Torries (1980).

RESULTS

Some meteorological data for Kuru during the period of study are presented in Table 1.

Table 1: Climatic Data

Month	Rainfall (mm)	Temperature (^{0}c)		Relative humidity (%)	Sunshine (hrs.)
		min.	max.		
January	0	13	27	31	252.8
February	0	16	30	25	277.3
March	13.5	18	31	34	240.8
April	96.2	20	28	59	189.5
May	143.8	19	28	71	186.4
June	202.3	18	25	80	150.2
July	214.8	18	23	81	123.8
August	308.7	17	22	84	770
September	256.3	17	25	78	68.3
October	276	17	28	51	200.6
November	76.4	14	28	32	276.7
December	0	12	28	34	269.2
2018					
2017					
January	0	11	26	18	276.6
February	10.05	15	25	20	265.4
March	36	19	26	22	223.9
April	28	18	26	56	257.1
May	218.5	19	25	64	212.2
June	156.4	17	22	73	165.3
July	283.3	18	24	80	148.2
August	310.8	18.0	26.0	75.0	147.3
December	0.0	12.0	27.0	17.0	278.4

Source: NRCRI Kuru Meteorological Station (2017/ 2018)

Table 2: Main Effects of variety and Supplementary Irrigation Rate on Water Use Efficiency of Potato

	Water Use Efficiency (Kgm^{-3})	
	2017	2018
Variety		
Diamat	3.15	3.10
Local variety	2.27	2.55
P-value	0.25	0.31
LOS	Ns	Ns
Supplementary Irrigation		
Control	0.52	0.49
200	2.43	2.47
400	4.66	4.83
600	3.25	3.51
P-value	0.033	0.031
LOS	**	**

Note: *= significant at 0.01, **=significant at 0.05, ns=not significant, Los = level of significant

Table 3: Interaction Effects of Variety x Supplementary Irrigation Rate on Water Use Efficiency of Potato

	2017		2018	
Irrigation	Diamat	Local Variety	Diamat	Local Variety
Control	0.79	0.23	0.76	0.24
200	2.74	2.12	2.64	2.29
400	5.38	3.93	5.31	4.36
600	3.71	2.80	3.69	3.33
P-value	0.03	0.08	0.04	0.08
LOS	***	Ns	***	Ns

Note: ***=significant at ($p<0.05$), ns=not significant,), W1-W4= Supplementary Irrigation at Different Level (0, 200, 400, and 600), V1= improved variety, V1= local variety, LOS = Level of Significance

CONCLUSION

Though, there was no statistically significant difference between the local variety and the improved (Daimat) variety, the improved variety had significant higher water use efficiency.SI improved WUE of potato. Variety Diamat interacted with SI of 400 m^3 to give better WUE of potato.

RECOMMENDATIONS

Variety Diamat X SI of 400m^3 is recommended for growers of potato.

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The Impact of Long-Term Cultivation on Soil Organic Carbon Fractions in Selected Wetland Soils of Ikole Ekiti, South Western Nigeria

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ABSTRACT

Understanding soil organic carbon (SOC) fractions in the context of long-term cultivation is crucial for sustainable land management. A research was conducted in wetland soils across four locations (Aloke, Ilotin, Iwodi, Obadoro) in Ikole-Ekiti, South Western Nigeria, to investigate the influence of extended cultivation on these SOC fractions. The study employed a factorial experiment design with two land use types (cultivated and uncultivated wetlands) across the aforementioned locations, laid in a Randomized Complete Block Design (RCBD) with three replicates. Soil samples were collected from the 0-20 cm depth and analyzed for bulk soil organic carbon (SOCb), hydrolysable organic carbon (HOC), non-hydrolysable organic carbon (NHOC), particulate organic carbon (POC), and mineral-associated organic carbon (MAOC), alongside key physical properties. Results exhibited significant disparities in SOCb and SOC fractions among the distinct locations. Additionally, variations in particle sizes and bulk densities were observed across locations, influencing soil texture, which ranged from sandy loam to sandy clay loam. Notably, cultivated wetlands displayed marked reductions in SOCb (16.15 g/kg), MAOC (7.02 g/kg), and HOC (8.06 g/kg), recording decreases of 38%, 49%, and 39% respectively compared to uncultivated wetlands. Conversely, POC and NHOC levels were similar between land use types. Interaction effects between land use and location underscored significant differences in SOC fractions, prominently influenced by SOCb levels specific to each location and land use type. Although, cultivated soils had higher clay, silt, and bulk densities compared to uncultivated soils, these characteristics did not correlate with SOC fractions except for silt positively correlating with HOC. Contrarily, uncultivated soils exhibited more correlations with physical properties; clay and silt showed positive correlations with NHOC ($r = 0.68^*$) and HOC ($r = 0.65^*$) respectively, while sand demonstrated a negative correlation with NHOC ($r = -0.72$). Notably, SOCb showed a very strong positive correlation ($r = 0.83^{**}$ - 0.98^{**}) with MASOC and HOC in both land uses but exhibited a weak relationship with NHOC in cultivated sites. In conclusion, cultivation practices in wetlands were found to deplete SOC fractions, suggesting the need for land management strategies that can enhance SOC storage and improve ecosystem resilience.

Key words: Wetlands, Hydrolysable carbon, non-hydrolysable carbon, Mineral associated carbon, particulate organic carbon, cultivation.

INTRODUCTION

Wetland soils are distinguished by their extended periods of water saturation throughout the year, which often leads to high nutrient concentrations, particularly in organic matter, thereby boosting soil fertility and supporting plant growth. This abundance of organic matter primarily results from the accumulation of plant residues combined with the slow rates of decomposition under waterlogged conditions (Reddy and DeLaune, 2008).

In agro-ecosystems, soil organic carbon (SOC) is a vital element of soil fertility. It plays a key role in optimizing soil structure, improving soil physicochemical properties, and regulating nutrients for crops (Dikgwatlhe *et al*. 2014). The levels of SOC represent a long-term and ongoing equilibrium involving processes of sequestration, mineralization, and emission (Dai *et al*, 2022; Hu *et al.* 2021).

Lavallee *et al.* (2020) describe two fundamentally different SOC pools based on their partitioning into particulate organic carbon (POC) and mineral-associated organic carbon (MAOC). Particulate organic carbon (POC) is associated with the sand fraction (> 0.053 mm) and is more available for microbial decomposition, while mineral-associated soil organic carbon (MASOC) refers to the fraction that is less accessible to microbial activity (< 0.053 mm) (Samson et al. 2020). MASOC is generally more persistent and nutrient-dense compared to POC, and when it detaches from minerals, it becomes a source of nutrients for plants (Zheng *et al.* 2023). Although POC is more accessible, it may include insoluble molecules that can eventually convert into MASOC over time, affecting decomposition processes (Zheng *et al.* 2023). Both POC and MASOC are crucial for maintaining soil structure and serve as energy sources for microorganisms. By classifying SOC into different functional pools, we can better understand the contributions of each fraction to soil quality.

One critical fraction of SOC is hydrolysable carbon, which encompasses labile organic carbon compounds that can be easily broken down by soil enzymes. Long-term cultivation practices can influence the amount and quality of hydrolysable carbon, which in turn affects soil fertility and ecosystem sustainability. Practices like regular tillage and synthetic fertilizer use can enhance microbial activity and speed up the decomposition of organic matter, breaking down hydrolysable carbon into simpler substances such as sugars and amino acids (Paul and Clark, 1996).

Non-hydrolysable carbon is important for soil aggregation and the formation of stable soil structures. However, intensive tillage and other disturbances can disrupt soil aggregates and reduce the protection of non-hydrolysable carbon from decomposition (Six et al. 2004). Additionally, poor soil management practices can lead to soil erosion, which can result in the loss of topsoil that contains stable organic matter, including non-hydrolysable carbon. This loss diminishes the overall pool of resistant carbon in the soil (Lal, 2004).

Changes in land use and management practices can greatly impact SOC levels through increased carbon degradation and erosion due to soil disturbances (Abera *et al*., 2020). For instance, the long-term cultivation of crops, reliance on monoculture cropping, and limited application of organic amendments in Ikole-Ekiti can lead to decreased SOC levels and increased greenhouse gas emissions, thereby contributing to global warming. Additionally, the reclamation of wetlands in Ikole-Ekiti for more fertile land can result in the loss of valuable wetland areas (Abera et al., 2020).

Long-term crop cultivation, monoculture cropping, and limited use of organic amendments as practiced in Ikole-Ekiti, can result in a decline in SOC levels and increase greenhouse gases, thereby promote global warming. In addition, reclamation of wetlands in search for more fertile soil may lead to loss of wetlands in Ikole Ekiti.

Several studies have explored how cultivation affects SOC levels in wetlands (Jia et al. 2020; Chen *et al.*, 2019). They reported that SOC levels were significantly reduced by cultivation, attributed to soil disturbances that promoted the oxidation of SOC as well as the decreased vegetation cover, which subsequently led to a reduction in SOC levels.

Many studies have evaluated the effect of long term cultivation on soil organic carbon in bulk soil but rarely in soil organic carbon fractions in wetland soils of Ikole Ekiti.

Therefore, the main objective of this study is to evaluate the effect of long term cultivation on soil organic carbon fractions in wetland soils of Ikole-Ekiti, South Western Nigeria.

2.0 MATERIAL AND METHOD

2.1 Description of study site

The research was carried out on four wetland soisl within Ikole-Ekiti, located in the rainforest ecological zone of south western Nigeria. The four locations include: Aloke, Ilotin, Iwodi, Obadoro, their respective GPS are as follows: Aloke with Latitude N 7^{o} 47' 45.20213", longitude E 5^{o}29' 19. 04681". Ilotin with Latitude N 7^{o} 30' 21.55813", longitude E 5^{o} 30' 21.55813". Iwodi with Latitude N 7^{o} 48' 9.9684", Longitude E 5^{o} 30' 24.82812" and Obadoro with Latitude N7^{o} 46' 53.53007", Longitude E 5^{o} 30' 10.87726". The area experiences an average rainfall and mean annual temperature of 1600mm and 25 ^{o}C respectively and average relative humidity of 80%. The area is characterized by gently undulating plain topography with increasing sparse natural vegetation. The soils in Ekiti State are alfisols, derived from granitic Precambrian basement complex (Bolarinwa *et al*., 2017).

2.2 Land Use History: The crops cultivated are maize (*Zea mays*) and green vegetable (*Amaranthus hybridus*) and the land has been under cultivation between 25 and 30 years. Farmers use inorganic fertilizers in the production of crops.

2.3 Experimental Design: The study was laid out as a 4 × 2 factorial experiment with 3 replicates in Randomized complete block design (RCBD). It consists of four locations (Aloke, Ilotin, Iwodi, and Obadoro) two land use types (cultivated and uncultivated wetland).

2.4 Land Preparation and Soil Sampling: The sites were chosen based on the availability of cultivated land and adjacent uncultivated wet land. The Transect method was used to collect soil samples. In this method an area measuring 21*21m was marked out, divided into three equal replicates. Thereafter, soil samples were collected at random from 10 points in each replicate at 0 – 15 cm depth and bulked to form a composite sample. This was repeated in each location, giving a total of 24 composite samples. In addition, core- samplers were used to collect undisturbed soil samples in triplicate per replicate, giving rise to 64 core samples. Samples were taken to the laboratory for laboratory analysis.

2.5 Laboratory Analysis

2.5.1 Fractionation of soil organic carbon (SOC) into Non-hydrolysable carbon (NHOC) and hydrolysable soil organic carbon (HOC)

Acid hydrolysis was used in fractionation of SOC into NHC and HOC (Leavitt *et al.*, 1996). 2 g of soil (< 2.00 mm) was mixed with 6 N HCl and allowed to react for 12 h. The samples were heated at 105 °C for 16 hours, washed three times with distilled water and then centrifuged to remove the HCl.

The residue was dried and the NHC concentration was determined by the wet oxidation method. The HOC concentration was calculated as the difference between SOC in < 2.00 mm and NHC concentration.

2.5.2 Fractionation of SOC into particulate soil organic carbon (POC) and Mineral associated soil organic carbon (MAOC)

The method outlined by Figueiredo *et al.*, (1986) was used in fractionating SOC into particulate organic carbon (POC). In the procedure, 20g of < 2mm air dried soil was weighed into a beaker, soaked for 24hr with 70-ml sodium hexa-metaphosphate solution at concentration of 5.0 g L^{-1} and shaken at 350 oscillations per min for 30 mins. The suspension was washed through a 53µm sieve to separate > 53µm and < 53µm fractions. Residue on > 53µm sieves which represent the POC was dried in an oven at 60 ^{0}C.

Soil organic carbon was determined both in bulk soil and POC by Walkely and Black method as modified by Nelson and Sommers (1996). The difference between SOC in bulk soil and POC represents the MASOC (Cambardella and Elliot 1992).

2.5 3 Particle size distribution

Particle size distribution of less than 2 mm fine soil fraction was measured by Hydrometer method using calgon as dispersing agent (Gee and Bauder, 1986).

2.5.4 Bulk density

Bulk density was determined by using the core method (Blake and Hartage,1986).

Total porosity= $1-\frac{BD}{PD}$ x 100 ……(1)

Where, PD is the particle density (2.65g/cm^3)

BD is Bulk density.

2.6 Statistical analysis

The data was subjected to analysis of variance (ANOVA) using Genstat Discovery software. F-LSD at 5% probability level was used to separate significant differences in the means. Correlation analysis was conducted to evaluate the relationship between soil organic carbon fractions and selected physical properties.

3.0 RESULTS AND DISCUSSION

3.1 The effect of cultivation and location on physical properties of wetland soils

Table 1 presents the effect of cultivating wetlands on soil physical properties. Cultivated land has higher clay (247.97 g/kg) content compared to uncultivated land (172.97 g/kg). Similarly, higher silt was observed in cultivated land. Consequently, higher sand content was observed uncultivated lands resulting to variations in texture. Increase in colloidal materials in cultivated soils may be attributed to downward movement and deposition of fine particle by rain to lower depths, brought to upper surface of the soil during tillage activities. Osakwe et al (2022) reported increase in clay with depth in soils of Ikole, Southwestern Nigeria, attributed to clay illuviation and eluviations

Although, cultivated land has a higher bulk density (1.300 g/cm³) than uncultivated land (1.075 g/cm³), both values were below the critical values that can restrict root growth and development. Total porosities and particle density remained similar in both land use types. Nevertheless, unsustainable soil management over a long period may eventually degrade the soil. The changes observed in soil physical properties due to cultivation of wetlands highlight potential impacts on sol fertility, water retention, and overall ecosystem health.

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The locations varied significantly in their particle's sizes culminating to different textures, as well as their bulk densities. The porosities and particle densities among locations were statistically similar, except for significantly lower total porosity in Aloke compared to Obadaro. The implication of these differences is that response of locations to cultivation is expected to vary. The interaction of location and land use emphasized that cultivation enhanced fine particle by bringing fine particles to the upper surface of the soil during tillage. As good as this appears, the gradual increase in bulk density is an indication of compaction.

By understanding these changes and their implications, farmers and land managers can adopt sustainable practices to maintain or improve soil health and productivity

Table 1: The effect of cultivation and location on physical properties of wetland soils

Parameters	Clay	Sand (g/kg)	Silt	Texture	BD (g/cm3	TP	PD (g/cm3)
Landuse							
Cultivated	248.00	580.00	173.00	SCL	1.30	0.50	2.56
Uncultivated	173.00	665.00	165.00	SL	1.08	0.56	2.50
Location							
Aloke	192.00	660.00	148.00	SL	1.34	0.47	2.81
Ikotin	170.00	663.00	172.00	SL	1.23	0.43	2.61
Iwodi	279.00	540.00	182.00	SCL	1.01	0.53	2.44
Obadoro	201.00	626.00	173.00	SCL	1.17	0.51	2.26
LOC.*Landuse							
Aloke Cultivated	232.00	618.00	150.00	SCL	1.50	0.42	2.76
Ikotin cultivated	232.00	598.00	170.00	SCL	1.43	0.53	2.43
Iwodi cultivated	295.00	521.00	183.00	SCL	1.01	0.52	2.60
Obadoro cultivated	233.00	580.00	187.00	SCL	1.26	0.53	2.31
Aloke uncultivated	152.00	701.00	147.00	SL	1.17	0.52	2.63
Ikotin uncultivated	109.00	728.00	173.00	SL	1.04	0.34	2.78
Iwodi uncultivated	262.00	558.00	180.00	SCL	1.02	0.54	2.27
Obadoro uncultivated	169.00	671.00	160.00	SL	1.08	0.50	2.21
LSD (0.05)							
Land use	4.48	7.67	4.92		0.06	ns	ns
Location	6.34	10.85	6.96		0.09	0.10	0.33
LOC*Landuse	8.96	15.35	9.84		0.12	0.14	0.46

LOC, Location, BD, bulk density, PD, particle density, TP, total porosity, SL is sandy loam, SCL is sandy clay loam,ns, not significant.

3.1 The effect of cultivation and location on soil organic carbon in bulk soil (SOCb) and soil organic carbon fractions (SOCFs) of wetland soils

Table 2, presents the effect of land use and location on SOCb and SOCF. From the results, soil organic carbon in bulk soil (SOCb), mineral associated soil organic carbon (MASOC) and hydrolysable carbon (HOC) declined by 38, 49 and 39 % as a result of cultivation of wet lands. This suggests that cultivation increased C mineralization possibly due to disintegration of aggregates and exposure to forces of climate, including removal of crop residue. Some studies showed that SOC levels decreased significantly with cultivation of wetlands in China (Jia *et al*. 2020; Chen *et al.* (2019). The authors attributed this to the disturbance of the soil, which led to the oxidation of SOC and reduction in vegetation cover, which in turn led to a decrease in SOC levels. In addition, higher fine particles in cultivated land use did not translate to more MASOC. This implies that MASOC may not have a linear relationship with fine particles. There are conflicting reports on the relationship of MASOC and clay, probably the studies focused on bulk organic carbon (Hassink *et al.*1997, Rasmussen, 2015). However, Georgiou *et al.*, (2022) from a global data analysis, reported that their results suggest that there is no universal linear relationship between MASOC (or SOC) and clay and silt, which agrees with the findings in this research. The non-significant impact of cultivation on POC can be attributed to the rapid mineralization processes occurring in sandy soils, applicable to both land use types. Furthermore, the increased nitrogen availability from inorganic fertilizers can lead to a quicker turnover of SOM and higher crop yields, which may, in turn, contribute to an even greater input of plant residues into the soil (Li *et al.* 2018). Thus, equilibrating the amount of POC in cultivated and uncultivated land use types.

In an addition, the recalcitrant SOC (NHOC) may not really change over a long time because it is the most stable form of C that can take thousands of years to be transformed (Ramnarine *et al.* 2018). The implication of these declines is loss of soil quality and increase in green house gases, consequently increasing global warming.

The location effect was significant on SOCb and SOCFs. SOCb ranged between 17.75 (Aloke) – 24.54 g/kg (Obadaro). Obadaro recorded the highest POC (24.54 g/kg), MASOC (14.42 g/kg) and HOC (15.51 g/kg) compared to other locations. These variations may be attributed to differences in soil management, soil type and the microclimate as noted by Hoyle *et al.* (2011). However, the NHOC was not significantly different among the locations except significantly lower values in Ilotin. As mentioned earlier, SOC that has accumulated over long periods under specific land management practices may persist even after changes in land use (Kallenbach *et al.* 2019).

Table 2: The effect of cultivation and location on soil organic carbon in bulk soil SOCb) and soil organic carbon fractions (SOCFs) of wetland soils

Parameters	SOCb	POC	MAOC (g/kg)	NHOC	HOC
Landuse					
Cultivated	16.15	9.13	7.02	8.083	8.06
Uncultivated	23.68	9.05	14.63	9.300	14.38
Location					
Aloke	17.75	8.75	9.00	7.900	9.85
Ikotin	18.03	9.02	9.01	8.600	9.43
Iwodi	19.33	8.46	10.86	9.233	10.09
Obadoro	24.54	10.13	14.42	9.033	15.51
LOC.*Landuse					
Aloke Cultivated	13.00	8.70	.4.30	8.43	4.57
Ikotin cultivated	16.07	8.86	7.21	8.77	7.30
Iwodi cultivated	15.43	8.59	6.85	7.60	7.83
Obadoro cultivated	20.09	10.36	9.73	7.53	12.55
Aloke uncultivated	22.50	8.79	13.71	7.37	15.13
Ikotin uncultivated	20.00	9.19	10.81	8.43	11.57
Iwodi uncultivated	23.22	8.34	14.88	10.87	12.35
Obadoro uncultivated	29.00	9.89	19.10	10.53	18.46
LSD (0.05)					
Land use	0.71	0.64	0.889	0.42	0.79
Location	1.00	0.90	1.258	0.59	1.11
LOC.*Landuse	1.42	1.27	1.778	0.83	1.58

SOCb, soil organic carbon in bulk soil, NHOC, non-hydrolysable carbon, HOC, hydrolysable carbon, POC, particulate organic carbon, MASOC, mineral associated soil organic carbon, LOC, Location

The interaction of land use and location on SOCF emphasized that response to land use was influenced by the location's characteristics such as SOCb. Hence, Obadaro uncultivated and cultivated recorded highest POC, while the same location in the uncultivated area demonstrated the highest MASOC. Furthermore, Obadaro and Iwodi uncultivated presented highest the highest NHSOC. The highest HOC was observed in the uncultivated site of Obadora. The result therefore suggests that SOCF was influenced by land use as well as the SOC in bulk soil at each location. Hu *et al.,* (2023) showed that increase in some SOCFs was influenced by the amount of SOCb in the specific soil.Therefore, land managers should employ conservation approaches that will reduce loss of SOC while increasing the same as an avenue for enhancing both labile and recalcitrant pools crucial for soil health and climate change mitigation.

3.3 Correlation analysis of soil physical properties and SOCb with SOCFs in cultivated and uncultivated wetlands

The correlations of selected soil physical properties and organic carbon in bulk soil (SOCb) with different soil organic carbon fractions (SOCFs) under cultivated and uncultivated wetlands are presented in Table 3.

In cultivated wetlands, physical properties did not show significant relationships with SOCFs except significant correlation of silt with HOC. However, SOCb showed highly significant relationship with all SOCFs except NHOC. These results suggest that management may not easily affect NHOC because it takes thousands of years to be transformed contrary to other fractions (Rovira and Vallejo, 2002). Similar significant correlations were observed in uncultivated wetlands but with potentially different patterns compared to cultivated wetlands. Clay and silt were positively correlated with NHOC (r = 0.68*) and HOC (0.65*) respectively while a negative relationship was observed between sand and NHOC (r -0.72). Furthermore, Particle density showed negative correlation with NHOC and MASOC. Furthermore, SOCb correlated strongly with HOC (r = 0.84**) and MASOC (r = 0.97**). Understanding these correlations can inform agricultural or conservation management practices on strategic soil management. For instance, reducing loss of fine particles by water erosion and increasing input of organic materials could potentially influence the storage or stability of different SOC fractions in uncultivated wetlands

Differences between cultivated and uncultivated wetlands highlight how land use changes can affect soil properties and SOC dynamics, which are crucial for understanding environmental impacts and carbon sequestration potential. Further research could explore these correlations in more detail to develop targeted soil management strategies that enhance carbon sequestration or improve soil health in wetland ecosystems.

Table 3: Correlation analysis of soil physical properties and SOCb with SOCFs in cultivated and uncultivated wetlands

Lamd use		**Cultivated**		
Parameter	NHOC	HOC (g/kg)	POC	MASOC
Clay	0.038ns	-0.03	0.21ns	0.38
Sand	.04ns	-0.38	-0.33ns	0.37ns
Silt	0.047ns	0.82**	-0.10ns	0.08ns
BD	0.64	-0.40	0.37	-0.07
PD	-0.35	-0.15	0..01ns	0.47
TP	0.20ns	0.15	0.86	0.19ns
SOCb	0.41	0.97**	0. 71**	0.98**
Lamd use		**Uncultivated**		
Parameter	NHOC	HOC	POC	MASOC

Clay	0.68*	0.20ns	-0.37ns	0.38ns
Sand	-0.72**	0.23ns	0.40ns	-0.35ns
Silt	-0.47ns	0.65*	0.31ns	0.15ns
BD	-0.04ns	0.55ns	0.07ns	.059ns
PD	-0.69*	0.53	0.11ns	-0.87**
TP	0.04ns	0.04	-0.18	0.51ns
SOCb	0.55ns	0.83**	0.41	0.97**

ns is not significant, **. Correlation is significant at the 0.01 level (2-tailed).*. Correlation is significant at the 0.05 level (2-tailed). SOCFs, soil organic carbon fractions, BD, bulk density, PD, particle density, TP, total porosity, SOCb, soil organic carbon in bulk soil, NHOC, non-hydrolysable carbon, HOC, hydrolysable carbon, POC, particulate organic carbon, MASOC, mineral associated soil organic carbon

CONCLUSION

The research evaluated effect of cultivation on soil organic carbon fractions in selected wet land soils. Conclusively, cultivation of wetlands resulted in decline in SOC in bulk soil and fractions—specifically MASOC, and HOC which underscores the accelerated mineralization and loss of organic carbon associated with cultivation practices. The variability observed across locations emphasizes the influence of local conditions on soil responses to cultivation, with implications for sustainable land management practices tailored to specific environmental contexts.

Cultivated lands generally exhibited higher clay and silt contents compared to uncultivated lands, influencing soil texture and bulk density. Despite higher bulk density in cultivated soils, both land use types remained within acceptable limits for root growth, indicating minimal immediate physical constraint but suggesting potential long-term implications if unsustainable practices persist.

Furthermore, significant correlations between soil physical properties and SOC fractions provided further insights into how these properties interact within different land use contexts. Addressing these complexities requires integrated approaches that consider soil physical properties, SOC dynamics, and local environmental conditions, aimed at enhancing carbon sequestration and improving soil health in wetland ecosystems.

Further research should focus on expanding our understanding of these relationships across broader geographical scales and under varying climatic conditions. This expanded knowledge base will enable more precise predictions and strategies for sustainable soil management, supporting global efforts towards climate resilience and environmental sustainability.

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Soil Organic Carbon Fractions in Response to Land Use and Depth in An Alfisol, South Western Nigeria

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ABSTRACT

The depth-wise quantification of SOC fractions under different land use types and depth is crucial in understanding SOC dynamics and sequestration. A study was therefore carried out in Ikole Ekiti, South western Nigeria in which total soil organic carbon (TSOC), Non-Hydrolysable soil organic carbon (NHOC), Hydrolysable Soil Organic Carbon (HOC), particulate soil organic carbon (POC) and mineral associated soil organic carbon (MAOC), alongside the soil organic carbon stock in the bulk soil were assessed in response to land use and depth. It was a 4 x 2 factorial experiment with three replicates in Randomized Complete Block Design. The numbers represent four land use types (Cashew Plantation, Oil palm Plantation, Leucaena Plantation and Secondary forest) and two depths (0-15cm and 15-30 cm).The main effect of land use showed that oil palm recorded significantly highest SOC in bulk soil (27.47 g/kg), MAOC (24.20g/kg), NHOC (18.11g/kg), HOC (9.22g/kg) SOC stock (52.16 tC/ha) compared to other land use types while the secondary forest land use indicated the highest POC (6.55g/kg) compared to the other land use types The main effect of depth depicted that the SOC par1.0ameters decreased with depth. Hence, there was 32, 41, 31, 23, 47 and 34% higher SOC in bulk soil, MAOC, POC, NHOC, HOC and SOC stock in 0-15cm compared to 15 -30cm respectively. The result showed that Oil palm plantation was more efficient in enhancing TSOC, SOC stock and all SOCFs except POC hence may be recommended for increasing SOC in agricultural lands. Improving SOC at lower depths may ensure protection of SOC from mineralization, thereby mitigating climate change.

Key Words: Depth, Land use, Total soil organic carbon, soil organic carbon fractions, soil organic carbon stock

1.0 INTRODUCTION

Soil organic carbon (SOC) is a crucial component of the soil ecosystem, playing a critical role in nutrient cycling, soil fertility, and carbon sequestration (Milne *et al.*, 2015; Gerke, 2022). It serves as a reliable indicator of soil health and its ability to sustain productive plant growth (Liptizin 2022). Studies in Southern Nigeria have shown that one of the effects of conversion of forests to other land uses is usually loss of SOC (Osakwe et al 2014, Osakwe et al 2016, Olorunfemi et al., 2020]. Plantation agriculture is an important form of land-use in the tropics and in many countries (Hartemink 2003). Some researchers opined that plantations especially on large scale may have the capacity to increase C sequestration in the soil, attributed to large biomass production and litter fall (Kanine et al 2013; Guo et al 2014, Njar. et al 2011).

Studies showed that the distribution SOC and its fractions varied with depth which may be key to land management practices with respect to agriculture, sequestration potentials of soils and climate change mitigation strategies (Xioa 2015; Hua *et al.* 2021).

In recent years, there has been a growing interest in evaluating SOC and its fractions, including Particulate soil organic carbon (POC), Mineral associated soil organic carbon (MAOC), Non-Hydrolysable organic Carbon (NHOC), and Hydrolysable Soil Organic Carbon (HOC). The Particulate soil organic carbon (POC) basically is undecomposed, physically protected. And can easily be accessed by microorganism (Dheri and Nazir 2021) while MAOM is associated with soil minerals,, hence not easily decomposed (Dheri and Nazir 2021). The Non-hydrolysable soil organic carbon (NHOC) (recalcitrant) consists of inherent plant litter which is highly resistant to degradation (Rovira and Vallejo, 2002). They contribute to the soil C sequestration and may have an important role for the global C budget (Silveira*et al.,* 2008), while the hydrolysable soil organic carbon (HOC) is highly decomposed, closely attached to soil mineral surfaces with higher specific density. (Gregorich *et al.,* 1996). Characterizing these different forms of SOC provides insights into their stability and vulnerability to degradation, ultimately helping to assess the potential for long-term carbon sequestration.

Understanding SOC dynamics is especially relevant in plantations, where land-use change and intensive management practices can significantly affect soil carbon stocks (Tadele, *et al.,* 2022). The knowledge of SOC and its fractions in plantation ecosystems, specifically in the context of depth-wise evaluation is essential for developing effective land management strategies to enhance carbon sequestration potential and promote sustainable plantation practices in Ikole-Ekiti, Ekiti State, Nigeria.

However, limited research has been conducted on the depth-wise evaluation of SOC and its fractions in plantation ecosystems. Specifically, there is a lack of studies focusing on the soil carbon dynamics within different soil depths in selected plantations in Ikole-Ekiti, Ekiti State, Nigeria. This research aims to address this knowledge gap and contribute to understanding the distribution and dynamics of SOC and its fractions.

2.0 MATERIALS AND METHODS

2.1 Description of Study Site

The research was conducted at Ikole-Ekiti (Latitude: 7^o 47’ 29” N. Longitude: 5^o 30’ 31” E) in the rainforest zone of Ekiti State, southwest Nigeria. Itis characterized by binomial rainfall pattern with mean annual rainfall of 1600 mm and average annual temperature of 24.2 °C. The soils are derived from Basement complex of Southwestern Nigeria (Shittu, 2014). The topography is characterized by gentle undulating plain with increasingly sparse natural vegetation.

2.2 Land use History

The study sites were previously a natural forest but wereconvertedto cultivation of arable crops, such as cassava, maize and vegetables, the arable land was under fallow prior to the establishment of cashew, leuceana and oil palm plantations by Ekiti State Agricultural Program (ADP) in 1996. In addition, the anthropogenic activities such as annual forest fire and logging changed the natural forests to secondary forests.

2.3 Experimental Design

The experiment was a 4 x 2 factorial experiment replicated three times in Randomized Complete Block Design (RCBD). The numbers represent four land use types which include cashew plantation (CPL), leucaena plantation (LPL), oil palm plantations (OPP) and secondary forest (SFR) and two sampling depths (0 – 15 cm and 15 – 30cm).

2.4 Soil Sampling

Stratified random sampling method (Peterson and Calving, 1986) that involved dividing each land use area (27m by 27m) into three replicates from which soil samples were taken. Soil samples were collected randomly from 0 -15 cm and 15 – 30 cm at 10 points in each replicate and made composite. A total number of six composite samples were collected at each landuse with a total of twenty-four composite samples. Core samplers were used to collect soil samples randomly in five (5) places in each replicate across the two depths. A total of 120 core samples and 24 composite samples were collected for laboratory analysis.

The twenty-four samples were air dried and passed through a 2 mm sieve and < 2mm soil were used for required laboratory analysis.

2.5 Laboratory Analysis

2.5.1 Soil physical properties

Particle size distribution of less than 2mm fine soil fraction was measured by the Hydrometer method (Gee and Bauder, 1986).Bulk density (BD) was measured by the core method, as described by Blake and Hartge (1986\)

Calculations

$$BD = \frac{\text{oven dry mass of soil (g)}}{\text{volume of soil (cm}^3\text{)}}$$

2.5.2 Determination of SOC, SOC fractions and SOC stock

The method outlined by Figueiredo *et al.*, (1986) was used in fractionating SOC into particulate organic carbon (POC). In the procedure, 20 g < 2 mm air-dried soil was weighed into a beaker, soaked for 24 h with 70 ml sodium hexametaphosphate solution at concentration of 5.0 g L^{-1} and shaken at 350 oscillations per min for 30 mins. The suspension was washed through a 53µm sieve to separate > 53 µm and < 53 µm fractions. Residue on > 53µm sieves which represents the POC was dried in an oven at 60 ^{0}C. A sample representing < 2mm soil and > 0.053 mm soil were used independently in the determination of total organic carbon (TSOC) and particulate soil organic carbon (POC) respectively. Soil organic carbon was determined both in bulk soil and POC by the Walkley and Black method as modified by Nelson and Sommers (1982). The result of each sample was used to calculate the TSOC and POC respectively. The difference between SOC in bulk soil (<2mm) and POC represents the mineral associated soil organic carbon (MASOC) (Cambardella and Elliot 1992).

The method of Silveira*et.al*., (2008) was used to fractionate SOC into NHOC and HOC. In this procedure, 2 g of soil (< 2.00 mm) was mixed with 6 M HCl and heated at 105 °C for 3 hours, washed three times with distilled water and then centrifuged for 10mins to remove the HCl. The residue was dried and analyzed for organic carbon which represents the NHOC. The HOC concentration was calculated as the difference between SOC in < 2.00 mm soil and NHC concentration (Mchlauchlan *et al.*, 2004).

SOC stock was calculated in tC/ha as follows:

SOC stock (tC/ha) = SOC (g/kg)* depth(cm)* BD (g/cm^3)

Statistical analysis

The data generated was subjected to analyses of variance following the procedure outline foranexperimental design using Minitab statisticalsoftware. Tukey test ata5% probability level was used to separate significant differences in the means of the treatments.

3:0 RESULTS AND DISCUSSIONS

3.1 Selected Physical Properties of the Soil

3.1.1 Particle size distribution, texture and bulk density

The result on selected physical properties of soils in each land use and depth is shown in Table 1 and 2 respectively. Sand content varied significantly among the land uses, with SFR (797 g/kg) and LPL (791 g/kg) exhibiting the highest sand content compared to CPL (760 g/kg) and OPP (727 g/kg). The highest clay content foundin OPP, CPL and LPL were significantly higherthan clay in SFR (102 g/kg). Enhanced clay content potentially leads to improved soil fertility and stability. Silt content also displayed notable distinctions across the land uses, with CPL (66 g/kg) and LPL (60 g/kg) showing lower silt values compared to SFR (101 g/kg) and OPP (96 g/kg). AHigher proportion of fine particles potentially enhances soil fertility, aggregate stability, water-holding capacity and nutrient retention Norkaew et al 2019). Nevertheless, the texture remained sandy loam in all land use. This is in agreement with other studies, that showed that management may not change the texture especially of soils under the the same parent (Obi 2002).

Furthermore, LPL exhibited higher compared to other land uses which was attributed to grazing activities in LPL High bulk densities impede seedling emergence, root penetration air and water movement in the soil.

Table 1: The Effect of Land use on soil particle sizes and texture.

Parameter	Sand	Silt	Clay	Texture	BD
Land use		g kg			g/cm^3
OPP	727c	96a	177a	SL	1.3c
SFR	797a	101a	102b	SL	1.5b
CPL	760b	66b	173a	SL	1.4bc
LPL	791a	60b	150a	SL	1.7a

Means in a column with the same letter are not significantly different at P=0.05

BD- Bulk density, Cashew- CPL, leucaena -LPL, Oil palm plantations - OPP and Secondary forest - SFR

Furthermore, there was significant effect of depth on sand, and clay while no significant effect was observed on silt and bulk density (Table 2). The higher clay at 15 – 30 cm may be attributed to clay eluviation while erosion which is a surface phenomenon may increase the sand fraction at the 0-15 cm depth.

Table.2:The main effect of depth on soil particle sizes and bulk density

Parameter Depth	Sand	Silt g/kg	Clay	BD g/cm^3
0-15cm	787a	75	138b	1.4
15-30cm	751b	84	163a	1.5

BD- Bulk density

3.2 Effect of land use on soil organic carbon in bulk soil and fractions

In Table 3, the main effect of different land uses on soil organic carbon (SOC) and its fractions is presented. The results show that the oil palm plantation has significantly highest SOC content (27.47 g/kg) compared to other land use types at a significance level of P=0.05. CPL (14.41 g/kg), SFR (13.80 g/kg), and LPL (11.37 g/kg) were statistically similar.

In terms of SOC fractions, the POC ranged from 2.45 g/kg (CPL) to 6.55 g/kg (SFR). The highest POC was recorded in the forest land use compared to other land use types. In addition, no significant difference was observed among other land use types. The reason for higher POC in forest may be due to different tree species in the forest that may have labile soil organic material. Particulate organic carbon is a labile fraction that is important as substrate for microorganisms and also source of nutrientsfor plants. The loss of labile SOC may affect soil fertility. The MAOC ranged between 8.88 g/kg (LPL) and 24.20 g/kg (OPP. The highest value registered in oil palm was significantly higher than other land use types while the others were similar. The result showed that oil palm which has the highest SOC in bulk soil recorded the highest MAOC. The result may imply that MAOC may be affected by the amount of SOC in the system. An increase in soil carbon in the MAOC fraction is important because it is more protected from microbial decomposition and loss to the environment (Klebere*et al.*, 2015). Therefore increase in MAOC may help in mitigating climate change.

Furthermore, the NHOC depicted the highest content in the oil palm land use (18.11g/kg) compared to other land use types. The lowest value in cashew land use (6.46 g/kg) was not different from forest and Leucena. The reason for the highest NHOC in oil palm may still be due to quality of organic material from litter as well as contribution from the root biomass.

OPP (9.22 g/kg) again depicted the highest HOC. However, it was not significantly different from other land use types except LPL (3.72 g/kg) with the lowest HOC. The lowest contribution of LPL to HOC may be ascribed to lower organic matter input through leaf fall as well as depletion of organic material by cattle grazing.

Overall, the results suggest that land use has a significant effect on SOC and its fractions, with oil palm plantations showing the highest carbon content and fractions compared to cashew plantation, forest, and leucaena plantation. The potential of oil palm in enhancing SOC storage in soils was also noted by Sanquetta*et al.*, (2015).

The implications of these findings are significant for land management practices, carbon sequestration and environmental sustainability.

Table 3: The main effect of land use on SOC in bulk soil and SOC fraction

Parameter	SOC	POC	MAOC	NHOC	HOC
Land use		(g/kg)			
OPP	27.47 a	3.13 b	24.20 a	18.11 a	9.22 a
CPL	14.41 b	4.06 b	10.25 b	6.46 b	7.87 a
SFR	13.80 b	6.55 a	7.28 b	7.38 b	6.46 ab
LPL	11.37 b	2.45 b	8.88 b	7.66 b	3.72 b

Means in a column with the same letter are not significantly different at P=0.05
Cashew- CPL, leucaena -LPL, Oil palm plantations - OPP and Secondary forest - SFR

SOC- Soil organic carbon, POC- Particulate soil organic carbon, MAOC- Mineral associated soil organic carbon, NHOC-Non hydrolysable soil organic carbon, HOC-Hydrolysable soil organic Carbon.

3.3 Effect of depth on soil organic carbon in bulk soil and fractions

The results presented in Table 4 demonstrate a significant effect of depth on soil organic carbon (SOC) as well as its various fractions. It is evident that as the depth increases from 0-15cm to 15-30cm, there is a substantial decrease in the mean SOC concentration (20.22 g/kg to 13.30 g/kg). The same trend is observed for all the SOC fractions including particulate organic carbon (POC), mineral-associated organic carbon (MAOC), non-hydrolysable organic carbon (NHOC), and hydrolysable organic carbon (HOC).

This finding aligns with previous studies that have reported a decline in SOC concentration with increased soil depth (Lepchaand Devi 2020). The decrease in SOC with depth can be attributed to organic matter input from plant residues and root exudates which is typically highest in the topsoil, leading to higher levels of SOC in the surface layer. The decrease in SOC with depth highlights the vulnerability of deeper soil layers to carbon loss, emphasizing the need to prioritize conservation and restoration efforts in these regions.

Table 4: The main effect of depth on SOC in bulk soil and SOC fractions

Parameter	SOC	POC	MAOC	NHOC	HOC
Depth			(g/kg)		
0-15cm	20.22 a	5.08 a	15.01 a	11.17 a	8.92 a
15-30cm	13.30b	3.02 b	10.30 b	8.64 b	4.72 b

3.4 Interaction of land use and depth on SOC in bulk soil and its fractions

The Interaction effect of land use and depth on SOC in bulk soil and its fractions was evaluated and the result presented in Table 5. The SOC in bulk soil ranged between 7.58 g/kg (LPL at 15-30 cm depth) and 31.80 g/kg (OPP at 0 -15 cm depth). The result showed that Oil palm (0 -15 cm) recorded significantlythe highest value compared to other land use types. However, the other land use types were not different from each other. Furthermore, the lowest SOC compared to other land use types was indicated in LPL at the depth of 15 - 30 cm, though not significantly different from cashew and forest at 15 – 30 cm depth.

The POC ranged from 1.33 g/kg (OPP 15 -30 cm) to 8.16 g/kg (SFR 0 -15 cm). The highest POC was recorded in the forest land use at the depth of 0 -15 cm compared to other land use types. Also no significant difference was observed among other land use types. The lowest POC was observed in oil palms 0 -15 cm (1.33 g/kg).

The MAOC ranged from 4.72 g/kg (forest 15 -30 cm) to 26.74 g/kg(oil palm 0 -15 cm).Oil palm at both depths was significantly higher than other land use types while the others were not significantly differentfrom each other. The NHOC ranged from 5.04 g/kg (forest, 15 -30 cm) to 18.87 g/kg (Oil palm, 0 -15 cm). The highest value registered in oil palm plantations at both depths was significantly higher than values in other land use types while the lowest NHOC was indicated in the forest at 15 -30 cm depth .This implies that oil palm at both depths can be recommended for increased NHOC.

The highest HOC in oil palm (0 -15 cm) was similar to all land uses at the same depth (except LPL and CPL at 15- 30 cm. These findings suggest that Oil palm plantationsexhibited higher SOC and its fractions content, especially MAOC, and NHOC, indicating the potential of this land use in sequestering organic carbon. This can have positive effects on climate change mitigation and soil fertility.On the other hand, forests had higher POC content, suggesting a higher turnover rate of organic carbon.

Long-term monitoring and comparative studies across different regions and land use types can provide valuable insights into sustainable land management practices for enhancing soil organic carbon sequestration.

Table 5: The Interaction of land use and depth on SOC and SOC fractions

Parameter	Land use	SOC	POC	MAOC	NHOC	HOC
Depth				(g/kg)		
0-15cm	OPP	31.80 a	4.93 b	26.74 a	18.87 a	12.79 a
	SFR	17.96 bc	8.16 a	9.84 bcd	9.71 b	8.29 abc
	CPL	15.96 c	4.28 bc	11.39 bc	6.52 c	9.14 ab
	LPL	15.16 cd	2.94 bcd	12.06 b	9.56 b	5.44 bc
15-30cm	OPP	23.14 b	1.33 d	21.67 a	17.35 a	5.65 bc
	SFR	9.63 de	4.95 b	4.72 d	5.04 c	4.62 bc
	CPL	12.87 cde	3.85 bcd	9.12 bcd	6.40 c	6.60 abc
	LPL	7.58 e	1.96 cd	5.70 cd	5.76 c	2.01 c

Means in a column with the same letter are not significantly different at P=0.05
SOC- Soil organic carbon, POC- Particulate Organic carbon, MAOC-Mineral Associated Soil organic Carbon, NHOC-Non hydrolysable Soil Organic Carbon-, Hydrolysable Soil Organic Carbon.

3.5 Effect of land use on soil organic carbon stock

The results, as presented in Fig 1, indicate significant differences in SOC stock across different land use types. The highest SOC stock was found in OPP, with an average stock of 52.16 tC ha-1. This finding suggests that the oil palm plantation has the potential to sequester large amounts of carbon in the soil, which can contribute to mitigating climate change. This result aligns with previous studies that have highlighted the carbon sequestration potential of oil palm plantations Pulhin *et al.,* 2014;

Sanquetta *et al.*, 2015; Rakesh *et al.*, 2020,).

On the other hand, the forest land use (SFR) exhibited a significantly lower SOC stock compared to the oil palm plantation, with an average of 31.19 tC ha^{-1}. This finding raises concerns about the impact of deforestation and land conversion on carbon storage in forest ecosystems. It is well-documented that deforestation leads to significant losses in SOC stock due to the disturbance of vegetation and the decomposition of organic matter (Houghton *et al.*, 2014).

Interestingly, both cashew and leucaena land uses displayed similar levels of SOC stock, with average values of 29.3 tC ha-1 and 27.90 tC ha-1, respectively. These findings suggest that these land use types have comparable capabilities in maintaining SOC stock levels. However, further research is needed to determine the factors contributing to this similarity and to explore potential management practices that can enhance carbon sequestration in these systems.

The results highlight the importance of preserving and restoring forest ecosystems to maintain SOC stock and mitigate climate change. Furthermore, the potential of oil palm plantations to sequester carbon in the soil should be considered in land use decision-making processes.

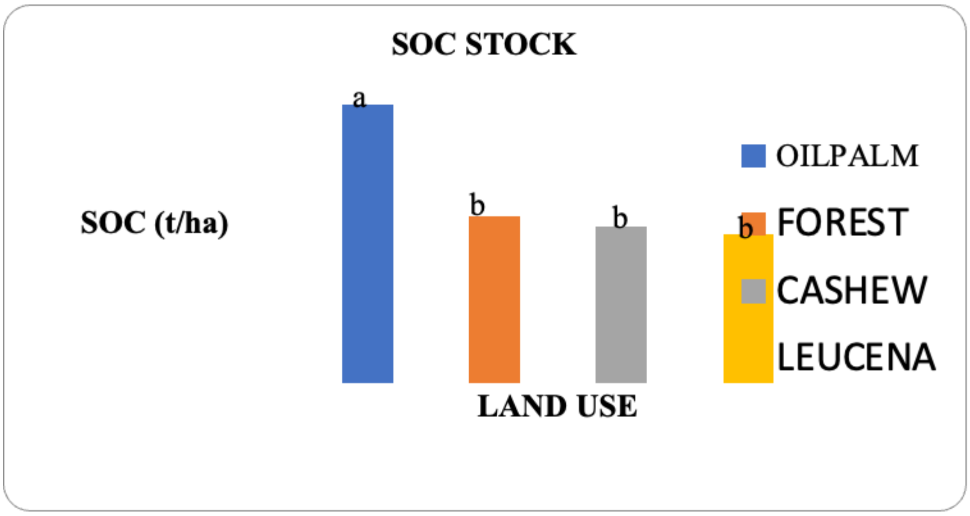

Figure 1: Effect of land use on soil organic carbon stock

4.6. The effect of depth on SOC stock

The result showed that SOC stock varied significantly with depth. At a depth of 0-15 cm, the SOC stock was found to be 42.50 tC ha-1 (Fig.2). However, at a greater depth of 15-30 cm, the SOC stock decreased to 27.77 tC ha-1.It can be attributed to factors such as greater decomposition rates, lower root activity, and reduced input of organic matter at deeper soil

The decline in SOC stock with depth highlights the need to consider soil profiles and not focus solely on the surface layer when assessing carbon sequestration potential. This can be achieved through practices such as conservation tillage, organic amendments, and incorporating cover crops, as they have been shown to enhance carbon stocks in deeper soil layers (Jiang *et al.*, 2018; Hua *et al.*, 2019).

Incorporating deeper soil layers into carbon storage calculations will provide a more accurate estimate of the total carbon storage capacity of a given area.

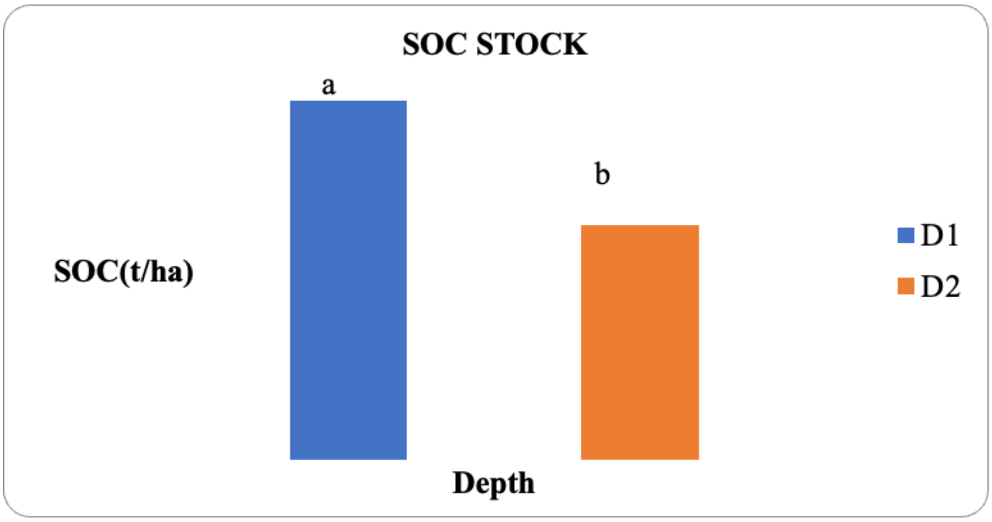

Figure 2: Effect of depth on soil organic carbon stock

D1- 0 - 30 cm, D2 - 15 - 30 cm

3.7. The interaction of landuse and depth on SOC stock

The results revealed that Oil palm plantation (0-15 cm) had the highest SOC stock compared to other land uses across the two depths with an average of 61.22 tC ha-1. This can be attributed to the organic matter input from oil palm residues and root systems, which contribute to higher carbon accumulation in the topsoil. On the other hand Leucena showed lowest value (19.15 tC ha-1) at 15 - 30 cm depth although at par with other land uses at both depths except Oil palm at both depths and secondary forest at 0-15cm.

The implications of these findings is that the establishment of oil palm land use systems can serve as valuable carbon sinks, contributing to climate change mitigation strategies.

On the other hand, land use systems like cashew and leucena demonstrated lower performance in terms of SOC sequestration, especially at greater soil depths. To maximize carbon sequestration potential, it may be necessary to optimize management practices in these systems, such as promoting organic matter inputs or adopting practices that enhance the stability of soil carbon.

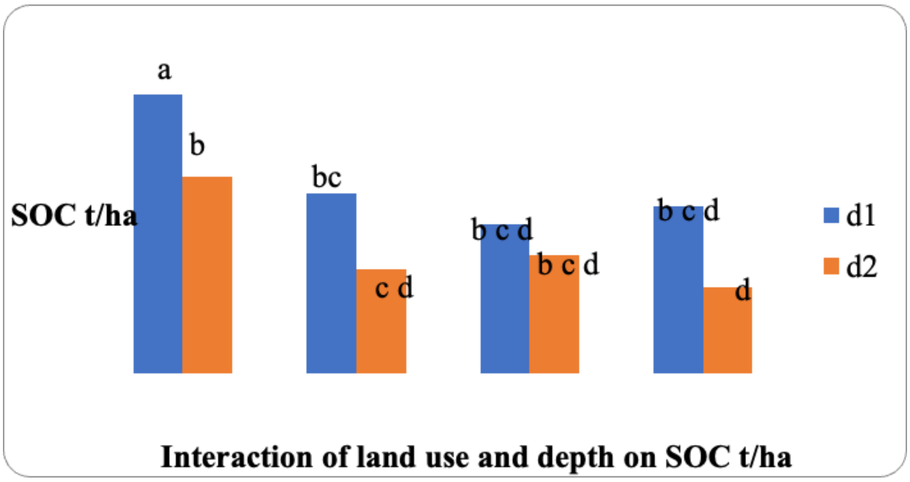

Figure 1: Interaction of land use and depth on soil organic carbon stock

d1- 0 - 30 cm, d2 - 15 - 30 cm

4.0 CONCLUSION

The research evaluated the effect of land use and depth on SOC and its fractions as well as SOC stock. Overall, the results suggest that land use has a significant effect on SOC in bulk soil and its fractions as well as SOC stock, with Oil palm plantation showing the highest potential compared to cashew plantation, secondary forest, and leucaenaplantation.These results emphasize the importance of considering land use decisions in the context of carbon sequestration and climate change mitigation.

Also decline on carbon storage was observed at greater depths. on all SOC parameters. This findings underscore the importance of considering soil profiles and adopting management practices that enhance carbon sequestration in both surface and deeper soil layers.

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Effects of Climates Change on The Physico Chemical Characteristics and Heavy Metals Concentration of Surface Water Harnessed for Irrigation in Kunji Town Yamaltu Deba, Gombe, Nigeria

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ABSTRACT

Effects of Climate change could have a negative impact on productivity of all crop types and suitability of agricultural land along with having an adverse impact on the quality and quantity of water. Order to better understand the intricate interaction between the surface water physicochemical characteristics and the content of Heavy metals were quantitatively determined in the study at kunji town. Thus, a total of 32 water samples used for irrigation were collected and analyzed. Parameters studied are pH, temperature, turbidity using HACP 2100p, conductivity, salinity, anions (PO_4, NO_3-, SO_4, and Cl) using Jenwey model 3510 meter and WTW conductivity meters Model and Heavy metals (Cd, Fe, Cr and Pb) using Flame Atomic Absorption spectrophotometer AAS (Agilent 240 FSAA Model). The results ranged from 5.04 to 7.34 for pH, 26.90 to 27.60^{o}C for temperature, 83.40 to 6420.0 µS/cm EC, 41.20 to 3260.0 mg/L for TDS, 4.27 to 50.91 NTU for turbidity, 12.37 to 129.0 mg/L for TSS, and 0.20 to 12.80 % salinity. The results revealed that parameters analyzed not above the permissible limit, electrical conductivity, chlorine and nitrite recorded in some samples exceeded the WHO permissible limit. The heavy metals concentration were in ranges from BDL to 0.0222 mg/L for Cd, BDL to 0.0829 mg/L for Fe, BDL to 0.0282 mg/L for Cr and BDL to 0.0018 mg/L for Pb, which were all below the WHO permissible limit of 0.01 mg/L, 0.30, mg/L, 0.05 mg/L, and 0.50 mg/L, The water is suitable for irrigation use respectively. However, monitoring and continuous stringent regulation should be imposed with regard to the usage of heavy metals in surface, and will help to develop specific mitigation for water management of agricultural use and other purposes.

Keywords, *climate change, surface water, physico-chemicals, heavy metals, kunji town*

Introduction

Water is one of the most significant natural resources because it makes up 80% of an ecosystem's components (Sulaiman et al., 2018), regarded as primary essentials that support life on earth (Barambu et al., 2020). According to Barambu et al. (2020), anthropogenic activities, natural processes, and the introduction of foreign substances into water bodies all contribute to the deterioration of water quality. People all over the world are suffering greatly as a result of unintended changes in the physicochemical and biological characteristics of water (Adefemi and Awokunmi, 2010). Water quality is a term that is used frequently which makes different people to take an interest in water for a specific application, which may include agricultural operations, waste water treatment hydro power generation, environmental monitoring, industrial expansion or research etc. There are frequently poor relationships among water users when it comes to quality because the desirable features of water vary depending on its intended use (Akhtar et al., 2021). Seasonal fluctuations in the water quality of rivers, streams, and lakes have a significant impact on the population density of aquatic plants and animals (Lawson, 2011; Adeyemo and Longe, 2008). Changes in the environment are caused by anthropogenic actions (such as bush burning and deforestation), natural processes (such as erosion, weathering, geochemical and geological aspects of the environment) (Arain et al., 2008; Festus, 2012). Numerous freshwater bodies, including lakes, rivers, ponds, streams, taps, wells, and a sparse network of streams, may be found throughout Nigeria. According to Kaaya et al. (2015), the majority of these freshwater habitats are being subjected to an increasing pollution load from contaminated urban run-off water from businesses, institutions, and sites like schools and hospitals. This pollution comes from industrial, agricultural, residential, and commercial regions as well as residential and recreational areas. According to Suleiman and Maigari (2016), it is possible to measure the quality of water by using its physical and chemical features to describe the waters' current condition. A complete image of the water quality must be provided by combining physical, chemical, and other monitoring approaches (Adeyemo, 2003). This shows the importance to determine the physicochemical characteristics of water in order to assess its suitability for a variety of uses, including irrigation and industry (Sulaiman and Maigari, 2016). Natural water quality is influenced by a number of chemical and physical factors, including pH, temperature, turbidity, sulphate, electrical conductivity, nitrates, phosphate chlorides, and alkalinity (Lawson, 2011; Nduka et al., 2008). The output of agricultural produce and the survival of aquatic organisms (flora and fauna) are constrained by these characteristics (Lawson, 2011; Umar et al., 2018). Heavy metals are naturally occurring elements of the earth's crust, found in soils, water, and rocks, with a diverse concentration in soil sediments, waterways, and organisms. Both anthropogenic and naturally occurring sources discharge Heavy metals into the environment. Chemical weathering of minerals is the primary natural source of metals in soils and water; human-caused sources are generally related to industrial, agricultural, mining, land disposal of waste, waste incineration, mechanic shops, and gasoline filling stations. (Christiane et al. 2012) Numerous studies on the toxicity of these substances have been published (Henry et al., 2021). There has been researches done in both the field and the lab that shows how high levels of Heavy metals affect soil processes, soil microbial makeup, and microbial growth (Christiane et al. 2012) According to him agricultural wastes and open defecation are likely to have contaminated the ground water and surface water in these locations, which may have low quality. As stated by (Sulaiman and Maigari, 2016), it is crucial to note that water parameters should not be disregarded, which is why these parameters have been clarified. Surface water sources can become contaminated by Heavy metals from a variety of anthropogenic sources, such as industrial runoff and agricultural practices. Climate change has significant and far reaching effects on water resources and hydrological cycles such as altered precipitation patterns, melting glaciers, sea level rise, changing river flow, increased evaporation, water quality issues, shifts in ecosystems, water scarcity, increased flooding, adaptation challenges, health impacts etc. Climate change can slow down the mobilization and transportation of Heavy metals within the water column, potentially increasing their concentration in surface water. A severe risk to agricultural quality comes from elevated heavy metal levels in irrigation water. With rising temperatures, changed precipitation patterns, and an increase in extreme weather occurrences in recent years, climate change has become a significant global concern. This phenomenon raises concerns about the physicochemical properties and the presence of heavy metals in the irrigation water and has the potential to affect both the quality and availability of the water used for irrigation. The purpose of the study is to determine the effects of climate change on the physicochemical characteristic, (electrical, total dissolve solids, total suspended solids, turbidity, salinity, and major anions) and heavy metals concentration of surface water harnessed for irrigation in Kunji, Yamaltu/Deba LGA of Gombe State, Nigeria.

Material and Methods

Study Area

Kunji is located at about 9 km on the Gombe-Biu road opposite Kwadon in Yamaltu-Deba local Government area of Gombe State, Northeastern Nigeria. It is situated between latitudes 10^o27 and 10^o31 N, and between longitudes 11.17 and 11.28^oE. The town is at an altitude of 306m above sea level in the northern Guinea Savannah ecological zone of Nigeria. The study area falls into Guinea savannah climate. The climate is tropical with two distinct seasons; a rainy season (May-October) and a dry/harmattan season (November-April) with 30.5°C and 62.5 mm mean annual temperature and precipitation respectively, and with the relative humidity ranged from 58% to 72% annually (Sulaiman et al., 2019). The study area is one of the major vegetable producers (tomato, onion, pepper, chili pepper lettuce, cabbage, etc.) in the region (Sulaiman et al., 2021).

Samples Collection

Thirty-two water samples were collected from eight predetermined sampling stations. Each station produced four water samples collected from irrigation streams in different parts of Kunji town in the planting season of 2022. The water samples was collected in 500 mL sterile bottles and transported to the laboratory for examination.

Determination of physicochemical parameters

The approach described by (Sulaiman and Maigari, 2016) was used to measure the water's temperature and pH in-situ using a Jenway pH metre, model 3510. With the help of a WTW Conductivity Metre, Model LF 90, the three parameters of electrical conductivity (EC), total dissolved solids (TDS), and total suspended solids (TSS) were calculated. With the use of a HACH 2100P Turbidity Metre, turbidity was measured.

pH

It was measured with a Jenway pH metre, model 3510. pH 4, pH 7, and pH 10 buffer solutions were used to standardise the pH metre. After being cleaned with distilled water and wiping it down, it was submerged in the water sample and held there for a brief period of time until the reading stabilised. From the display, the reading was then taken and recorded.

Conductivity

Temperature WTW Use of the LF 90 Conductivity Metres. With a 0.01M KCl solution, the conductivity metre was calibrated. After being cleaned with deionized water, the electrode was wiped and dipped into a water sample. The reading was then left to stabilise for a while. A micro-Siemens per centimetre (uS/Cm) readout of the reading shown on the screen was then taken.

Total dissolved solid

WTW Conductivity Meter, Model LF 90 was used for the determination of total dissolved solids. 20 mL of sample was measured into a 25 mL sample cell. The sample cell was taken to the conductivity meter and the value obtained was recorded.

Determination of heavy metals

Deionized water was used to wash cellulose membrane filters with a 0.45-m pore size before filtering water samples. Samples were then treated with HNO3 to make them acidic to a pH of less than 2, after which they were kept chilled at 4°C for further examination. Using an Agilent 240 FS AA type flame atomic absorption spectrophotometer, the amount of heavy metal in the dissolved phase (filtered water samples) was determined.

Analysis of Data

Using the SPSS programmed version 25 and the data from the study, simple descriptive statistics (mean and standard deviation) were estimated.

Results and Discussions

Physics-Chemistry Parameters

Tables 1 and 2 show the findings for the major physico-chemical parameters and heavy metal concentration found in water samples from the various sources in Kunji. The sampled water had a pH between 5.04 to 7.34. Some samples had mean pH readings that fell just short of the 6.5–8.5 WHO limit (WHO, 2006). It can be deduced from this that the water samples were only mildly alkaline. These results are consistent with those of Ayers et al. (1985) and other studies on the sample water in Gombe that showed a similar trend in the acidic nature, as reported by Ahmed et al. (2013). From 26.90 to 27.60 ^{o}C are the reported temperature values for all samples, the critical thermal minimum and maximum for fish are 8^{o}C and 30^{o}C respectively, which are the normal range of temperature in the tropics to which fish is acclimated. While conductivity does not provide information about specific compounds, it does indicate the presence of dissolved solids and contaminants, particularly electrolytes. The conductivity values of the water samples ranged from 83.40 to 6420.0 S/cm. Because fertilizer is used on agricultural land, run-up water from that area may be the cause of the water samples' high conductivity. This shows that there are significant amounts of dissolved inorganic substances or ions. Indirect measurements of the concentration of organic compounds in water are frequently made using this procedure. The number of dissolved materials in the water, such as metal ions, is indicated by the total dissolved solids (TDS). From 41.20 to 3260.0 mg/L, the TDS values from the study were obtained. Olatunji et al. (2015) reported a value, which our observation exceeds. Some of the samples' TDS results were found to be higher above the permissible limit of 500 mg/L (WHO, 2006). In this investigation, turbidity measurements were made, with ranges between 4.27 to 50.91 NTU. The study's turbidity measurements were almost all within the 5 NTU (WHO, 2006) upper limits. According to Morokov (1987), erosion and surface runoff bringing soil and silt as well as partially or completely dissolved organic materials are to blame for the increasing turbidity values. In this investigation, turbidity measurements were made, with ranges between 4.27 to 50.91 NTU. Total suspended solids (TSS), also known as non-filterable solids, are those solids that cannot be removed by filtering them via asbestos mats or filter papers. TSS evaluates the physical observable dirtiness of a water supply. The TSS obtained, which ranged from 12.37 to 129.0 mg/L, was within acceptable bounds. Due to the presence of percolate matter, such as clay silt, finely divided organic matter, etc., turbidity is caused by a drop in transparency. According to the FAO (1988), salinity is the concentration or amount of dissolved mineral salts in water and soil-water expressed as a unit of volume or weight. The salinity values found in this investigation ranged from 0.20 to 12.80%. Less than 700 S/cm of salinity indicates no or very little salinity.

Table 1: Physico-chemical parameters of the water samples from Kunji, Y/Deba LGA, Gombe

Sample	pH	Temp (^{O}C)	E.C (µS/cm)	T.D.S (Mg/L)	Turbidity (N.T.U)	T.S.S (Mg/L)	Salinity (%)
1 A	6.85±0.01	27.6±0.01	405.5±1.1	202.5±0.4	4.27±0.02	12.37±0.37	0.8±0.01
1 B	7.34±0.01	27.3±0.01	83.4±0.01	41.2±0.01	18.51±0.01	47.69±0.08	0.0±0.01
1 C	6.24±0.01	26.9±0.01	635.0±0.7	314.5±0.4	10.06±0.02	32.78±0.23	1.2±0.01
1 D	7.12±0.00	27.1±0.01	208.0±0.4	103.0±0.01	7.01±0.01	29.15±0.14	0.4±0.01
2 A	6.93±0.01	27.1±0.01	338.5±0.4	164.0±0.7	12.37±0.11	30.82±0.29	0.7±0.01
2 B	6.71±0.01	27.2±0.01	281.5±2.5	140.5±1.1	9.18±0.05	26.16±0.11	0.5±0.01
2 C	6.05±0.00	27.2±0.01	1288.0±0.5	642.0±0.4	20.27±0.13	51.68±0.19	2.5±0.01
2 D	6.66±0.00	27.3±0.01	234.0±0.7	115.5±0.4	6.04±0.01	21.28±0.33	0.5±0.01
3 A	6.41±0.00	27.4±0.01	236.5±0.4	116.5±0.4	5.57±0.10	14.48±0.13	0.5±0.01
3 B	5.04±0.02	27.5±0.01	6420.0±0.1	3260.0±0.1	50.91±0.51	129.0±1.41	12.8±0.01
3 C	6.05±0.02	27.3±0.01	1443.0±0.1	719.0±0.7	11.71±0.02	29.53±0.28	2.8±0.01
3 D	6.37±0.00	27.5±0.01	365.0±1.4	182.3±0.5	9.29±0.05	30.86±0.54	0.7±0.01
4A	6.31±0.00	27.4±0.01	236.5±0.4	116.5±0.4	5.57±0.10	14.48±0.13	0.5±0.01
4B	5.00±0.02	27.5±0.01	6420.0±0.1	3260.0±0.1	50.91±0.51	129.0±1.41	12.8±0.01
4C	6.02±0.02	27.3±0.01	1443.0±0.1	719.0±0.7	11.71±0.02	29.53±0.28	2.8±0.01
4D	6.25±0.00	27.5±0.01	365.0±1.4	182.3±0.5	9.29±0.05	30.86±0.54	0.7±0.01
5A	6.78±0.01	27.1±0.01	338.5±0.4	164.0±0.7	12.37±0.11	30.82±0.29	0.7±0.01
5B	6.66±0.01	27.2±0.01	281.5±2.5	140.5±1.1	9.18±0.05	26.16±0.11	0.5±0.01
5C	6.01±0.00	27.2±0.01	1288.0±0.5	642.0±0.4	20.27±0.13	51.68±0.19	2.5±0.01
5D	6.48±0.00	27.3±0.01	234.0±0.7	115.5±0.4	6.04±0.01	21.28±0.33	0.5±0.01
6A	6.93±0.01	27.1±0.01	338.5±0.4	164.0±0.7	12.37±0.11	30.82±0.29	0.7±0.01
6B	6.61±0.01	27.2±0.01	281.5±2.5	140.5±1.1	9.18±0.05	26.16±0.11	0.5±0.01
6C	6.02±0.00	27.2±0.01	1288.0±0.5	642.0±0.4	20.27±0.13	51.68±0.19	2.5±0.01
6D	6.54±0.00	27.3±0.01	234.0±0.7	115.5±0.4	6.04±0.01	21.28±0.33	0.5±0.01
7A	6.89±0.01	27.1±0.01	338.5±0.4	164.0±0.7	12.37±0.11	30.82±0.29	0.7±0.01
7B	6.68±0.01	27.2±0.01	281.5±2.5	140.5±1.1	9.18±0.05	26.16±0.11	0.5±0.01
7C	6.04±0.00	27.2±0.01	1288.0±0.5	642.0±0.4	20.27±0.13	51.68±0.19	2.5±0.01
7D	6.60±0.00	27.3±0.01	234.0±0.7	115.5±0.4	6.04±0.01	21.28±0.33	0.5±0.01
8A	6.83±0.01	27.6±0.01	405.5±1.1	202.5±0.4	4.27±0.02	12.37±0.37	0.8±0.01
8B	7.32±0.01	27.3±0.01	83.4±0.01	41.2±0.01	18.51±0.01	47.69±0.08	0.0±0.01
8C	6.18±0.01	26.9±0.01	635.0±0.7	314.5±0.4	10.06±0.02	32.78±0.23	1.2±0.01
8D	7.11±0.00	27.1±0.01	208.0±0.4	103.0±0.01	7.01±0.01	29.15±0.14	0.4±0.01

From the observation, phosphate levels of between 0.87 and 20.44 mg/L were measured in both seasons. The phosphate levels were less than the allowable limit. In comparison to the values reported by Odiba et al. (2014), less data were collected in this investigation. This might imply that the water bodies have been fertilised with fertiliser that contains a lot of phosphate. In the study, the nitrate levels in the water samples ranged from 20.90 to 60.63 mg/L. The research area's nitrate concentration was higher than the 50 mg/L threshold that is advised (WHO, 2006). This showed that leachate from the body of farmland had an impact on the water samples. The sulphate levels that were measured ranged from 83.40 to 534.91 mg/L. In comparison to the value reported by Ahmed et al. (2013), the values in this study are greater. In this investigation, the majority of the samples had sulphate levels that were higher than the permitted limit of 250 mg/L. Biological processes have no impact on chlorides because they are mineral salts. Water takes on a specific flavour when the chloride content is 250 mg/L or above. The acquired water samples for this study had chloride ion contents that ranged from 78.56 to 1137.39 mg/L. While Odiba et al. (2014) stated their results; the values found in this investigation are higher. Some samples in this investigation had chloride concentrations above the 250 mg/L WHO threshold that is considered to be the acceptable level (WHO, 2006).

Table 2: Anions concentrations of the water samples from Kunji, Y/Deba LGA, Gombe

Samples	PO_4 Mg/L	NO_3 Mg/L	SO_4 Mg/L	Cl Mg/L
1 A	7.11 ± 0.00	39.02 ± 0.42	161.60 ± 0.78	381.40 ± 0.93
1 B	0.87 ± 0.01	76.22 ± 0.02	83.40 ± 0.00	78.56 ± 0.77
1 C	8.33 ± 0.02	21.83 ± 0.24	303.37 ± 1.29	621.11 ± 0.67
1 D	2.43 ± 0.00	46.92 ± 1.04	113.22 ± 0.26	192.75 ± 0.78
2 A	5.63 ± 0.01	60.63 ± 0.09	152.79 ± 0.47	319.76 ± 2.09
2 B	1.57 ± 0.01	53.66 ± 0.22	225.07 ± 0.26	253.96 ± 2.51
2 C	20.44 ± 0.01	30.94 ± 0.17	534.91 ± 2.09	1137.39 ± 6.28
2 D	3.26 ± 0.00	23.57 ± 0.75	241.24 ± 0.10	218.14 ± 1.05
3 A	3.19 ± 0.01	20.90 ± 0.01	261.42 ± 0.59	221.10 ± 0.43
3 B	71.59 ± 0.17	15.92 ± 0.01	1841.75 ± 1.94	6372.66 ± 1.80
3 C	22.88 ± 1.11	11.03 ± 0.13	552.36 ± 0.00	1330.75 ± 1.94
3 D	5.91 ± 0.01	19.50 ± 0.24	285.93 ± 2.66	315.33 ± 0.43
4 A	7.09 ± 0.00	39.02 ± 0.42	161.60 ± 0.78	381.40 ± 0.93
4 B	0.82 ± 0.01	76.22 ± 0.02	83.40 ± 0.00	78.56 ± 0.77
4 C	8.23 ± 0.02	21.83 ± 0.24	303.37 ± 1.29	621.11 ± 0.67
4 D	2.33 ± 0.00	46.92 ± 1.04	113.22 ± 0.26	192.75 ± 0.78
5 A	5.43 ± 0.01	60.63 ± 0.09	152.79 ± 0.47	319.76 ± 2.09
5 B	1.37 ± 0.01	53.66 ± 0.22	225.07 ± 0.26	253.96 ± 2.51
5 C	20.24 ± 0.01	30.94 ± 0.17	534.91 ± 2.09	1137.39 ± 6.28
5 D	3.16 ± 0.00	23.57 ± 0.75	241.24 ± 0.10	218.14 ± 1.05
6 A	3.08 ± 0.01	20.90 ± 0.01	261.42 ± 0.59	221.10 ± 0.43
6 B	71.49 ± 0.17	15.92 ± 0.01	1841.75 ± 1.94	6372.66 ± 1.80
6 C	22.72 ± 1.11	11.03 ± 0.13	552.36 ± 0.00	1330.75 ± 1.94
6 D	5.84 ± 0.01	19.50 ± 0.24	285.93 ± 2.66	315.33 ± 0.43
7 A	4.93 ± 0.01	60.63 ± 0.09	152.79 ± 0.47	319.76 ± 2.09
7 B	1.17 ± 0.01	53.66 ± 0.22	225.07 ± 0.26	253.96 ± 2.51
7 C	19.28 ± 0.01	30.94 ± 0.17	534.91 ± 2.09	1137.39 ± 6.28
7 D	3.16 ± 0.00	23.57 ± 0.75	241.24 ± 0.10	218.14 ± 1.05
8 A	3.06 ± 0.01	20.90 ± 0.01	261.42 ± 0.59	221.10 ± 0.43
8 B	71.45 ± 0.17	15.92 ± 0.01	1841.75 ± 1.94	6372.66 ± 1.80
8 C	22.68 ± 1.11	11.03 ± 0.13	552.36 ± 0.00	1330.75 ± 1.94
8 D	5.81 ± 0.01	19.50 ± 0.24	285.93 ± 2.66	315.33 ± 0.43

Heavy metals such as Cadmium (Cd), Chromium (Cr), Arsenic (As), and Lead (Pb), have been considered as the most toxic metals in the environment. The persistent nature of heavy metals in the environment is due to their inability to get biodegraded (Henry et al. 2021). The concentrations of Cd obtained in this study (Tables 3), ranged from BDL-0.0222 mg/L. Fe concentration ranged from BDL-0.0829 mg/L. The chromium concentrations in this study ranged from of BDL-0.0282 mg/L. Pb levels between BDL - 0.0018 mg/L were found in the water samples.

Table 3: Heavy metals concentration in water samples from Kunji, Y/Deba LGA, Gombe

Samples	Cd Mg/L	Fe Mg/L	Cr Mg/L	Pb Mg/L
1 A	BDL	0.0829±0.0002	0.0000	BDL
1 B	0.0124±0.0002	0.0104±0.0001	0.0209±0.0001	BDL
1 C	0.0209±0.0000	0.0282±0.0001	0.0015±0.0001	BDL
1 D	BDL	BDL	0.0022±0.0001	0.0018±0.0000
2 A	0.0222±0.0002	0.0163±0.0002	0.0011±0.0000	BDL
2 B	0.0013±0.0000	0.0607±0.0002	BDL	BDL
2 C	0.0460±0.0000	0.0425±0.0001	0.0135±0.0002	BDL
2 D	0.0076±0.0001	BDL	0.0021±0.0001	BDL
3 A	0.0061±0.0001	BDL	0.0014±0.0000	0.0079±0.0002
3 B	0.2070±0.0002	0.1319±0.0001	0.0262±0.0001	0.0123±0.0001
3 C	0.0156±0.0003	0.0891±0.0003	0.0214±0.0001	BDL
3 D	0.0023±0.0001	0.0428±0.0002	BDL	0.0022±0.0001
4 A	BDL	0.0829±0.0002	0.0000	BDL
4 B	0.0124±0.0002	0.0104±0.0001	0.0209±0.0001	BDL
4 C	0.0209±0.0000	0.0282±0.0001	0.0015±0.0001	BDL
4 D	BDL	BDL	0.0022±0.0001	0.0018±0.0000
5 A	0.0220±0.0002	0.0163±0.0002	0.0011±0.0000	BDL
5 B	0.0012±0.0000	0.0607±0.0002	BDL	BDL
5 C	0.0450±0.0000	0.0425±0.0001	0.0135±0.0002	BDL
5 D	0.0072±0.0001	BDL	0.0021±0.0001	BDL
6 A	0.0061±0.0001	BDL	0.0014±0.0000	0.0079±0.0002
6 B	0.2065±0.0002	0.1319±0.0001	0.0262±0.0001	0.0123±0.0001
6 C	0.0149±0.0003	0.0891±0.0003	0.0214±0.0001	BDL
6 D	0.0021±0.0001	0.0428±0.0002	BDL	0.0022±0.0001
7 A	BDL	0.0829±0.0002	0.0000	BDL
7 B	0.0122±0.0002	0.0104±0.0001	0.0209±0.0001	BDL
7 C	0.0205±0.0000	0.0282±0.0001	0.0015±0.0001	BDL
7 D	BDL	BDL	0.0022±0.0001	0.0018±0.0000
8 A	0.0221±0.0002	0.0163±0.0002	0.0011±0.0000	BDL
8 B	0.0012±0.0000	0.0607±0.0002	BDL	BDL
8 C	0.0456±0.0000	0.0425±0.0001	0.0135±0.0002	BDL
8 D	0.0073±0.0001	BDL	0.0021±0.0001	BDL

CONCLUSION

The study tested the presence of some toxic chemicals in streams of water found in the irrigation region of Kunji town. The test observed ranged from 5.04 to 7.34 for pH, 26.90 to 27.60°C for temperature, 83.40 to 6420.0 µS/cm EC, 41.20 to 3260.0 mg/L for TDS, 4.27 to 50.91 NTU for turbidity, 12.37 to 129.0 mg/L for TSS, and 0.20 to 12.80 % salinity. The results revealed that parameters analyzed not above the permissible limit, electrical conductivity, chlorine and nitrite recorded in some samples exceeded the WHO permissible limit. The heavy metals concentration were in ranges from BDL to 0.0222 mg/L for Cd, BDL to 0.0829 mg/L for Fe, BDL to 0.0282 mg/L for Cr and BDL to 0.0018 mg/L for Pb, which were all below the WHO permissible limit of 0.01 mg/L, 0.30, mg/L, 0.05 mg/L, and 0.50 mg/L,. The study found the deposition of fertilizers, agro allied chemicals and unscientific means of cultivating crops may increase the metals level in soils through the water and thereby causing the metal uptake by the vegetables to upsurge the leading to an increment in their concentration in the vegetable and vice versa.

RECOMMENDATION

Based on the findings of this study, the following recommendations for further action and studies are suggested:

- There is the need for further studies on the presence of these toxic chemicals in agricultural produce grown in Kunji town The study could suggest further research is needed with a huge number of samples and heavy metals contamination in irrigation soil, plants and water in the area of the studied considering agricultural practices, local geology, industrial activities and proper action need to be done.
- There is a need to develop an environmental monitoring and management program for heavy metals in Nigeria and therefore suggested that regular monitoring of physico chemical parameters and heavy couple with climates shifts in order to prevent excessive build ups in our water bodies, plants and soils..
- The study also add knowledge to the existing one, which is going to serve as current stage of data.

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Effect of Land Use on Hydraulic Properties and Erodibility Indices of Degraded Ultisols in Southeastern Nigeria

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ABSTRACT

Land use contribute significantly to soil loss through soil erosion. The study investigated the effect of land use on hydraulic properties and erodibility indices of degraded ultisols in southeastern Nigeria. Seventy-two (72) soil samples were collected from 0-20 cm depth across three land use types (cultivated land, grassland and forestland) for determination of soil hydraulic properties and soil erodibility indices. The results showed that saturated hydraulic conductivity (Ksat), bulk density (BD), macro porosity (Macrop), micro porosity (Microp), total porosity (TP), percent clay and total sand content except AS and MWD differed significantly across the land use. In addition, the results showed that dispersion ratio (DR), clay ratio (CR), modified clay ratio (MCR), critical level of organic matter (CLOM), erodibility K-factor, predicted soil loss (PSL) and organic matter contents differed significantly ($P<0.05$) across land use types. The cultivated land recorded the highest soil loss of 235.5 t/ha/yr compared to the 73 t/ha/yr for forestland. The results also showed that the SOM content was lower in the cultivated plot (1.37%) compared to other land use types (1.41% and 2.62%). The study concluded that land use types have significant impact on critical soil properties such as SOM, aggregate stability, soil erodibility indices including erodibility K-factor, predicted soil loss in the study location.

Keywords: erosion, soil loss, SOM, land use types, soil erodibility

4.0 INTRODUCTION

Soil is a very important part of ecosystems and plays important role in earth system functions that support the delivery of primary ecosystem services (Keesstra et al. 2016; Robinson et al. 2017). One of the major threats to soil resources is soil erosion (Borrelli et al. 2017). Soil erosion is considered a major environmental problem in the world since it seriously threatens natural resources and the environment (Rahman et al. 2009). In Nigeria, it is the worst environmental disaster that many towns and villages in Southeastern Nigeria have had to deal with over the years (Adekalu et al., 2007; Nwankwo and Nwankwoala 2018). Soil erosion is a gradual process that occurs when the impact of water or wind detaches and removes soil particles, causing the soil to deteriorate. The consequences of soil erosion include destruction of farmlands and decline in agricultural output, and large swaths of land or portions of agricultural lands becoming unsuitable for agriculture. Soil erosion is common in areas where forest cover has been removed for agricultural purposes, and in areas where surface soils have been unevenly compacted by foot and automobile activities on highways and in off-road locations. Although, man has helped in reshaping and preserving the earth surface, yet man has also helped in causing instability of equilibrium in the natural ecology and hence the rapid spread of environmental problem such as soil erosion.

Globally, soil erosion is responsible for the loss of billions of tonnes of soil (Ibitoye and Adegboyega 2012) and it remains the world's largest environmental problem threatening both plants and animals (Abegbunde et al. 2006). In southeastern Nigeria, gully erosion is the most prevalent soil erosion menace (Chiemelu et al. 2013; Nwankwo and Nwankwoala, 2018). Gully erosion is influenced by the amount and intensity of rainfall, erodibility of the soil, and the surface runoff generated. Girma (2001) has shown that the major causes of soil erosion are rapid population increase, deforestation, low vegetative cover and unbalanced crop and livestock production. Besides the human induced causes, factors such as land topography, ecology, rainfall, land cover and land use, and soil types can also contribute to soil erosion.

Erodibility is the resistance of the soil to both detachment and transport (Emeka 2014). It can also be seen as the ability of soil to resist erosion based on the physical characteristics of each soil in an area. Generally, soils with faster infiltration rates, higher levels of organic matter and improved structure have a greater resistance to erosion (Dexter 2004; Emeka 2014). Water easily disperses and transports highly erodible geologic materials. The soil erodibility factor K is a quantitative expression of the inherent susceptibility of a particular soil to erode at different rates when the other factors that affect erosion are kept constant (Ezeabasili et al. 2014). According to Igwe (2012), erodibility varies with soil texture, aggregate stability, SOM contents and hydraulic properties of the soil. Soils below the plough layers are often compact and less erodible. A soil with relatively low erodibility factor may show signs of serious erosion, yet the soil could be highly erodible and suffer little erosion (Nyakatawa et al. 2001). This is because soil erosion is a function of many factors as stated in the universal soil loss equation (USLE). These factors include rainfall factor (R), soil erodibility factor (K), slope length (LS), crop factor (C) and control practice factor (P) with respect to the area, soil textures, aggregates, stability, shear strength, soil structures, infiltration capacity, soil depth, bulk density, soil organic matter and chemical constituents.

Land use is a complex process shaped by human activity and affected by ecological, economic and social drivers capable of influencing a wide range of environmental and economic conditions (Agarwal et al. 2000; MacDonald et al. 2000). The major cause of soil erosion in southeastern Nigeria is inappropriate use of land for different socio-economic activities. Human activities contributing to soil erosion in the region are deforestation, overgrazing and agricultural intensification without erosion control measures, and when sustained for a long period deteriorate the land (Teferi 2016). Land use types such as farming practices often lead to some forms of soil erosion (Ritter and Eng 2012), with cultivated lands showing continuously increasing trend at the expense of forest land and grass land in the last four decades (Gete et al. 2000). In addition, Girma (2001) indicated that the major causes of soil erosion in southeastern Nigeria are rapid population increase, severe soil loss, deforestation, low vegetative cover and unbalanced crop and livestock production.

As the human population has expanded, more and more land will be cleared for agriculture and other pursuits, further degrading the soil and making erosion more likely to occur. Therefore, investigating the impact of land use on soil hydraulic properties and soil erodibility indices including erodibility k-factor and predicted soil loss is imperative for future soil conservation practices and policies. The objective of this study was to determine the effect of land use types on soil hydraulic properties, erodibility k-factor and erodibility indices of degraded ultisols in southeastern Nigeria.

2.0 MATERIALS AND METHOD

2.1 Description of Study Site

The study involved two different locations namely; Amufia-agu Affa in Udi local government area and Eha-Alumoma in Nsukka local government area, all in Enugu State, southeastern Nigeria (Figure 1). Amufia-agu Affa is located on latitude 06° 57^{l} N and longitude $07°23^{l}$ E with an elevation of 179 m above sea level. It has a variable relative humidity between the ranges of 42 – 50 % (Asadu et al, 2002). Eha-Alumoma is located on latitude $06°82^{l}$ N and longitude $07°46^{l}$ E with an elevation of 484 m above the sea level. Nsukka has a variable relative humidity that rarely falls below 60 % (Asadu et al 2002). The locations are characterized by two seasons, the rainy and dry seasons. The rainy season starts from April to October and the dry season is from November to March. There is a short break (August Break) usually in the month of August. The sites have an average annual rainfall between the ranges of 1500 – 2000 mm with average minimum and maximum temperatures of about 22 and 30°C, respectively. The soils of the area have high percentage of sand and granular structure at the top with low percentage of clay, loam, and silt. The soils are Ultisols characterized by rapid to very rapid permeability (Obi and Asiegbu 1980; Nwadialo 1989).

2.2 Vegetation and Land Use

There are three different types of land use that was considered in this study namely; Forest Lands, Cultivated Lands and Grass Lands. These land uses are in the two locations (Udi and Nsukka) both in Enugu state. Udi samples were collected at a forestland at Ugwu-ife land in Amufia-agu

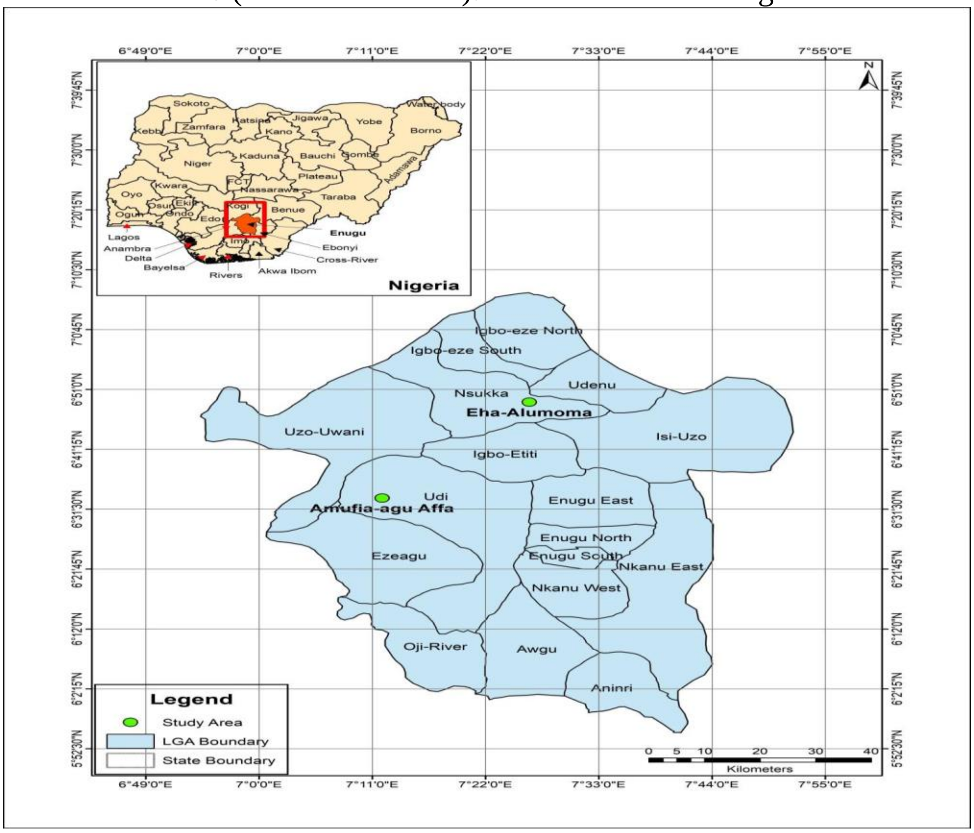

Figure 1: Location of the study area in Enugu State, Nigeria

Affa. The forestland in Amufia-agu Affa is a primary forest of over 80 years. The villagers have never used the land for any agricultural purposes except for fetching of firewood. It is called Ugwu-ife forest because a mighty hill is close to the forest and this place (Ugwu-ife hill) was where the villagers were settling years back before they came down to Amombori Affa land. The grassland in Udi is at Ife-agu (wilderness) Agbani land in Amufia-agu Affa, it is called wilderness because no living eye have ever seen someone cultivated in this area because they believe that the land is not fertile. The land is only used for fetching of firewood and grazing of animal. The cultivated land in Udi is at a camp known as ugwu-ife land in Amufia-agu in Affa. This land has been cultivated for a minimum of 10 years and cultivation is still on going. Common crops cultivated are cassava, maize and coco yam. In Nsukka, soil samples were collected from: Forestland located at Umuaroji-Uwanyi village in Ehaulo community. The land is a primary forest of over 80 years. The cultivated land is at Ogbungbor village in Eha-ulo, and the land has been cultivated for a minimum of 10 years and cultivation is still on going. Common crops cultivated are cassava, maize and coco yam. The grass land is at Eha-ulo community near the meteorological observatory in University of Nigeria Nsukka, and has been a grass land for over 15 years. The grassland is mainly used for grazing of different animals.

2.3 Field study

One hundred and twenty (120) soil samples made up of 60 disturbed and 60 undisturbed soil samples were randomly collected from the two locations at a minimum of 10 m intervals from the different land use types. The soil samples were collected from 0-20 cm depth in each land use within a location. In each land use, 10 disturbed and 10 undisturbed soil samples were randomly collected. The disturbed soil samples were collected using soil Auger whereas the undisturbed soil samples were collected with core samplers of 5 cm x 5 cm dimension. The soil samples were packaged with polythene bags and properly labelled before they were transported to the laboratory for analysis. The disturbed soil samples were air dried for 1 week and sieved with 2 mm sieve before the laboratory analysis. The undisturbed soil samples were trimmed, tied with kaliko cloth at the bottom and saturated for at least 48 hours for determination of saturated hydraulic conductivity and other properties. All the laboratory analysis were carried out in the Department of Soil Science undergraduate laboratory, University of Nigeria, Nsukka using standard laboratory procedure.

2.4 Laboratory Analysis

Soil particle size distribution was determined using the Hydrometer method as described by (Gee and Bauder 1986) using NaOH as a dispersing agent.

Saturated hydraulic conductivity (Ksat) was determined by the constant head permeameter method (Klute and Dirksen 1986). Darcy's equation for analysis of constant head method, as described by Youngs (2001) was used for the computation of Ksat as follows:

$$K_{sat}\ (\text{cm hr}^{1}) = \frac{Q}{At} \times \frac{L}{\Delta H} \quad \text{……………………………(1)}$$

Where Q is steady-state volume of flow (cm^3), L is length of the soil core (cm), A is cross sectional area of the soil core (cm^2), t is time interval (hr.), and ΔH is hydraulic head change (cm).

Thereafter, the pore size distribution of the soil core was determined using the method described by Flint and Flint (2002). In this method, macro porosity was determined as shown in equation 2 below;

$$Macroporosity = \frac{volumetric\ moisture\ content\ of}{bulk}$$ ….. (2)

The micro porosity was determined as shown in equation 3 below;

$$Microporosity = \frac{volumetric\ moisture\ content\ of\ the\ soil\ retained\ at\ 60\ cm\ (water)\ tension}{bulk\ volume\ of\ soil}$$ ……. (3)

The total porosity (macro porosity + micro porosity) is represented by equation 4 below;

$$Total\ porosity = \frac{Total\ volume\ of\ water\ in\ the\ soil\ at\ saturation}{bulk\ volume\ of\ soil}$$ ……………………………. (4)

Bulk density was determined by the core method as described by Blake and Hartge (1986).

The size distribution of water stable aggregates (WSA) was determined by the wet sieving method (Kemper and Rosenau 1986). In this method, twenty-five grams (25 g) of the air-dried soil sample retained on 2 mm sieve was weighed out and put on the topmost of the nest of sieves of 2, 1, 0.5 and 0.25 mm. The content was soaked initially for 5 minutes to prevent slaking, and thereafter oscillated vertically in water for 5 minutes at the rate of 30 oscillations per minute and at an amplitude of 4 cm. Thereafter, soil aggregates left on each sieve were oven dried at 105˚C for 24 hours and weighed.

The aggregate stability (AS) as percent of water-stable aggregates (WSA) > 0.5 mm on each sieve was calculated from the equation below:

$$\frac{\text{Weight of stable aggregate} > 0.5\ \text{mm} - \text{weight of sand}}{\text{Weight of sample} - \text{weight of sand}} \times 100$$ ……………………………………….(5)

The mean weight diameter (MWD) of WSA was calculated based on the equation proposed by Chaney and Swift (1984) as:

$$\mathbf{MWD = \sum Xi\ Wi}$$ ……………………………………………..(6)

Where X_i is the average diameter of each sieve size or fraction, and W_i is the weight ratio of aggregates remained on the ith sieve

Soil organic carbon (OC): organic carbon was determined by wet oxidation method (Nelson and Sommer 1996), and converted to organic matter by multiplying with a constant factor of 1.724.

2.6 Computation of soil Erodibility indices

Erodibility indices are dependent on not only soil textures but also on the presence of organic matter (OM) content, soil permeability and soil structures. Apart from quantitative indices for soil erodibility to estimate soil erosion, some other indices which are qualitative in nature have also been used by researchers to understand the proneness of soil to erosion. These includes;

i. Dispersion Ratio (DR): $= \frac{\%\ silt + \%\ clay\ (undispersed)}{\%\ silt + \%\ clay}$

ii. Clay Ratio (CR) : $= \frac{(\%\ \text{sand} + \%\ \text{silt})}{\%\ \text{clay}}$

iii. Modified Clay Ratio (MCR): $= \frac{(\%\ \text{sand} + \%\ \text{silt})}{(\%\ \text{clay} + \%\ \text{OM})}$

iv. Critical level of soil organic matter (CLOM): = $\frac{\%\ \text{OM}}{\%\ \text{clay} + \%\ \text{silt}}$

To estimate soil erodibility K-factor, the USLE nomograph published by Wischmeier *et al.* (1971) was used which is in accordance to the Equation below;

$$K = 2.73 \times 10^{-6} M^{1.14}(12 - OM) + 3.25 \times 10^{-2}(S - 2) + 2.5 \times 10^{-2}(P - 3)$$ …………. (11)

Where K is Soil erodibility factor (t. ha. h. ha^{-1}. Mj^{-1} .mm^{-1}) and M is texture from each soil depth and is calculated using Equation 12, based on soil primary particle percentage. OM is percentage organic matter content that could be determined in the laboratory, S is soil structure code and P is soil permeability class and both can be obtained from USDA published documents based on soil texture.

$$M = [(100 - Ac).(L + Armf)]$$ ……………………………………. (12)

Where Ac is percentage of clay (<0.002 mm), L is percentage of silt (0.002-0.05 mm) and Armf is percentage of very fine sand (0.05-0.1 mm).

Six classes are identified based on soil permeability classification (Wischmeier and Smith 1979) in cm/h as follows:

1. High to very high (>12.5)
2. Moderate to high (6.25-12.5)
3. Moderate (2-6.25)
4. Moderate to low (0.5-2)
5. Low (0.125-0.5)
6. Very low (<0.125)

Predicted soil loss was calculated based on the formula given by Roose (1977) as stated below;

$$A = 2.24\ RK$$ …………………………………… (13)

R = Rainfall factor given as 0.5H, A = Soil loss converted to ton/ha, H = Mean annual rainfall, H for the location of study in southeastern Nigeria = 1600 mm.

2.7 Statistical Analysis

The data obtained were subjected to analysis of variance (ANOVA) using GenStat Discovery Edition. In the cases of significant treatment effects, mean separation was by the Fisher's least significant difference (F-LSD) procedure at 5 % level of probability (P < 0.05) as described by Obi (2002). Pearson correlation coefficient was used to determine the relationships between soil hydraulic properties and erodibility indices, erodibility K-factor and predicted soil loss.

3.0 RESULTS

3.1 Effects of land use types on soil hydraulic properties

Table 1 shows the main effect of land use on soil hydraulic properties. The results showed that aggregate stability (AS), mean weight diameter (MWD), saturated hydraulic conductivity (Ksat), bulk density (BD), macroporosity and microporosity were significantly (P<0.01) influenced by land use. The AS ranged from 28.90% in the cultivated land to 50% in the grassland. Similar trend was obtained for MWD and microporosity. The Ksat, total porosity and macroporosity gave their highest values in the forestland and their least values at the cultivated land. As expected, BD was highest on the cultivated land and lowest on the forestland. Other results showed that the clay and sand contents differed significantly (P< 0.05) across the land use types. Grassland soil has the highest clay content (18.60%), but lowest sand content (76.72%). Cultivated land had the highest sand content (82%) and lowest clay content (14.1%).

Table 1: Main effects of land use on soil hydraulic properties

Land use	AS (%)	MWD (mm)	K_{sat} (cmh^{-1})	BD (gcm^{-3})	TP (%)	Macp (%)	Micp (%)	CL (%)	ST (%)	TS (%)
Cultivated land	29.80	0.78	4.75	1.70	35.87	15.03	20.84	14.1	3.9	82.0
Forestland	47.40	0.91	13.49	1.41	46.58	20.24	26.34	17.1	4.2	78.7
Grassland	50.00	0.94	10.88	1.53	42.17	15.16	27.01	18.6	4.7	76.7
F-LSD$_{(0.05)}$	5.45	0.12	1.98	0.09	3.53	2.44	4.63	1.28	NS	1.23

AS = Aggregate stability, MWD = Mean weight diameter, K_{sat} = Saturated Hydraulic conductivity, BD = Bulk density, TP = Total porosity, MACP = Macro porosity, MICP = Micro porosity, CL = Clay percent, ST= Silt percent and TS = Total sand.

3.2: Effects of Land use types on soil organic matter, soil erodibility indices and predicted soil loss

Table 2 shows the main effect of land use on soil organic matter (SOM), soil erodibility indices including the erodibility K-factor and the predicted soil loss. The results showed that SOM, all erodibility indices except critical level of organic matter (CLOM), erodibility K-factor and the predicted soil loss differed significantly ($P<0.01$) across the three land use types studied. Dispersion ratio was lowest (19.63) in the cultivated land and highest (21.89) in the grassland. The clay ratio CR), modified clay ratio (MCR), erodibility k-factor and the predicted soil loss have their highest values in the cultivatedland and their lowest values in the forestland. Soil organic matter (SOM) was highest (2.62%) in the forestland and lowest (1.37%) in the cultivated land.

Table 2: Effects of Land use on soil organic matter, soil erodibility indices and predicted soil loss

Land use	DR (%)	CR (%)	MCR (%)	CLOM (%)	K-factor (%)	PSL (t/ha/ya)	SOM (%)
Cultivated land	19.63	4.16	5.52	3.98	0.131	235.5	1.37
Forestland	21.89	6.07	7.64	5.34	0.048	73.0	2.62
Grassland	22.90	4.88	6.29	4.76	0.051	111.3	1.41
F-LSD$_{(0.05)}$	1.49	0.42	0.50	N.S	0.012	22.19	0.25

DR = Dispersion ratio, CR = Clay ratio, MCR = Modified clay ratio, CLOM = Critical level of Organic matter, K = Erodibility factor, PSL = Predicted soil loss and soil organic matter.

4.0 Discussions

The particle size distribution irrespective of land use types showed that the soils have high sand contents with low silt and clay contents. This could be linked to the parent materials in the study locations which are mostly false-bedded sandstones. Generally, soils formed from false-bedded sandstone tend to be sandy in nature (Akamigbo and Asadu 1985). However, another reason for this could be the accumulation of the heavier sand fractions over time due to removal and transportation of the lighter materials by runoff flow (Akamigbo and Igwe 1990). Large or heavier particles such as sand are less erodible and erosion resistant because the force required to displace them is more compared to silt and fine sand (Olaniya et al. 2020). The results also showed that the sand, silt and clay fractions differed significantly across the land use types. The result of this study confirms the findings of Nkana and Tonye (2003), Braimoh and Vlek (2004) and Amara et al. (2022). Similarly, Wu and Tiessen (2002) reported significant difference between sand fraction in soils of long-term farmlands (i.e. 40 years), rangelands and slightly or moderately degraded rangelands. Although several authors (Wu and Tiessen 2002; Evrendilek et al. 2004; Amara et al. 2022) had reported non-significant differences in the amount of silt fractions among land use types, the result of this study showed that the amount of silt fractions differed significantly among the land use types considered. Similarly, the significant difference in the clay contents among the land use types was supported by Su et al. (2004) and, Wu and Tiessen (2002) but contradicted the findings of Amara et al. (2022).

Generally, the bulk density of the soils are high across the land use types investigated. According to Mbagwu et al. (1998), high bulk density could be caused by translocation of clay from alluvial horizon with simultaneous loss of structure and closer packing of sand grains in the alluvial horizon. It could also be caused by low soil organic matter due to a strong and negative correlation between soil organic matter and bulk density (Athira et al. 2019; Sakin 2012; Sakin et al. 2011). Interestingly, the soil organic matter content of the soils in the three land use types were very low and decreased with increasing bulk density. The low soil organic matter content may be due to increased decomposition or mineralization rate caused by high temperature and high intensity rainfall characteristics of the humid tropics (Davidson and Janssens 2006; Birkas et al. 2009). Other reasons for the low soil organic matter content could be attributed to the variation in leaf litter amongst the land uses and their rate of decomposition (Ray et al. 2006). According to Igwe (2004), the low soil organic matter may be due to the high erodibility of the soils as result of high rainfall and their fragile nature. Quinton et al. (2010) also reported that high erodibility of soils could cause large quantities of soil organic matter and nutrients to be lost through soil erosion processes. Such low soil organic matter is capable of causing increased soil bulk density and make the soil prone to compaction through unsustainable land management practices (Birkas et al. 2009).

The estimated erodibility indices such as dispersion ratio (DR), clay ratio (CR), modified clay ratio (MCR) and critical level of organic matter (CLOM) suggest that the soils studied under the three land use types were erodible and susceptible to erosion. However, it appears that soils under the cultivated land are more erodible than soils under either grass land or forest land. According to Arulanandan (2003), soils having DR greater than 0.15 or 15% are erodible in nature and this view was corroborated by Chakrabarti (1990) who reported that susceptibility to erosion is significantly related to the dispersion ratio. The soils investigated across the land use types have DR values ranging from 19.63 – 22.90% and are considered susceptible to erosion. The CLOM is related to soil aggregate formation capability which offers resistance to soil erosion Generally, soils with CLOM < 5% are said to be highly susceptible to erosion, CLOM 5-7% are moderately susceptible to erosion and CLOM > 9% indicates that the soil is stable and offer more resistance to erosion (Pieri 1991). Based on the CLOM values, the soil under the cultivated land and grassland are highly susceptible to erosion while the soil under the forestland use is moderately susceptible to erosion. The clay ratio (CR), which is the estimation of particle resistance to external forces in the presence of the higher amount of clay particles (Bouyoucos 1935), is inversely related to soil erodibility. This is also true for MCR, which was shown by earlier studies to be another index for erodibility (Mukhi 1988; Tarafdar and Ray 2005). Both CR and MCR values showed that soils under the forestland use were less erodible or susceptible to erosion compared to the soils under the cultivated and grassland land uses. The result of this study corroborated the findings of Olaniya et al. (2020) who has previously reported the lowest CR and MCR values for forestland compared to agricultural land and wasteland.

The K-factor obtained from this study ranged from 0.051 to 0.131 across the land use types. According to the erodibility classification of Foster et al. (1981), these K-factor values are considered high and showed that the soils are highly susceptible to erosion. Similar high K-factors were also reported for the southwestern soils of Owo and Akoko areas of Ondo state in Nigeria (Olumuyiwa 2019) and soils from Anambra basin in southeastern Nigeria (Ezeabasili et al. 2014). Interestingly, Ezeabasili et al. (2014) found K-factors that ranged from 0.05 to 0.15 for soils from the Anambra basin, with the southeastern Nigeria. Antonino et al. (2018) also reported similar high K-factor values ranging from 0.0325 to 0.0338 Mg ha h ha^{-1} MJ^{-1} mm^{-1} for a subtropical ultisol in Brazil using both direct and analytical methods. The high K-factors obtained could be attributed to the low clay/silt ratio of the soil. The clay/silt ratio mainly serves as binding materials or agents and strengthens inter-molecular forces, which increases the cohesion of soil particles, and help in resisting the detachability of soil by erosion agents (Isikwe et al. 2012). Such K-factor resulted to high estimated soil losses which were significant across the various land use types (73-236 tons/ha/yr). Similar high estimated soil loss ranging from 19-185 tons/ha/yr was reported for soils of Owo and Akoko in Ondo state (Olumuyiwa 2019). Feiznia and Nosrati (2007) have also reported significant influence of land use on soil erodibility and soil loss in Iran. Borrelli et al. (2020) reported a decline in the estimated soil erosion rates or soil loss from cropland to the forest and other vegetation.

5.0 Conclusions

In conclusion, soil hydraulic properties as well as soil organic matter, soil erodibility indices including the erodibility K-factor and the predicted soil loss were significantly affected or influenced by land use types except the critical level of organic matter. The study found that the erodibility of the soils are high taking into consideration the erodibility indices, erodibility K-factor and the predicted soil loss. The implication is that high quantity of soils in the study area will be lost especially where there is no adequate vegetative cove. The study concluded that adequate land use and soil management practices, and good policies could help to improve the soil hydraulic properties, reduce soil erodibility and minimize soil loss at the study area.

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Determination of Saturated Hydraulic Conductivity Using Laboratory Method and Predicted Model of Some Farmlands in Yola South, North-Eastern Nigeria

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ABSTARCT
The study aimed to determine saturated hydraulic conductivity (K_{sat}) using laboratory method and predicted model of some farmlands in Yola South, North-eastern Nigeria. Two profile pits were dug in each of the three selected farmlands (Mbamba, Bole and Yolde pate) and representative soil samples were collected from three points in each of the location at depth of 0-15cm, 15-30 cm and 30-60 cm respectively. The K_{sat} value for each of the sample was measured in the laboratory using simplified permeameter method and predicted using Relative Effective Porosity Model (REPM). The results revealed that the soil texture at Mbamba and Bole areas were dominated with sandy loam and loam textured at Yolde-pate. In addition, the Bd, Pd, TP and AP were characterized as moderate to high ranges from 1.5-1.79 g/cm^3, 2.53-2.71 g/cm^3, 32.0-40.07 % and 19.99-32.32% respectively. The measured and predicted Ksat values shows a unit magnitude difference at Mbamaba (1.4 to 2.0 ×10^{-4} m/s and 1.1x 10^{-5} m/s to 8.1×10^{-6} m/s) and Bole arable lands (2.8×10^{-3}-5.7×10^{-5} m/s and 1.2×10^{-4} m/s to 6.4×10^{-6} m/s) while Yolde-pate shows irregular Ksat magnitude differences. It is concluded that the measured and the REPM model could not be used to determine K_{sat} for low porous soils (loamy, clay loam, clay) and could not fit for all locations in the study area.

Keywords: Farmlands, Laboratory, Predicted Model, Saturated hydraulic Conductivity, Yola South.

INTRODUCTION

Soil hydraulic conductivity is a measurement of its capacity to transmit water. It is used to define the rate that water moves through the soil pore system when it is saturated. Soil's water conductivity plays an important role in the effective use of water resources, as well. Saturated hydraulic conductivity (K_{sat})is a constant associated with the flow of a fluid through a saturated conducting medium (Oshunsanya, 2013). Saturated hydraulic conductivity of the surface soil is required for agronomic and water management purposes including design of irrigation systems.

Saturated hydraulic conductivity is the most critical soil hydraulic property of the soil matrix (Rawls *et al.,* 1998) and one of the most difficult hydraulic properties to obtain (Suleiman and Ritchie, 2001). It is a key parameter that is important for irrigation, drainage, water balance, modelling of water flow and chemical transport through the soil, and has been estimated from various soil properties by several researchers with success (Ihakur *et al.,* 2007). Different methods were used to determine the K_{sat} of soils which include direct and indirect methods. The direct measurement of soil hydraulic properties is expensive and time consuming, and indirect methods are increasingly used to predict soil hydraulic properties from easily measurable soil parameters such as soil texture and bulk density. Thus, the use of pedo-transfer functions is the most commonly used indirect method (Wosten *et al.*,2001). It could be derived from an empirical relationship established by Darcy's law which involves the rates of flow of water through saturated columns of soiland hydraulic head loss. It is influenced by soil texture and structure which in turn is influenced by total porosity and pore size distribution (Oshunsanya, 2013). In addition, Ankeny *et al.,* (1991) method was adopted for determining in situ hydraulic conductivity near saturation from steady state infiltration rates measured using a disc permeameter. Saturated hydraulic conductivity has also been estimated by Mbagwu (1995) from effective porosity using the generalized Kozeny-Carman equation.

Soils of arable lands in Yola South Local Government Area are seriously undergoing changes in their hydro- physical characteristics due to indiscriminate deforestation, intensive agricultural activities and overgrazing which eventually reduced their productivity (Sadiq *et al.,* 2019). Based on the preliminary survey conducted by the authors, crops are seriously affected in most of the farmlands in the area especially when dry-spell was observed. Thus, long term cultivation decreased hydraulic conductivity of soils indicating surface sealing, consequently influencing water infiltrationas reported by Cook *et al.* (1992). Therefore, there is need to determine the K_{sat} of some farmlands in the area for sustainable crop production. It is based on this background this present work aimed to determine saturated hydraulic conductivity using laboratory method and predicted model of some farmlands in Yola South, North-eastern Nigeria.

METHODOLOGY

Study Area

The study was conducted in Yola South Local Government Area of Adamawa State, Nigeria. The study area lies between Latitude 9˚14'Nof the Equator and Longitude 12˚28'Eof the Greenwich Meridian, having an average elevation of about 192 m (Adebayo 2020). The area falls within the Northern Guinea Savannah Zone and has a tropical wet and dry climate. The dry season commences in November and ends in April; while the wet season is from May to September (Adebayo, 2020). Mean annual rainfall is about 700 mm (Adebayo *et al.,* 2012). Yola South Local Government Area has a tropical type of climate marked by distinct dry and raining seasons (Adebayo, 2020; Zemba, 2010).

Soil Sampling Techniques

Three (3) farmlands were selected in the study area namely Mbamba, Yolde pate and Bole. Two profile pits were dug at each site where soil samples were collected from the identified horizons. In addition, at each site three (3) auger points were sampled from the month of November 2020 to March 2021 so that to cover the dry season period. Random sampling method was adopted at three (3) different depths of 0-15 cm, 15-30 cm and 30-60 cm depths of soils thereby amounting to samples for the selected three farmlands. Samples collected were transferred into polythene bags for the determination of $K_{sat.}$

Determination of some selected soil properties

The following were some of the important selected soil physical properties to be determined for the purpose of this study;

Particle size distribution

Particle size distribution was determined using Bouyocous Hydrometer Method (Bouyoucos, 1962). The texture of the soil was then determined using Marshal's textural triangle.

Bulk density

The soil bulk density was determined by collecting undisturbed sampled using soil core sampler, the collected samples were oven dried at 105 ^{0}C for hours to a constant weight. The volume of e soil core was determined from the internal radius and height and the height of the core. The weights of 100 cm^3 stainless steel cylinders (m0) and soil cores with fresh soil samples (m1) were recorded. The soil cores were placed in a large plastic container, and water was added to the plastic container until the water surface was just at the top of the soil cores. The soil cores were kept saturated for 24 h. After that, the soil core was placed on dry sand for 2 h at room temperature, and the resulting weight was recorded (m2). In that way, only the capillary water remained in the soil core. Then, the soil core was moved back onto the dry sands for 48 h, and the soil core (m3) was weighed. In the end, the soil cores were moved into the oven to dry at 105 °C until constant weight (m4). The BD (g/cm^3), was calculated as follows:BD = m4–m0/ 100 (Dumitru *et al.* 2009).

Total porosity

Total porositywas calculated according to the following formula (Dumitru *et al.* 2009):TP = 100 (1- Bd/Pd) where Bd is bulk density (g/cm^3) and Pd is particle density (g/cm^3).

Compaction rate

Soil compaction was appreciated depending on the values obtained for CR (%,), calculated according to the formula (Dumitru *et al.*, 2009): CR = [(MNP - TP)/MNP] 100, where MNP is minim necessary porosity, established on the basis of the following calculation: MNP = 45 + 0.163C (where C is the <0.002 mm clay content, %).

Determination of Saturated hydraulic conductivity (K_{sat} m/s)

The laboratory measured Ksat was conducted using simplified permeameter method as described by Diminescu *etal.*, (2019). Meanwhile, the predicted method was achieved using Relative Effective Porosity Model (REPM) described by Suleiman, and Ritchie, (2001).

Simplified Permeameter Method

The simplified permeameter method involved the use of plastic container tubeswith one end covered by a filter. The cylinder was placed in a water tank. The soil samples tested were 100 % saturated with water and left to compacted naturally to stimulate an underground environment. Then, a column of 17 cm of soil samples were added into the cylinder and compacted. The cylinder was then inserted into the container and the soil sample was filled with water from the bottom up, to remove the air. Next, water was carefully poured into the top of the cylinder, above the top reference mark. Water level decreases and the time needed to travel 50 mm, the distance highlighted on the cylinder by Star and Stop notations, was measured. The water temperature during the testing was 20 ^{o}C.

Relative Effective Porosity Model (REPM)

Relative Effective Porosity Model (REPM) proposed by Suleiman and Ritchie (2001) given as follows;

Ks= 75 (ᶲer)^2 (cm/d)**.**

Therefore**,** using the concept of relative effective porosity (ᶲer),

which is defined as = ᶲe / FC,

whereᶲer = relative effective porosity,

ᶲe = the total porosity,

FC = field capacity.

RESULTS AND DISCUSSIONS

Saturated Hydraulic Conductivity (K_{sat}) of the Laboratory method and Predicted model (m/s) of the Studied Soil Profile

Mbamba Farm Location

The profile pit 1 at Mbamba farm location described three distinct pedons (Ap, Bw1 and Bw2) where at horizons Ap(0-20 cm) and Bw2 (70-160 cm) depths shows that the measured K_{sat} was lower than the predicted K_{sat} by two orders ofmagnitude with the corresponding values of 1.0×10^{-4} m/s and 3.5×10^{-6}, and 1.5×10^{-5} m/s and 2.3×10^{-7} m/s respectivelyas depicted on table (23). These trends might be attributed to the homogeneity of the textural class of loamy sand at the two horizons (Ap and Bw2) coupled with the influence of low porosity and low aeration percentage than the middle horizon (Bw1) 20-70 cm depth which was dominated by sand. Conversely, at horizon Bw1depth the Ksat shows the same order of magnitude with the laboratory measured value of 4.0 x 10^{-5} m/s and 1.1×10^{-5} m/s predicted value (REPM). This might be linked to the sandy texture of the soil class with low bulk density of 1.50 g/cm^3, high porosity (47 %) as shown on table 1. However, it has been reported by Suleiman and Ritchie, (2013) that model prediction of K_{sat} revealed similar order of magnitude when compared with the laboratory test values on sandy soils considering the REMP as good for K_{sat} predictions. They also concluded that these results suggest that new model gives reasonable estimates of K_{sat} for different soils. However, sandy soils were known to have high hydraulic conductivity than the loamy sand, clay loam or clay soils. Thus, it relatively gives nearer values for both laboratory and predicted (REPM) methods.

One would ordinarily assume that decrease in soil permeability with depth is as a result of decreasing porosity resulting from greater packing density of soil particles. These findings are in conformity with that of Mamadou (1977), who stated that the hydraulic conductivity of a tillman-hollister soil decrease with depth having Ksat values of 1.4 x 10^{-5} m/s at 20-30 cm 3.2×10^{-5}m/s at 40-50 cm and 9.6×10^{-6} m/s 120-130 cm depth. When a soil shows a distinct layering, it is often found that the representative K-values of the layers may differ. Generally, the more clayey layers have a lower K-value than the sandier layers, but this is not always true (Oosterbaan and Nijland, 1994). However, the experimental results of Childs and Bybordi, (1969) refute this supposition.It would be argued that this variation might be influenced by the structural and porosity dispositions of the soil at the upper horizon as influenced by either agronomic factorsuchastillage practices within the plow layer which enhances porosity and eventually affects the soil permeability. It is generally accepted that such management practices modify the soil structure and pore size distribution (PSD). In effects, the saturated and near-saturated soil hydraulic properties are very sensitive to these management-induced changes (Ahuja *et al.*, 2006).

Similarly, in 0-17 cm depth (Aphorizon) of the profile (2) of Mbamba arable soils both the measured and predicted K_{sat} values shows similar order of magnitude with both the methods having the K_{sat} value of 5.6×10^{-5} m/s and 3.1×10^{-5} m/s predicted value accordingly. In contrast, the horizon AB (17- 55 cm) of the soil profile revealed to have difference of three orders of magnitude between the measured and the predicted K_{sat} with the corresponding values of 1.8×10^{-5} m/s and 7.0×10^{-8} m/s, (table 1) respectively. The high variation obtained with thepredicted method of low K_{sat}could be connected to the very low aeration percentage (3.96 %) with an extremely high compaction rate (> 19 %) which might be cause by intensive tillage practices and overgrazing on the arable lands making the soils loose adequate porosity and highly compacted thereby reducing the permeability capacity. Osman (2013) reported that tillage operations could stimulate soil compaction and then destroy soil structure, increase BD, reduce soil porosity, and limit movement of water and air within the soil. In agricultural practice, the applied force is related to soil water potential which is dependenton the size and shape of particles, the compactness of structures and some other factors (Eruola *et al.,* 2019).

In addition, pedon Bw (55-164 cm) which is characterized with loamy sand texturedsoil, shows a relative decline in the trend with one order magnitude difference which exist between the measured (3.0×10^{-5} m/s) and predicted (6.7×10^{-6} m/s) K_{sat} values with predicted method having the higher order magnitude than the measured K_{sat} value (table 1). Nevertheless, all the three (3) pedons (Ap, AB and Bw)were found to have similar order magnitude of 10^{-5} m/s using laboratory method while the REPM method shows relative variations of an order magnitude. It has been noted that the predictive model methods usually provide higher K_{sat} values than the laboratory values. Similar findings were reported by Hyoun-Tae*et al.* (2017) who concluded that empirical methods produced the highest relative variation in the estimation results of hydraulic conductivity. However, Ahuja *et al.*, (1984) explained that models did not give good estimates of the saturated hydraulic conductivity when applied to soils different from a homogenous granular medium.

4.8.2 Bole Farm Location

The results of hydraulic conductivity for both the laboratory measured and predicted using (REPM) model methods were also portrayed on table 1. Pit 1 showdistinctive four (4) horizon which ranges from 0-164 cm depth. At horizon Ap(0-25 cm),AB (25-70 cm) and Bw1(70-140 cm), K_{sat} values of measured and predicted (REPM) methods were found to have two order magnitude differences with the REPMK_{sat}values higher (10^{-7} m/s) than the measured values (10^{-5} m/s) with soil texture ranges from loamy sand to sandy loam. Lee et *al.*(1985) make it clearly by saying that the measured K_{sat}values ranged over an order of magnitude on the sand, one to two orders of magnitude on the loams, and three orders of magnitude on the clay. In contrast, in the horizon

Bw2(140-164 cm depth) a very wider variation was found between the two methods of K_{sat} determination employed in this research work, with four (4) orders magnitude of predicted (REPM) method higher than the laboratory measured method with corresponding values of 1.0×10^{-8} m/s and 1.7×10^{-4} m/s. The irregularity was observed with the laboratory method at horizon Bw2 (140-164 cm) which shows relatively high permeability of K_{sat} (1.7×10^{-4} m/s) than the upper horizons above it, despite the fact that the horizon (140-164 cm) possessed highest rate of compaction (65.97 %), very low aeration percentage (-3. 49 %) coupled with lowest total porosity. Furthermore, in profile (2) three different horizons were identified (Ap, Bw1 and Bw2). The result (table 1) revealed that the laboratory measured K_{sat} values were low which signifies high permeability of water compared with the predictive values with one order magnitude at pedon Ap and Bw1(0-23 cm and 23-80 cm) with a corresponding measured values of 4.0×10^{-5} m/s and 5.5×10^{-5} m/s, and 6.3×10^{-6} m/s and 3.1×10^{-6} m/s predicted K_{sat} values respectively. The laboratory method of K_{sat} values of sand and sandy loam soils obtained is buttressed apparently with the measured laboratory K_{sat} values found by Eruola,*et al.*(2019), with arable soilsof Federal University of Agriculture Abeokuta (FUNAAB)having permeability coefficient ranges from 2.7×10^{-5} to 4.2×10^{-5}m/s, of sandy-loam and loamy sand textures.

Conversely, in pedon Bw2(80-164 cm depth) of the profile 2 of Bole arable soils it was found that two order magnitude variation exist between the measured and the predicted saturated hydraulic conductivity. This increase of variation of order of magnitude between the methods should be clearly viewed and relate to the soil properties. However, the texture shows a relative homogeneity of sand to sandy loam within the horizons, but notwithstanding other driving properties explained apparently an increase of Ksat using prediction method with an order magnitude where presence of lowest total porosity (30.76%), very low aeration percentage (8.32 %), high bulk density (1.8 g/cm^3) and strongly compacted (31.64) leading to decrease in permeability of water as positively and linearly predicted by REPM(1.0×10^{-7} m/s) unlike the measured K_{sat} which decline with one order magnitude (1.7×10^{-4} m/s) signifying the increase in permeability of the soil despite the existing soil properties. Thus, K_{sat} significantly decreased with increasing soil BD (Liu*et al.*, 2019). On the other hand, it could be intensively argued that soil texture plays a pivotal role towards influencing the rate of soil permeability using field, laboratory or predictive models. Smedema and Rycroft (1983) warn that soils with identical texture may have quite different K-values due to differences in structure. In relation to the findings of this research, it could be concluded that REPM gives an overestimate of K_{sat} values which is in conformity with the statuses of the soil properties (TP, Bd, CR and AP), likewise the laboratory measured method provides K_{sat} values within the range of the soil texture (sand to sandy loam) within the horizons of the profile as observed in the area.

Conclusively, the results of K_{sat} obtained from this study were compared and in conformity with Bear's values (1972) which gave hydraulic conductivity of fine sand and loam in the range of 10^{-3} to 10^{-5}, thus making them semi pervious in nature and varying from very fine sand to silt, loess and loam. The figure 1 below shows the range of values of hydraulic conductivity for various geological materials. Values are for typical fresh groundwater conditions using standard values of viscosity and specific gravity for water at 20°C and 1 atm.

K (cm/s)	10^2	10^1	10^0=1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (ft/day)	10^5	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							

Source: Modified from Bear, (1972)

Figure 1: The saturated hydraulic conductivity (K) values found in nature

Yolde Pate Farm Location

Two profile pits were dug in the area where the first profile shows four (4) discrete horizons(Ap,AB, Bw1and Bw2)ranges from 0-174 cm depth (table 1). The results on the measured and predicted (REPM) K_{sat} values were also depicted on table 1.The findings revealed that one order magnitude difference exist between the two adopted method of K_{sat} determination in the horizon Ap(0-30 cm), AB(30-70 cm) and Bw2(116-174 cm) with the following corresponding values of 2.7×10^{-5} m/s, 2.0×10^{-5} m/s and 1.7×10^{-5} m/s of measured K_{sat}, while the predicted K_{sat} were 1.6×10^{-6} m/s, 5.5×10^{-6} m/s, and 4.7×10^{-6} m/s, respectively. In contrast, at horizonBw1(70-116 cm) predicted (REPM) method shows an overestimated Ksat value of three (3) order magnitudes (7.5×10^{-8}m/s) over the laboratory measured method (1.8×10^{-5} m/s). This abrupt variation of order magnitude attained by the REPM is directly connected to the strongly compacted rate of the soil (40.44 %), with extreme poor aeration (-4.67 %) and low total porosity (26.8 %) due to high bulk density (1.7 g/cm^3) than the other existing horizons with the profile. Even though, the measured K_{sat} value was in conformity with the result of Bears (1972) and validated using the soil texture uniformity of sandy loam (figure 1) respectively. In addition, measured K_{sat} shows uniformity of 10^{-5} order of magnitude within all the horizons indicating the semi permeability of the soil materials within the profiles.

Profile 2 of Yolde pate soils expressed difference of one order magnitude in all the three (3) divergent pedons(Ap, B and Bw)with predicted K_{sat} higher than the measured Ksat with the recorded values of 2.5×10^{-6} m/s, 8.7×10^{-6} m/s and 1.2×10^{-6} m/s of REPM method, while 3.8×10^{-5}m/s, 1.8×10^{-5} m/s and 5.0×10^{-5} m/s of laboratory method correspondingly. This uniformity of order magnitude in both the methods might be attributed to the homogeneously defined properties of the soils with little and /or insignificant different which has less effects on the saturated hydraulic conductivity variations.

Table 1. Measured and predicted K_{sat} of the studied profiles as influenced by some soil properties in the selected farmlands

Location	Pedon	Depth (cm)	Textural class	Bd (g/cm^3)	Pd (g/cm^3)	TP (%)	CR (%)	FC (%)	Relative effective porosity (ϕer),	Measured K_{sat} (m/s)	Predicted K_{sat} (m/s)
	Ap	0-20	LS	1.92	2.35	18.90	59.35	11.11	1.70	1.0×10^{-4}	3.5×10^{-6}
MBAMBA 1	Bw1	20-70	S	1.50	2.85	47.36	-5.24	22.00	2.15	4.0×10^{-5}	1.1×10^{-5}
	Bw2	70-160	LS	1.60	2.22	27.92	37.95	24.00	1.16	1.5×10^{-5}	2.3×10^{-7}
	Ap	0-17	SL	1.66	2.35	29.36	34.75	10.10	2.90	5.6×10^{-5}	3.1×10^{-5}
MBAMBA2	AB	17-55	SL	1.53	2.35	34.89	22.46	32.03	1.08	1.8×10^{-5}	7.0×10^{-5}
	Bw	55-164	LS	1.60	2.66	39.84	11.46	21.21	1.87	3.0×10^{-5}	6.7×10^{-6}
	Ap	0-25	LS	1.80	2.85	36.84	18.13	28.00	1.31	1.7×10^{-5}	8.1×10^{-7}
	AB	25-70	LS	1.80	2.50	28.00	37.77	32.35	0.86	1.7×10^{-5}	1.1×10^{-7}
BOLE 1	Bw1	70-140	SL	1.40	2.35	40.42	10.22	33.33	1.21	5.5×10^{-5}	3.4×10^{-7}
	Bw2	140-164	LS	1.88	2.22	15.31	65.97	17.17	0.89	1.7×10^{-4}	1.0×10^{-8}
	Ap	0-23	S	1.60	2.66	39.84	11.46	21.42	0.53	4.0×10^{-5}	6.3×10^{-6}
BOLE 2	Bw1	23-80	SL	1.63	2.66	38.72	13.95	24.24	1.59	5.5×10^{-5}	3.1×10^{-6}
	Bw2	80-164	SL	1.80	2.60	30.76	31.64	26.26	1.17	1.7×10^{-5}	2.3×10^{-7}
	Ap	0-30	S	1.60	2.85	43.85	2.55	30.47	1.43	2.7×10^{-5}	1.6×10^{-6}
	B	30-70	L	1.63	2.85	42.80	4.88	23.76	1.80	2.0×10^{-5}	5.5×10^{-6}
YOLDE	Bw1	70-116	SL	1.72	2.35	26.8	40.44	29.52	0.90	1.8×10^{-5}	7.5×10^{-8}

PATE 1											
	Bw2	116-174	LS	1.56	2.85	45.26	-0.57	26.00	1.74	1.7×10^{-5}	4.7×10^{-6}
	Ap	0-23	LS	1.80	2.66	32.33	28.15	21.00	1.53	3.8×10^{-5}	2.5×10^{-6}
YOLDE PATE 2	B	23-55	SL	1.42	2.66	46.6	-3.55	23.23	2.00	1.8×10^{-5}	8.7×10^{-6}
	Bw	55-165	SL	1.60	2.85	43.85	2.55	31.62	1.38	5.0×10^{-5}	1.2×10^{-6}

Measured and Predicted Saturated Hydraulic Conductivity (m/s) of the collected Soil Samples

Bole Farmlands

The results of hydraulic conductivity obtained for Bole arable soils were depicted on table 2. The results show that for all the three replicated samples there was a consistent difference of one order magnitude between the predicted and measured hydraulic conductivity. For the first replication high $K_{sat}$was obtained at 15-30 cm depth with a measured value of $2.8×10^{-3}$ m/s while the predicted (REPM) value of $1.2×10^{-4}$ m/s. This might be enhanced by the bulk density (1.65 g /cm^3) of the soil due to the intensive tillage practices which gives rise to moderate porosity that permits the relatively high free flow of water through the soil medium as was also observed by Moret and Arrúe, (2007).In addition, at the depth of 0-15 cm medium $K_{sat}$was measured to be $2.8×10^{-4}$ m/s with a predicted (REPM) value of $8.7×10^{-5}$ m/s respectively. At 30-60 cm depth the predicted (REPM) method increases with one order magnitude than the laboratory measured K_{sat} values of 6.5 x 10^{-6} m/s and 5.7 x 10^{-5} m/s correspondingly, signifying the low permeability of water compared with the other horizons which might be attributed to the clay loam texture with extremely low draining capacity (-1.02 %). However, it was observed that there was a relative decrease in saturated hydraulic conductivity with an increasing depth in all the soil depths at point A of Bole soils as influenced by the relative uniformity of the soil texture. At point B, the measured K_{sat} shows low conductivity in all the soil depths with measured valuevaries from $1.6×10^{-5}$ m/s to $5.5×10^{-5}$ m/s while the predicted K_{sat} was consistently higher with one order of magnitude having an estimated valueranges from 3.3 $×10^{-6}$ m/s to $6.4×10^{-6}$ m/s respectively. Generally, it was revealed that there was consistent similar difference of one order of magnitude at point B for both the measured (10^{-5} m/s) and REMP method (10^{-6} m/s) respectively. Similar finding was reported that the estimated K_{sat} values for all the samples using REMP method were within an order of magnitude (Hyoun-Tae*et al.,* 2017).

Conversely, at point C, the K_{sat} was found to have similar order of magnitude for both methods at 0-15 cm and 30-60 cm soil depths with a corresponding laboratory measured values of $3.9×10^{-5}$ m/s and 5.6 x10^{-5} m/s and $5.6×10^{-5}$ m/s and $1.5×10^{-5}$ m/s using predicted method respectively. In contrast, at 15-30 cm shows a magnitude difference of one order ($1.0×10^{-5}$ m/s REMP method) compared with the measured value ($1.7×10^{-4}$ m/s) as presented on table 4. However, Hyoun-Tae*et al.,* (2017) drew a conclusion that disagreed with this result outcome;they noted that estimates from the REPM method were consistently lower than those obtained from the other methods.

Mbamba Farmlands

The values for saturated hydraulic conductivity obtained for Mbamba arable soils were depicted on table 2. The K_{sat} result shows that at point A, there were consistently lower values using laboratory measured method in all the three depths (0-15cm, 15-30cm and 30-60 cm) with corresponding values of $1.5×10^{-4}$ m/s, $1.7×10^{-4}$ m/s and $2.0×10^{-4}$ m/s respectively. However, the values increased with one order of magnitude at 0-15 cm (1.1 $×10^{-5}$ m/s) and 15-30 cm ($4.0×10^{-5}$ m/s) using predictive (REPM) method which signifies the relative increase in K_{sat} using the predictive (REPM) method within the soil horizons. Thus, Hyoun-Tae, *et al.,* (2017) showed that the empirical methods overestimated the saturated hydraulic conductivities when compared to those derived from the measured or tracer test analyses. In opposite narration, Cheng and Chen (2007) reported that the saturated hydraulic conductivities obtained from the empirical methods were relatively lower than those estimated by laboratory pumping test method. In addition, it could be observed that the K_{sat} values increases with an increasing depth in all the horizons using both the laboratory measured and REPM methods. Conversely, at 30-60 cm depth shows two orders of magnitude differences with an overestimated predicted method (REPM) Ksat value of 4.1×10^{-6} m/s than the measured K_{sat} value of 2.0×10^{-4}). At Point B of Mbamba soils the predicted values of K_{sat} was higher than the measured Ksat values with one order magnitude unit at 0-15 cm and 15-30 cm depths with predicted K_{sat} values of 1.5×10^{-5} m/s and 1.7×10^{-4} m/s and 1.8×10^{-6} m/s and 5.6×10^{-5} m/s values. In contrast, at 30-60 cm depth both the methods were found with the same order of magnitude of 2.8×10^{-5} m/s and 6.7×10^{-5} m/s K_{sat} values. Similar conclusion was drawn by Hyoun-Tae, *et al.*, (2017) stated that the REPM method provided relatively similar estimates compared to the measured method because the differences analyses were less than one order of magnitude except for the medium sand.Conversely, at point C the soil depth 0-15 cm and 15-30 cm shows low K_{sat} values with similar magnitude of 10^{-5} m/s of both the methods as shown table 2 while variation of two orders magnitude was found between the measured and predicted methods at 30-60 cm depth with the K_{sat} values of 1.4×10^{-4} m/s and 8.1×10^{-6} m/s.

Yolde Pate Farmlands

The hydraulic conductivity values for Yolde pate arable soils were presented on table 2. The result shows distinct variations of K_{sat} values between the measured and predicted methods. At 0-15 cm depth of point A, the measured K_{sat} value was found to be 1.0×10^{-4} m/s while the predicted K_{sat} value which shows very low conductivity of 6.8×10^{-6} m/s with two orders magnitude variation. In this finding measured K_{sat} was found to give a closed value in relation to soil texture of sandy loam (10^{-4}) to that of Bear's values (1972) having semi porous permeability. Likewise, the present study result concords and was validated with permeability and drainage characteristics of soils as adopted after Terzaghi *et al.*(1996) describing the soil with good drainage sands ranges from 10^{-1} to 10^{-6} m/s as depicted in figure 2 below.

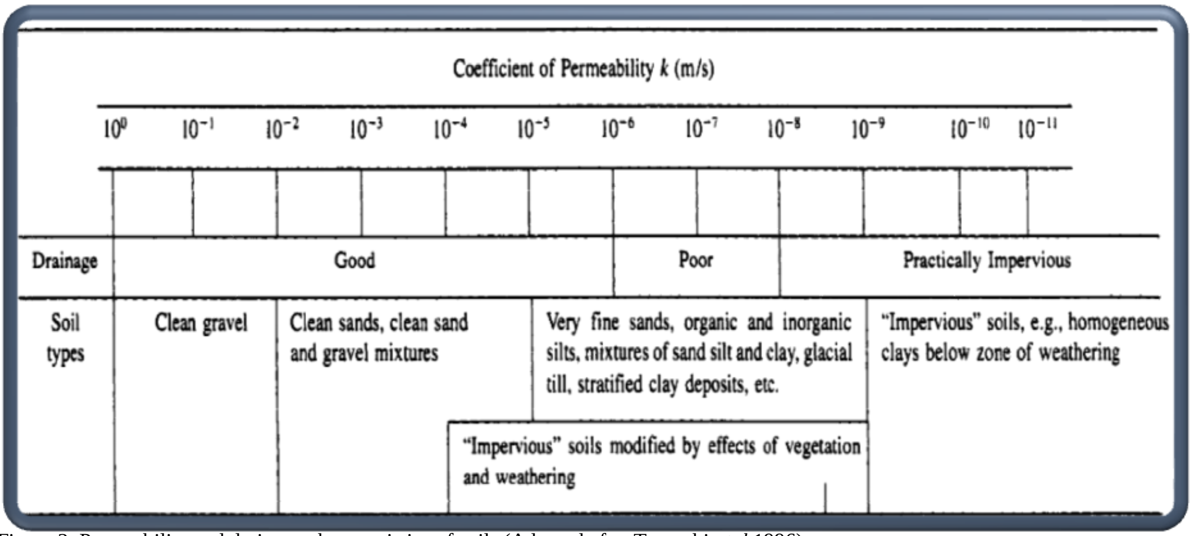

Figure 2. Permeability and drainage characteristics of soils (Adopted after Terzaghi *etal.*1996).

Moreover, the trend also progressed at 15-30 cm depth with four order magnitudes variation between the measured K_{sat} of 3.8×10^{-5} m/s and predicted Ksat of 3.7×10^{-9} m/s respectively. This result shows low permeability level of K_{sat} which is directly linked to the loam texture of the floodplains soils of Yolde pate with bended stable soil aggregates, low bulk density (1.9 g/cm^3) that gives rise to low total porosity (24.0 %) making the soil strongly compacted rate (46.66 %) as shown on table 2which enhanced extremely low draining capacity and eventually retardates the flow of water through the soil horizons. This finding was validated by Bear (1972) K_{sat} values and Terzaghi *et al.* (1996), defined as practically less or impermeable. Thus, REPM predicted method gives a nearer estimate (10^{-9} m/s) than the laboratory measured values (10^{-5} m/s). Similarly, Smedema and Rycroft (1983) identified K_{sat} values of loam, clay loam and clay ranges from 6.0×10^{-9} m/s to 2.4×10^{-8} m/s and very fine sandy loam ranges from $2.4\times10^{-9}$to 6.0×10^{-9} m/s which wasalso concords with the K_{sat} values identified in the study area.

One order magnitude variation exists at 30-60 cm depth where measured K_{sat} value was obtained to be 1.8×10^{-5} m/s while the predicted K_{sat} was estimated to have 3.7×10^{-6} m/s (table 2). This trend of high K_{sat} conductivity with the Yolde pate soils at point A, one could have linked to illuvial depositions of soil textural materials ranges from clay loam-silt loam–clay with double layer of sedimentation. At point B of the Yolde pate arable lands variations of K_{sat} values were obtained with one order magnitude difference of both the measured (10^{-4} m/s) and predicted methods (10^{-5} m/s) at 0-15 cm and 30-60 cm depth as described on table 2. In contrast, at 15-30 cm depth, both methods show similar K_{sat} values of 10^{-4} m/s which signifies high porous flow of water through the soil medium within the depth of 15-30 cm. Laboratory method was found to give similar consistent order of magnitude in all the soil depths as presented in table 2. In this study it has been noted that laboratory measured K_{sat} gives results within the order magnitude of 10^{-3} m/s to 10^{-5}m/s as was validated by Bear' values which described significant effectiveness of the method as predicated by the textural class. Similarly, at point C,K_{sat} value shows one order magnitude variation of both the measured (10^{-5} m/s) and predicted methods (10^{-6})m/s at 0-15 cm and 30-60 cm depths while at 15-30 cm depth two orders of difference of magnitude was obtained with measured K_{sat} value of 1.9×10^{-5} m/s considered lower than the predicted K_{sat} value of 2.6×10^{-7} m/s characterized as impermeable or very low conductivity influenced by silt loam soils having 1.85 g/cm3 bulk density, strongly compacted soil with about 42.22 % rate, low porosity (26 %), with extremely low draining capacity of -17.62 % and underlying clay textured soils above the upper horizons due to alluvial depositions due to the tillage operations respectively.

Table 2. Measured and predictedsaturated hydraulic conductivity (Ksat m/s) of the selected soil samples at the three (3) location

			Yolde Pate Farm Location		**Bole Farm Location**		**Mbamba Farm Location**	
Points	Samples	Depth (cm)	Measured K_{sat} (m/s)	Estimated K_{sat}(m/s)	Measured K_{sat} (m/s)	Estimated K_{sat} (m/s)	Measured K_{sa} (m/s)	Estimated K_{sa}(m/s)
	1	0-15	1.0×10^{-4}	6.8×10^{-6}	2.8×10^{-4}	8.7×10^{-5}	1.5×10^{-4}	1.1×10^{-5}
Point A	2	15-30	3.8×10^{-5}	3.7×10^{-9}	2.8×10^{-3}	1.2×10^{-4}	1.7×10^{-4}	4.0×10^{-5}
	3	30-60	1.8×10^{-5}	3.7×10^{-6}	5.7×10^{-5}	6.5×10^{-6}	2.0×10^{-4}	4.1×10^{-6}
	1	0-15	1.4×10^{-4}	7.2×10^{-5}	1.6×10^{-5}	6.4×10^{-6}	1.7×10^{-4}	1.5×10^{-5}
Point B	2	15-30	1.0×10^{-4}	1.2×10^{-4}	2.6×10^{-5}	3.3×10^{-6}	5.6×10^{-5}	1.8×10^{-6}
	3	30-60	1.5×10^{-4}	1.3×10^{-5}	5.5×10^{-5}	5.5×10^{-6}	2.8×10^{-5}	6.7×10^{-5}
	1	0-15	2.0×10^{-5}	1.2×10^{-6}	3.9×10^{-5}	1.1×10^{-5}	5.6×10^{-5}	2.9×10^{-5}
Point C	2	15-30	1.9×10^{-5}	2.6×10^{-7}	1.7×10^{-4}	1.0×10^{-5}	5.4×10^{-5}	4.8×10^{-5}
	3	30-60	1.5×10^{-5}	6.5×10^{-6}	5.6×10^{-5}	1.5×10^{-5}	1.4×10^{-4}	8.1×10^{-6}

CONCLUSION AND RECOMMENDATIONS

The results revealed that the measured K_{sat} (m/s) shows uniform order magnitude of a unit difference while the predicted model revealed irregular variations of order magnitude which could be a result of the presence of finer particles of the soil textural class of some farmlands in the area. Therefore, it could be concluded thatboth the laboratory and predicted model methods used in this study can be suitable on medium to high coarse textured soils (sandy loam, loamy sand) than on the finer textured soils (loamy, clay-loam and clay) respectively, and cannot be adopted efficiently and effectively in all the locationsof the study area. However, their applicationon medium to high porous soils are highly imperative in assessing the K_{sat} values as revealed in this study for further decision making. It is recommended therefore, farmers at Bole and Mbamba farmlands should therefore integrate the use of organic materials (such as green manure, animal dung, residues incorporation etc) that helps to retain sufficient moisture within the soil horizon with the aim of improving the soil permeability and moisture characteristics of the soils. The use of REPM should be adopted on the soils (sandy loam-loamy sand) of area in order to revalidate the outcome of the other methods (field and laboratory) as it gives reasonable estimate of K_{sat} values.

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Bulk Density and pH as Soil Quality Indices in the Coastal Plains Sand, Imo State, Nigeria

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ABSTRACT

Demographic pressure that has resulted in land fragmentation makes assessment of soil quality in the many agricultural fields of the coastal plains sand of Imo State, Nigeria, complicated and costly. As a measure to reduce cost, the soils of the location were evaluated on the bases of Bulk density and pH. This was done using 20 profiles spread along the entire location. Samples were taken from specific depths, 0-25cm, 25-50cm, 50-75cm, 75-100cm, of freshly dug pits within fallow fields. The soil bulk densities and pH values were determined in the laboratory using standard procedures. Data got were evaluated based on critical values of soil bulk densities not exceeding 1.6 g/cm^3 within 50cm, and 1.8 g/cm^3 within 100cm of soil surface; pH not exceeding the bounds (3.0) 3.5-8.5 (9.0) within 150cm of soil surface. Starting with the topmost layer, the average BD for the depths were 1.28 g/cm^3, 1.43 g/cm^3, 1.49 g/cm^3, 1.48 g/cm^3; while for the pH they were 4.95, 5.10, 5.07, 5.01, respectively. At the topsoil, the range of values for BD was 0.90-1.60 g/cm^3, that being equivalent to a Coefficient of Variation (CV) of 15.75%, while for pH it was 4.0-5.9, which was equivalent to a CV of 11.09%. Critical levels were got within the floodplains indicating some level of degradation. Data were influenced by soil depth. There was low and insignificant (at 5%) correlation of the two parameters at all the depths. None of the parameters should be taken in isolation of the other. The usual short fallows in the location need augmentation by management to balance soil quality and that should aim at a pH greater than 5.5 and a BD less than 1.5 g/cm^3. So, to minimize cost, the simple tests adopted in this study are recommended for soil quality assessment.

Keywords: Soil Quality, Bulk density, pH, Coastal plains sand.

Introduction

Sustainability of land management systems is achieved by determining and ensuring soil quality. Calleja-Cervantes et al. (2015) were of the opinion that the identification of soil properties that control soil quality indicators is considered vital to plan appropriate soil management practices. However, there is no single widely accepted index of soil quality due to the complex relationship between soils and bio-productivity (Doran, 1996). Soil quality is noted to be influenced by climate, soil type, vegetation type, moisture regime, soil structure, soil texture, soil chemistry, soil ecology and land management (Boone, 1986). It is in recognition of this fact that it is recommended that evaluation of soil quality should incorporate spatial and temporal variation of functions which should be done in relation to environment and land use (Idowu, 2003; Ogunkunle, 2015; Young, 1998). Considering the foregoing, soil quality indicators include soil texture, soil structure, bulk density, saturated hydraulic conductivity, soil organic carbon, soil pH, total nitrogen, available phosphorus, exchangeable cations, cation exchange capacity, heavy metals (Fe, Mn, Zn, Cu), microbial biomass and activity, CO_2 fluxes etc. (Adaikwu and Ali, 2013; Filip, 1998; Okolo et al; 2020; Rodrigo-Comino et al, 2019).

The intense cultivation of soils of the Coastal plains sand, Imo State Nigeria, due to high population density that results in short fallow periods and differing management practices over short distances due to land fragmentation, makes tests to determine soil quality complex and difficult to carry out by farmers most of who are resource poor. This is further compounded and confounded by climate change which is noted to affect soil properties (Amalu and Isong, 2017; Brevik, 2013; Okon et al., 2019). The situation thus requires simple, easily measured, affordable tests, even if for purposes of preliminary evaluation. Oluwatosin et al. (2006) opined that where land evaluation studies are lacking, as noted by Ukaegbu, et al. (2022) of the location of study, assessment of soil quality using minimum data set becomes handy for land use planning. Haigh (1998) suggested the use of Bulk density and pH to ensure soil quality standards for successfully reclaimed surface coal-minded lands. Reason being that both indices is easily measured. While Bulk density captures soil architecture, pH reflects soil reactions affecting processes in soils.

Study thus evaluated qualities of soils under fallow at different sites of location of study using Bulk density and pH. How soil depth influenced the values of the parameters was also recorded. The variation of parameters in the location with soil depth is lacking in literature. Study shows impact of fallow on soils' properties and a general overview of the soils qualities.

Materials and Methods

Location. Study area is the Coastal plains sand, Imo State, Southeast Nigeria. It is within Lat. $5^0 15^|$N and $5^0 45^|$N; Long. $7^0 30^|$E and $6^0 45^|$E. The location is within the humid tropics, having total annual rainfall of 2250mm-2500mm, that is bimodal having a break in August. The mean annual temperature is 27-28^{0}C (80-82^{0}F). The area is in the lowland rainforest region dominated by oil palms (*Elaeis guineensis*) and Hyparrhenia grass species. Dominant geology is the coastal plains sand. The location covering a land area of about 3,401.29km^2 (340,129ha) has an average population density of 1,206 persons per square kilometer.

Field Study. Using free survey technique 20 profiles were sited within study location, being guided mainly by physiography and to a less extent the development of the vegetation. In terms of physiography, sampling covered – Depressions/valleys, slopes (mid and foot), plains (Coastal and Deltaic). Within the physiographic units, sites with well-established shrubs (estimated to be over 10 years fallow) were looked out for and sampled in some cases. In a few of such cases, length of fallow was ascertained by land owners who were identified.

Altitudes and slope angles on profile sites were got using a hand held GPS device and the Abeny level respectively. With the core sampler a pair of soil samples was taken from specific depths of freshly dug pits thus; 0-25cm, 25-50cm, 50-75cm, 75-100cm. Due to wetness some of the sites could not be sampled at 75-100cm depth. Average values for each depth was got and taken to the laboratory. Sampling was during the rainy season.

Table 1 gives details of descriptions of sites sampled. Table shows altitudes of sites to vary from 18m to 124m above sea level, while slope angles ranged from 0.5% to 9%. Sampling thus included both well drained and poorly drained soils. Classes of the poorly drained soils as shown by same table were – Fluvaquentic Eutrudepts, Fluvaquentic Dystrudepts, Arenic Eutrudepts (ST), while their FAO equivalents were Arenic Gleysols, Gleyic Fluvisol, Gleyic Acrisol. The main classes for the well-drained soils were – Typic Paleudult and Typic Kandiudult (ST), while their FAO equivalent was mainly Haplic Acrisol.

Table 2 gives in more detail land uses at sites sampled. It shows land uses to be mainly fallow arable fields with tree crops in some cases.

Laboratory Analyses. With the core samples, Bulk density was determined by the core method of Black (1965). Part of the core sample was used in determining soil pH, by a glass electrode pH meter in a soil-to-water ratio of 1:2.5.

Statistical Analyses. Variations of the data for each depth sampled over the entire location were expressed in terms of coefficient of variation (C.V.%) given by

$$\frac{\text{Standard deviatioin}}{\text{Mean}} \times 100$$

The C.V.s were rated on the basis of the scale of Wilding et al. (1994): C.V. (%) ≤15%, low; C.V. (%) >15 to ≤35%, moderate; C.V. (%) >35%, high.

Relationships of data for the two parameters at each of the depths sampled were determined using Pearson's Product Moment Correlation Model at 5% significance level.

Evaluation Procedure. Data were directly rated based on the rating recommended by Haigh (1998) thus: Land should have soil bulk densities not exceeding 1.6g/cm^3 within 50cm, and 1.8g/cm^3 within 100cm of the soil surface and a soil pH not exceeding the bounds of pH (3.0) 3.5-8.5 (9.0) within 150cm of the soil surface. These standards were however supported with related studies in the area of study.

Results and Discussion

Soil bulk density is noted as the best single indicator of soil quality as it is easily measured. It reflects soil architecture and of course the physical conditions of soils. Table 3 presents the bulk densities of soils of location of study. The table shows that the lowest value of 0.90 g/cm^3 was got at the topsoil (0-25cm) of profile 12, while the highest value of 1.83 g/cm^3 was got at the depth 25-50cm of profile 2. The average values of the bulk densities for the various depths starting with the topmost were, 1.28 g/cm^3, 1.43 g/cm^3, 1.49 g/cm^3, 1.48 g/cm^3 respectively. This shows the bulk densities to increase with depth. The same table shows the bulk densities for the entire location to vary most at the topsoil (0-25cm) with a coefficient of variation (C.V.) of 15.75%, while varying least at depth 50-75cm with a CV. of 7.35%.

The bulk density values got agree with Savalia et al. (2009) who noted bulk densities to typically range from less than 1 g/cm^3 to nearly 2 g/cm^3. The results of the study also agree with other similar studies in the area. Ogban and Ekerette (2001) recorded B.D. values of 1.27 g/cm^3 to 1.42 g/cm^3 at the topsoil, which increased to 1.6 g/cm^3 at the subsoil, in their study of soils of coastal plains sand, southeastern Nigeria. Osujieke et al. (2018) recorded comparable figures in their study of soils of Izombe which is in the zone of sub recent alluvium. The figures ranged from 1.14 g/cm^3 to 1.59 g/cm^3 at the topsoil which increased to 1.79 g/cm^3 at the subsoil. The high bulk densities of the soils are attributable to the dominance of sand fraction in the soils. According to Kolay (2000) dry soils of finer texture have more spaces filled with air and have lower B.D. than sandy soils as the particles of the later lie close to each other. Corroborating this fact, Ogban and Ekerette (2001) found a high significant positive correlation between sand fraction and bulk density in their study. They further noted in the same study that 99.3% variation in bulk density was explained by variation in the sand fraction of the soils. Explaining further they noted that the sand particles lay in close contact as bridging materials such as OM were low in the soils. The relative fine textures of soil of site 5 (Ukaegbu et al. 2022) might have contributed to the low bulk density value of 0.94 g/cm^3 at the topsoil (Table 3). In addition to the sandy nature of soils, the high values of B.D. got in the floodplains (sites 1 to 5) might have been contributed to by structural degradation of the soils, irregular packing of the sand grains due to constant flooding and drying, reworking and sorting of the soils resulting in pedocompaction as noted by Igwe et al. (2005) of soils of river Niger floodplain that is also in Southeast Nigeria. The wet conditions limit microbial activity which in turn encourages structural degradation. The intense cultivation of soils of location of study might have influenced their bulk densities as well. Kolay (2000), notes that excessive amount of cultivation for growing arable crops like potato and maize oxidizes soil humus thereby destroying soil aggregates which then increases bulk density.

The increase in bulk densities with depth as shown by the average values for the different depth zones is due to low organic matter content in the lower layers, compaction resulting from the pressure of upper layers of the soils as well as the use of implements and machinery (Savalia et al., 2009). This is supported by the work of Ngwu et al. (2005) who found the removal of the top soils of soils derived from sandy deposits of false bedded sandstones and Coastal plains sand at Nsukka, Southeastern Nigeria, to increase sand but decrease silt and clay, thereby increasing bulk density while reducing porosity with increasing depth of desurfacing. It should be further noted that the compaction of surface soils resulting from cultivation also affects adversely faunal activities at the sub soils. Such compaction limits moisture getting into the sub soils where some faunal animals burrow into when the surface soils dry out. Increases in B.D. have been shown to reduce levels of soil OM (Brevik and Fenton, 2012) as such reduce soil aeration, root penetration, making it more difficult for organisms to move and conduct typical activities (Guo et al., 2016).

By the standards of Wilding et al. (1994) the B.D. values at the topsoil (0-25cm) varied just moderately with a C.V. of 15.75%, while at the other depths the variations were low with C.V.s ranging from 7.35% to 13.80% (Table 3). This finding agrees with Tsegaye et al. (1998) who studied the intensive tillage effects on spatial variability of soil physical properties such as particle size, bulk density, soil strength, mean pore size, saturated hydraulic conductivity and found that all soil physical properties with the exception of saturated hydraulic conductivity were weakly spatially dependent for the 6 to 9cm depths, and moderately spatially dependent for 27 to 30cm soil depth. Similarly, Ukaegbu and Nnawuihe (2020) recorded low to moderate influence of land use on spatial variation of soils' particle sizes at the topsoil in the location of study. Gulser et al. (2016) reported that spatial variations of soil physical properties in the field are generally controlled by the particle size distribution as a fundamental factor. While the period soils were fallow might have reduced variability of the bulk densities (Ghartey et al., 2012), differences in management of the soils may have influenced results got. Asadu et al. (2020) found in Nsukka area of Southeast Nigeria that previous land uses significantly (at 5%) affected soil bulk density after 13 years of fallow. Site 12 with a B.D. of 0.90 g/cm^3 was confirmed to have been fallow for over 20 years, while for site 11 with a value of 1.53 g/cm^3 was under the first year of fallow after cultivation. Site 16 with a B.D. of 1.52 g/cm^2 was subjected to cattle grazing. Asadu et al. (1999) found also in Nsukka area of southeast Nigeria that the soils' mean silt content, macro-porosity and hydraulic conductivity were generally significantly lower in grazed than ungrazed fields, while bulk density was higher in grazed than ungrazed fields. They found the mean values of B.D. to be 1.46 g/cm^3 for the ungrazed and 1.65 g/cm^3 for the grazed. They attributed the compaction of surface soil in grazed fields to trampling by grazing animals, devegetation resulting from grazing, direct rain drop impact on the exposed soils. The findings have been corroborated by Ivan et al. (2016) and Yeneayehu et al. (2019) in comparable studies.

Colluviation processes bringing about sorting of soil particles in the location of study may also explain in part the little variation in bulk densities of the soils. Obi et al. (2020) reported that slope processes of coastal plains sand resulted in variability and re-arrangement of the particle size fractions and subsequently other soil properties. They further explained slope elements to significantly influence very coarse, coarse and very fine sand, bulk density, porosity and hydraulic conductivity. Ukaegbu et al. (2015) had earlier reported a significant negative correlation between slope angle and bulk density of surface soil at 5% level of significance in the location of study. Table 1 shows slope angles at sites sampled to range from 0.5 to 9%, this being equivalent to a high coefficient of variation of 112%.

The differences in bulk density values reflect also differences in qualities of soils at the different sites. Evaluating the physical fertility of degraded and un-degraded acid sands in Akwa Ibom State of Nigeria, Ogban and Edem (2005) found bulk density of the soils to average 1.50 g/cm^3 in degraded and 1.45 g/cm^3 in the un-degraded. On his part, Kolay (2000) was of the view that the B.D. of sandy soils and clay soils should be less than 1.4 g/cm^3 and 1.2 g/cm^3 respectively for optimum crop growth. Veihmeyer and Hendrickson (1948) found that roots do not easily penetrate clays of densities above 1.46 g/cm^3. Based on these standards, the surface soils are marginally of good quality in general terms.

Savalia et al. (2009) noted that bulk densities less than 1 g/cm^3 are often soils that contain large amounts of organic matter. The lowest value of 0.90 g/cm^3 was got at site 12 which was an old homestead site that was confirmed to have been fallow for over 20 years. The site had turned into a secondary forest. Akamigbo (1999) and Nnaji et al. (2002) found soils under forest in the area of study to have significantly higher organic matter contents than soils under cultivation. The low value of B.D. got in the site as well as that of site 5 (0.94 g/cm^3) signify high content of OM. Due to its role in the soils, Keestra et al. (2016) opine that OM contents of mineral soils could be a suitable symbol for soil quality. Lal (2006) notes high SOC enhances soil water holding capacity, increases soil fertility through cation exchange and mineralization processes and improves soil structure. For these reasons, he concludes that OM has a disproportionately large impact on food security in developing countries. However, there has been no clear evidence of threshold levels of SOM or SOC that defines the point at which processes become dysfunctional in a soil and affect plant growth (Sanchez et al., 2003). One of the suggestions to overcome this challenge is to regard soils in undisturbed or productive state as reference value for identical soils. So, the OM content at topsoil of site 12 can thus be a reference value for the well drained soils that are generally identical as indicated by their classifications, while that for sites 5 serves the same purpose for soils under the influence of water. So, by determining the bulk densities of soils, such productive soils can be identified. So, bulk densities higher than the value got at site 12 pre-suppose some level of degradation.

Table 4 shows the lowest pH value of 4.0 was gotten at 0-25cm depth of site 3 while the highest of 6.2 was got at depth 50-75cm of site 13. By the rating of Chude et al. (2011) the soils' reactions ranged from 'very strong acidity' to moderate/slight acidity. The average values for the various depths starting with the shallowest were 4.95, 5.10, 5.07 and 5.01 respectively. So, on the average, the topmost layer is the most acidic. The range of values at the topsoil was 4.0 for site 3 to 5.9 for site 20. Sites 6, 13, 20 with values 5.8, 5.7, 5.9 respectively were fallow for long, with the length of fallow estimated to be over 10 years. The most acidic with a pH value of 4.0 was got at site 3 which was under the influence of water (i.e. hydromorphic). The soils' reactions have low variation at all depths with the lowest coefficient of variation of 8.65% got at depth 75-100cm while the most with a value of 11.09% was got at the depth of 0-25cm. This agrees with Asadu (1990) who noted soil pH not to vary widely in soils of Southeast Nigeria due mainly to the highly weathered nature of soils, acidic nature of the soils' parent materials and ofcourse the humid nature of the climate.

The lower average pH at the topsoil may be due to leaching of bases into the subsoil, losses by run-off, as well as rapid uptake of nutrients by vegetation as a result of increasing biomass. Asadu et al. (2020) adduced such reasons in the early years of fallow which gets reversed as fallow period increases and litter fall adds more nutrients to the soil thereby increasing the amount of nutrients and ofcourse the pH at the topsoil. Generally, the average length of fallow in the location has reduced to two years due to demographic pressure (Osuji et al., 2002).

The varying lengths of fallow of the sites may explain the slightly greater variation of soil pH at the topsoil. Other factors may have contributed as well. Abdillah et al. (2019) noted natural acidity activity (pH) of soil to be affected by several factors namely, the prime soil material, precipitation, natural vegetation, plant growth, soil depth and nitrogen fertilizers. However, earlier studies (Akamigbo, 1999; Enwezor et al., 1981; Nnaji et al., 2002) had recorded the soils' reactions as strongly acidic. Such has implications for soils other chemical properties. In a study in the Congo basin, Tejnecky et al. (2020) noted the most marked trends in translocating forest soils into agricultural plots to be significant decrease of pH, increase of Al, decrease of Ca/Al ratio in A-layer, and rapid loss of organic C. They went further to explain that soil chemical characteristics develop towards the new equilibrium typical for each landuse following the translocation. The major crops cultivated in the area (e.g. Maize, Roots and Tubers) will need some level of liming to improve soil productivity. However, burning of trash following clearing of bush during cultivation ameliorates the strong acidity of soils (Fraser and Scott, 2011; Nye and Greenland, 1964) at least temporarily.

Results got in present study as indicated in Tables 3 & 4 show that improvements in Bulk density at a site has not always resulted in improvement in soil reaction (pH) thus reflecting the complex relationship between both parameters. Table 5 shows the two parameters to have low and insignificant correlation at 5% at all the depths sampled. The B.D. at site 12 (Table 3) is 0.90 g/cm^3 while the pH for same site (Table 4) is 4.7 at the topsoil. Asadu et al. (2020) found fallowing for 13 years a piece of land (at Nsukka, Southeast Nigeria) that had been cultivated for 7 consecutive years to have restored the nutrients content of the soils to what it was under virgin forests prior to cultivation without having the same amount of restorative effects on the physical properties such as Bulk density, transmission porosity, saturated hydraulic conductivity. On the other hand, Basil (2019) found effects of different landuse types on soil quality indicators in the crystalline basement complex in Abeokuta, S.W. Nigeria, to cause more severe chemical degradation than either of physical and biological degradation. But in some of the sites of present study, there seemed a positive correlation in both parameters assessed. Sites 6 and 13 with relatively good bulk densities (1.19 g/cm^3 and 1.04 g/cm^3 respectively) also had relatively good soil reactions with pH 5.8 and 5.7 respectively. Both sites were fallow for long. Site 16 with not so good B.D. of 1.52 g/cm^3, had relatively good soil reaction as the pH was 5.5 at topsoil. This is due to the effect of animal manure (cow-dung) on the soils' reaction. Ano and Ubochi (2007) found the application of animal manure (Rabbit, Swine, Goat, Poultry, Cow) to increase the pH of an ultisol at Umudike by decreasing the soil exchangeable acidity.

Long fallow that is recommended for restoration of soils' fertility is not possible in the location of study due to high population density. A few of the sites that were fallow for long must have been so for reasons including dispute over land ownership, the owner of the piece not being at home etc. This makes it imperative that soils under fallow should be enhanced by introducing fast growing leguminous trees and shrubs (MacDicken, 1990) as well as other measures. Obi and Ofoduru (1997) recommended that poultry manure levels higher than 40t ha^{-1} applied over a period exceeding two years would optimize the physical environment of a severely degraded ultisol in Southeast Nigeria. It would also improve soil reaction as earlier noted. Managing the soils under fallow should aim at a pH above 5.5 and a B.D. less than 1.5.

Conclusion

Study showed the soils under fallow to generally have relatively good quality as values of data got were mostly within permissible levels. However, the critical levels were got at some sites within the floodplains indicating some level of degradation. Data were influenced by soil depth. While the worst average soil reaction was got at the topsoil the best of bulk density was at the topsoil, signifying a poor correlation of the parameters. None of the parameters should be taken in isolation of the other and there is the need for management intervention during the generally short fallow period in the location to balance soil quality. To minimize cost the two parameters can be used to monitor progress made during fallow.

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Table 1: Descriptions of sites sampled.

Profile No.	Location	Altitude (Metres above sea level)	Slope		Drainage	Parent material	Soil classification
			Angle	Position			
1.	Lat. 5^{0}19'35.2''N Olokwu, Long. 6^{0}58'17.3''E Emeabiam	28	1%	Foot slope	Poorly drained Subsoil	Colluvium / Alluvium	Fluvaquentic Eutrudepts (ST), Arenic Gleysols (FAO)
2.	Lat. 5^{0}40'52.5''N Ngbele, Long. 6^{0}51'20.1''E Oguta	33	4%	Foot of rolling slope	Poorly drained	Colluvium / Alluvium	Fluvaquentic Eutrudepts (ST), Gleyic Fluvisol (FAO)
3.	Lat. 5^{0}27'5.2''N Itu, Ezinihitte, Long. 7^{0}20'53.8''E Mbaise	54	1%	Valley bottom	Poorly drained	Alluvium	Fluvaquentic Dystrudepts (ST), Gleyic Acrisols (FAO)
4.	Lat. 5^{0}29'30.5''N Azaregbelu, Long. 7^{0}8'24.1''E Owerri	70	1%	Valley bottom	Poor	Alluvium	Arenic Eutrudepts (ST), Arenic Gleysol (FAO)
5.	Lat. 5^{0}22'5.4''N Nri-Achara, Long. 7^{0}18'56.6''E Amuzu	42	0.5%	Valley bottom	Poor	Coastal plains sand / Imo Clay Shale	Oxyaquic Udorthents (ST), Gleyic Fluvisol (FAO)
6.	Lat. 5^{0}20'34.8''N Ohekelem, Long. 7^{0}13'29.6''E Ngo-Okpala	65	2%	Foot slope	Well drained	Coastal plains sand	Typic Plinthudults (ST), Plinthic Acrisol (FAO)
7.	Lat. 5^{0}19'42.0''N Olokwu, Long. 6^{0}59'0.5''E Emeabiam Owerri	49	3%	Mid slope	Well drained	Colluviums/Coastal plains sand	Typic Paleudult (ST), Haplic Acrisol (FAO)
8.	Lat. 5^{0}27'13.6''N Itu, Ezinihitte, Long. 7^{0}20'50.8''E Mbaise	62	1.5%	Foot slope	Well drained	Coastal plains sand	Typic Paleudult (ST), Haplic Acrisol (FAO)
9.	Lat. 5^{0}19'56.3''N Ohekelem, Long. 7^{0}15'51.5''E Ngor-Okpala	88	0.5%	Plain	Well drained	Coastal plains sand	Typic Paleudult (ST), Haplic Acrisol (FAO)
10.	Lat. 5^{0}16'51.3''N Umulu Eziama, Long. 7^{0}13'41.1''E Ngor-Okpala	78	0.5%	Plain	Well drained	Coastal plains sand	Typic Paleudults (ST), Haplic Acrisol (FAO)
11.	Lat. 5^{0}37'50.7''N Izombe, Long. 6^{0}51'33.7''E	44	1%	Plain	Well drained	Coastal plains sand	Typic Kandiudult (ST), Haplic Acrisol (FAO)
12.	Lat. 5^{0}24'23.2''N Lorji, Long. 7^{0}16'56.9''E Aboh-Mbaise	83	0.5%	Plain	Well drained	Coastal plains sand	Typic Kandiudult (ST), Haplic Acrisol (FAO)
13.	Lat. 5^{0}29'47.2''N By Alvana Sec. Sch., Long. 7^{0}0'53.9''E Owerri	75	0.5%	Plain	Well drained	Coastal plains sand	Typic Kandiudult (ST), Haplic Acrisol (FAO)
14.	Lat. 5^{0}35'14.4''N Ifakala, Long. 7^{0}0815'E Mbaitoli	124	0.5%	Plain	Well drained	Coastal plains sand	Typic Kandiudult (ST), Haplic Acrisol (FAO)
15.	Lat. 5^{0}28'26.9''N Emekeukwu, Long. 7^{0}6'55.5''E Owerri	81	9%	Mid slope	Well drained	Coastal plains sand/Colluvium	Typic Paleudult (ST), Haplic Acrisol (FAO)
16.	Lat. 5^{0}28'21.0''N By Imo Broad-Casting Station, Long. 7^{0}3'^{24}8.1''E Owerri	59	5%	Mid slope	Well drained	Coastal plains sand/Colluvium	Typic Paleudult (ST), Haplic Acrisol (FAO)
17.	Lat. 5^{0}32'3818.3''N Orji, Long. 7^{0}8'29.6''E Owerri	90	7%	Mid slope	Well drained	Coastal plains sand/Colluvium	Typic Paleudult (ST), Haplic Acrisol (FAO)
18.	Lat. 5^{0}33'39.5''N Ukwugba, Long. 6^{0}45'6.1''E Egbema	23	0.5%	Plain	Well drained	Subrecent Alluvium	Typic Paleudult (ST), Haplic Acrisol (FAO)
19.	Lat. 5^{0}41'27.1''N Oguta Long. 6^{0}47'33.3''E	24	0.5%	Flat/Depression	Well drained	Subrecent Alluvium	Oxyaquic Paleudult (ST) Eutric Fluvisol (FAO)
20.	Lat. 5^{0}33'52.1''N By Orashi River/Gas, Long. 6^{0}43'57.6''E Turbine	18	0.5%	Flat	Poor at subsoil	Subrecent Alluvium	Oxyaquic Paleudult (ST), Haplic Gleysol (FAO)

Table 2: Landuse on and about sites sampled.

Profile No.	
1.	Sample taken from a cleared fallow arable field surrounded by Raparian forest, oilpalm and Rubber plantations.
2.	Rubber plantation, Raparian forest.
3.	Cassava field, Raparian forest.
4.	Arable field planted to Maize and cassava, oilpalm and plantain plantations, Raparian forest.
5.	Raffia palm plantation, cassava and water yam.
6.	Fallow arable field with cassava as main crop.
7.	Fallow arable field
8.	Wild oil palm + Arable (cassava)
9.	Fallow arable (cassava)
10.	Fallow arable (cassava)
11.	Fallow arable by oilpalm plantation.
12.	Secondary forest with Gacinia Kola, Oilbean, oilpalm, Rafia palm, local pear and cassava field.
13.	Fallow with well established shrubs.
14.	Just fallow with wild oilpalms.
15.	Cassava field; well established shrubs.
16.	Cattle grazing field beside a slaughter.
17.	Fallow arable field bordering cassava plot.
18.	Fallow arable field bordering cassava plot.
19.	Oil palm plantation; Rubber plantation.
20.	Secondary forest, cassava plot.

Table 3: Bulk densities (g/cm^3) of soil samples from various sites and depths.

Profile	0 – 25cm	25 – 50cm	50 – 75cm	75 – 100cm
1.	1.61	1.62	1.49	-
2.	1.45	1.83	1.61	-
3.	1.50	1.43	1.45	-
4.	1.23	1.69	1.62	-
5.	0.94	1.18	1.35	1.46
6.	1.19	1.02	1.53	1.63
7.	1.37	1.47	1.33	-
8.	1.33	1.60	1.51	1.65
9.	1.41	1.18	1.57	1.55
10.	1.03	1.36	1.44	1.46
11.	1.53	1.58	1.69	1.67
12.	0.90	1.50	1.36	1.45
13.	1.04	1.32	1.47	1.41
14.	1.25	1.29	1.33	1.39
15.	1.13	1.32	1.45	1.35
16.	1.52	1.55	1.55	1.53
17.	1.35	1.38	1.47	1.23
18.	1.25	1.23	1.30	1.37
19.	1.14	1.46	1.55	1.52
20.	1.48	1.67	1.64	1.60
$\bar{X}$	**1.28**	**1.43**	**1.49**	**1.48**
C.V.(%)	**15.75**	**13.80**	**7.35**	**10.44**

Table 4: pH values of soil samples from various sites and depths.

Profile	0 – 25cm	25 – 50cm	50 – 75cm	75 – 100cm
1.	5.3	5.7	5.8	5.6
2.	5.0	5.2	5.2	4.9
3.	4.0	4.9	4.5	-
4.	4.6	4.6	5.2	-
5.	4.9	4.8	4.8	4.8
6.	5.8	4.9	4.9	4.9
7.	4.1	4.4	4.5	4.9
8.	4.3	4.9	5.2	5.5
9.	4.3	5.5	4.5	4.7
10.	4.8	4.1	4.7	4.4
11.	5.2	5.8	4.6	5.0
12.	4.7	4.8	4.7	4.7
13.	5.7	5.2	6.2	5.8
14.	4.9	5.3	5.0	5.1
15.	4.5	5.1	4.7	5.5
16.	5.5	5.9	5.5	5.0
17.	5.4	5.6	6.1	5.6
18.	4.8	5.0	5.1	4.5
19.	5.3	5.5	5.7	5.1
20.	5.9	4.7	4.5	4.2
$\bar{X}$	**4.95**	**5.10**	**5.07**	**5.01**

C.V.(%)	**11.09**	**9.12**	**10.38**	**8.65**

Table 5. Relationships of Bulk Density and pH expressed in terms of Correlation Coefficient (r)

Soil depths (cm)	**Correlation Coefficient (r)**
0 – 25	0.00056
25 – 50	0.07
50 – 75	0.054
75 – 100	-0.2997

Non-significant correlation between the parameters at 0.05 level of significance at all depths

SECTION FOUR: SOIL FERTILITY AND PLANT NUTRITION

Effects of Organic Wastes and Rice Varieties on Soil Physico-Chemical Properties at Yandev, Benue State, Nigeria

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ABSTRACT

The effects of three organic wastes often used as soil amendments in upland rice farming systems on soil physico-chemical properties were evaluated during the 2004 and 2005 cropping seasons at Yandev, Benue State, Nigeria. The trial was a split plot in RCBD where three upland rice varieties, FARO 46 (FA), WAB 450-1-B-P160-HB (WA) and WAB 189-B-B-B-H-HB (WB) formed the main plot treatments. The subplot treatments were five types of soil amendments; namely soybean trash (Sb), rice husks (Rc), cowpea husks (Cp), mineral fertilizer (Ft) and control (Co). These were replicated three times. The results of the study indicated that bulk density levels were significantly (P<0.001) reduced in 2005 due to the incorporation of organic amendments. Saturated hydraulic conductivity (K_{sat}) values were significantly increased in Cp and Sb amended plots during the first season. The interaction effect of amendments x variety was significant (P = 0.05) on K_{sat} in 2004. Organic C levels increased significantly by over 65% in Sb amended plots at the end of 2005. Similarly, total N, available P and exchangeable K values were significantly (P≤ 0.05) increased due to the amendments. The pH values obtained from plots under Ft treatment were significantly (P = 0.01) lower than those from plots amended with the other organic materials.

Keywords: organic wastes, rice, soil properties

INTRODUCTION

Crop production poses great challenges to the soil because of the high demand on it. Many of the technologies and approaches used in food production systems exploit the natural resources and degrade the environment (Aruleba and Ogunkunle, 2005). Physical deterioration of soils is associated with the depletion of soil organic matter, a situation that can worsen with inorganic fertilizer application. Therefore, the management of soil organic matter becomes central in the development of low input technology for improvement of soil physical and chemical characteristics. Such alternative would have to permit agricultural land use at optimum and sustainable levels without degrading the soil resource base.

Incorporation of organic residues such as cow dung, poultry droppings and swine wastes has been shown to improve soil conditions (Obi and Ebo, 1995: Mbagwu, 1992). Most of the investigations involved animal wastes. However, there is need for information on the potentials of different plant materials as improvers of soil physical properties and chemical qualities. The objective of this study therefore was to determine the effect of some crop residues on selected soil physico-chemical properties in an upland rice production culture.

MATERIALS AND METHODS

Site location and characteristics

The two-year study was conducted at Yandev (Lat 7^0 23^1N and Long 9^0 01^1 E) in Benue State, Nigeria. Yandev, which is one of the settlements on the outskirts of Gboko town, falls within the Southern Guinea Savannah vegetation zone with a sub-humid tropical climate. The field had been used for soybean cultivation for four years prior to the study

Soil properties

Based on its physico-chemical properties, the soil of the experimental site is an Alfisol classified as Aquic Arenic Kandiustalf (USDA). The profile horizons have very low to low CEC, organic matter content, N, P, K, Ca and Mg; high base saturation and moderately acidic soil reaction. The texture of the soil varies from sandy loam in the upper horizons to sandy clay in the subsurface horizons.

Treatments and experimental design

The trial comprised three upland rice varieties namely FARO 46 (FA), WAB 450 –1-B-P 160-HB (WA) and WAB 189 – B-B-B-H-HB (WB). The subplots consisted of soybean trash (Sb), rice husks (Rc), cowpea husks (Cp), the recommended mineral fertilizer (Ft) and control (Co). The treatment combinations were laid out in a spit plot arrangement using the randomized complete block design with three replicates spaced 1.0 m apart. Individual plots measured 5 m x 5 m and spaced 0.5 m apart. The vegetation and litter were cleared manually and removed from the plots before the imposition of treatments.

Cultural practices

After marking out of the field, core and auger soil samples were collected from each plot at 0-20cm depth for laboratory analysis. The subplots were then tilled manually using traditional hoe. The organic residues were then incorporated at an estimated rate of 10 t ha^{-1} in the subplots that needed their application. Planting of the crops was on the flat by dibbling in the second week of July for both seasons. About 5 seeds were planted per hole with a spacing of 25cm x 20 cm. The recommended rates of mineral fertilizer (60kg N, 30kg P_2O_5 and 30 K_2O kg ha^{-1}) was applied in the assigned plots for fertilizer treatment. All of P and K and half of N were applied at 21 days after sowing (DAS) using NPK 15:15:15 compound fertilizer. The remaining half of N was top dressed at 60 DAS using Urea (46%N) fertilizer. The plots were kept weed free by manual weeding.

Data collection

Particle size distribution was determined by the Bouyoucos hydrometer method as described by Gee and Barder (1986), saturated hydraulic conductivity (K_{sat}) was determined using a constant head permeameter (Bouwer, 1986). The Darcy's formula for vertical flow of liquid was used to calculate K_{sat}. bulk density was determined by the core method (Landon, 1981) while total, macro-and micro-porosities were calculated. Organic carbon (OC) was determined by the Walkley and Black dichromate oxidation method (Nelson and Sommers, 1982), total N by the macro Kjeldahl method (Bremmer and Mulvaney, 1982) and available P by the Bray II method (Olsen and Sommers, 1982). Soil pH determination was at a ratio of 1:2.5 soil : distilled water

(McLean, 1982). Exchangeable cations (Ca, Mg, K and Na) were extracted with 1N NH_4OAC solution at pH 7.0. The Na and K were determined with a flame photometer while Ca and Mg were obtained from the atomic absorption spectrophotometer. Exchangeable acidity was determined in 1N KCl and Effective Cation Exchange Capacity (ECEC) expressed as the summation of the exchangeable basses and exchangeable acidity. The data were subjected to analysis of variance and treatment means compared using the least significant difference at 5% probability level (Obi, 1986)

RESULTS AND DISCUSSION

The selected physicochemical properties of the soil prior to planting are summarized in Table 1. The soil is sandy loam and has high bulk density (BD) values. The soil has low nutrients content and is acidic in reaction.

Table 2 shows some of the chemical properties of the organic amendments used. The values indicate that Sb materials have a greater potential for increasing soil OC as well as N levels. Its lower C:N ratio implies that decomposition will be faster and its nutrient release quicker.

Table 1. Soil physical and chemical properties prior to planting.

Property	**2004**	**2005**
Sand (g/kg)	710	720
Silt (g/kg)	130	150
Clay (g/kg)	160	130
Texture	**Sandy Loam**	**Sandy Loam**
BD (g/cm^3)	1.73	1.70
K_{sat} (cm/hr)	19.0	18.0
Organic C (%)	0.39	0.40
Total N (%)	0.03	0.04
Available P (mg/kg)	3.44	3.30
Exch.K (Cmol/kg)	0.07	0.08
Exch. Mg “	0.52	0.53
Exch. Ca “	1.66	1.68
ECEC “	4.04	4.11
pH	5.0	4.96

Table 2: Chemical properties of the organic materials used.

Property	Sb	Rc	Cp
Organic C (%)	30.23	28.8	25.49
Total N (%)	1.40	0.66	0.98
C.N Ratio	22	44	26
Avail P (ppm)	0.18	0.36	0.06
Exch. K (cmol/kg)	0.22	0.16	0.07

Note: Sb = soybean trash, Rc = rice husks , Cp = cowpea husks

The influence of organic amendments on some physical properties is summarized in Table 3. Bulk density (BD) was significantly ($P < 0.01$) reduced by Sb and Rc compared with other amendments in 2005. The mean values obtained from Sb and Rc were not significantly different. Those from Cp, Ft and Co were also not statistically different from each other. There was a reduction of between 5.8% and 4.0% in the plots amended with organic materials with the highest occurring in Sb plots and the least in Cp plots. This results support the findings of MacRae and Mehuy (1985) that the addition of organic materials to a soil decreases its bulk density because the added material is of lower density than the soil matrix. Varietal effects were not significant on BD values.

Table 3: Effects of treatments on some soil physical properties in 2004 and 2005

Amendment	BD(g/cm^3)	K_{sat}(cm/hr)	Totalpo (%)	Macrop (%)	Micropo (%)
			2004 season		
Sb	1.70	24.0	47.47	15.31	32.18
Rc	1.71	18.96	50.24	14.12	36.13
Cp	1.71	19.95	50.64	18.58	32.06
Ft	1.72	16.87.	40.64	11.16	29.48
Co	1.73	16.41	36.37	10.16	26.21
LSD (5%)	ns	3.16	ns	5.13	5.22
Rice Variety					
FA	1.73	19.01	50.16	19.77	30.39
WA	1.71	17.42	47.54	17.70	29.82
WB	1.71	17.69	49.38	15.99	33.41
LSD (5%)	ns	ns	ns	3.03	ns
			2005 season		
Sb	1.62	24.47	51.07	18.60	32.47
Rc	1.65	19.01	51.17	17.80	33.37
Cp	1.71	17.65	49.32	17.57	31.75
Ft	1.71	17.77	51.76	15.52	36.24
Co	1.72	14.49	52.75	14.81	37.89
LSD (%)	0.019	3.44	ns	ns	ns
Rice Var					
FA	1.68	19.77	50.97	16.37	34.59
WA	1.67	19.90	51.56	16.32	34.74
WB	1.67	16.37	51.11	17.38	33.70
LSD (5%)	ns	ns	ns	ns	Ns

Note: Treatment Sb = soybean trash, Rc = rice husks , Cp = cowpea husks, Ft = mineral fertilizer, Totalp = total porosity, Macrop= macroporosity, Microp = microporosity, Co = control; Rice variety FA = FARO 46, WA = WAB 450-1-B-P160-HB and WB = WAB 189-B-B-B-H-,

Organic amendments significantly ($P< 0.01$) increased the K_{sat} values during both seasons. In 2004 the increases in Cp and Sb amended plots were 22 and 46% respectively. In 2005, the increases in Sb and Rc amended plots were also significant over the control. The increases probably resulted from the decrease BD values and the accompanying variations in soil porosities as a result of organic matter addition. Hati (2007) obtained increased

K_{sat} levels and attributed it to better aggregation and lower bulk densities owing to soil organic matter (SOM) addition. The influence of rice variety was not significant on K_{sat} values. However, the interaction effects of amendments x rice variety were significant (P= 0.05) in 2004. Amendments did not significantly influence total porosity values. However, both Cp and Sb amended plots gave macroporosity values significantly higher than Co in 2004. During the same period microporosity mean values were in the order Rc = Sb = Cp> Ft = Co. Mbagwu (1992) and Obi and Ebo (1995) found increases in total and macroporosity with SOM application while Hati (2007) obtained significant increases in macro- and micro porosity with application of organic materials.

Most chemical properties tested were significantly increased due to amendment effects comparing with the control particularly in 2005 (Table 4). For instance, OC values significantly increased between 33 and 49% in 2004 and between 30 and 65% in 2005. The order of this increases was Sb = Rc > Cp > Ft = Co in 2004 and Sb = Rc = Cp> Ft > Co in 2005. The superior performance of Sb reflected the higher levels of organic C in the amendment used (Table 2). Apart from this, the lower C: N ratio values might have ensured their faster decomposition and therefore release of C to the soil than the other amendments.

Total N, available P and exchangeable K values were significantly (P< 0.05) increased with incorporated materials particularly in 2005.For instance, total N increased between 18 and 50% over control in 2004 and between 83 and 110% in 2005. On the other hand, available P increased by as much as 138% in the Sb plots in 2005. This improvement may be due to the conversion of fixed P into available P because of the induced biological and enhanced chemical conditions.

Table 4: Effect of amendments on some soil chemical properties

	2004 Season					2005 Season				
Amendment (A)	OC %	N %	P mg/kg	K cmol/kg	pH (H_2O)	OC %	N %	P mg/kg	K cmol/kg	pH (H_2O)
Sb	0.57	0.03	3.89	0.07	4.81	0.66	0.06	7.44	0.10	5.50
Rc	0.55	0.04	3.87	0.08	5.04	0.64	0.05	7.86	0.11	5.37
Cp	0.51	0.04	3.85	0.08	4.93	0.62	0.06	7.30	0.09	5.42
Ft	0.40	0.03	3.59	0.08	4.90	0.52	0.04	3.49	0.08	4.74
Co	0.38	0.03	3.44	0.07	5.0	0.40	0.03	3.30	0.08	4.96
LSD (5%)	0.03	0.002	Ns	Ns	Ns	0.062	0.001	0.74	0.013	0.24
Rice Variety										
FA	0.462	0.034	3.70	0.077	4.97	0.53	0.048	5.93	0.093	5.33
WA	0.496	0.037	3.80	0.084	4.94	0.58	0.049	5.61	0.094	5.12
WB	0.497	0.031	0.66	0.071	4.95	0.58	0.045	6.09	0.093	5.14
LSD (5%)	0.021	0.002	Ns	0.005	Ns	ns	0.001	ns	ns	ns

Note: Treatment Sb = soybean trash, Rc = rice husks , Cp = cowpea husks, Ft = mineral fertilizer, and Co = control; Rice variety FA = FARO 46, WA = WAB 450-1-B-P160-HB and WB = WAB 189-B-B-B-H-

The values of exchangeable K in 2005 showed that only Sb and Rc materials differed significantly from the control. Organic materials were found to improve total N, available P and exchangeable K levels by Adetunji

(1977) and Mbagwu (1985). In addition Mbagwu (1985) found that organic residues differed markedly in their concentrations of N, P, K and OC and this difference reflected in their improvements of soil chemical conditions. The lower level of N, P and K in the Ft plot could mean that these readily available elements were utilized more quickly by the crop and their residual potentials became less. The amendments significantly increased the pH values in 2005. The order of increase was Sb > Cp > Rc. Nottidge *et al* (2005) and Hati (2007) did not obtain significant effects in pH with the application of organic materials.

Varietal effects were significant ($P < 0.05$) on organic C, total N and exchangeable K in 2004. Only total N levels were significantly ($P<0.001$) influenced by the rice varietal effects in 2005. The order was WA = FA > WB Exchangeable K levels in 2004 reflected the order of total N. Conversely, WB, with the least values in both N and K had the highest OC levels of O.497%.

Conclusion

This study demonstrated that the organic amendments tasted had higher influence on BD and K_{sat} values of the soils than the mineral fertilizer. Similarly, the organic amendments were more effective in increasing OC, N and soil pH and that their residual potentials were better. Consequently, their use in upland rice farming systems is recommended because of this potential for increasing soil fertility on a more sustained basis.

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Review on Use of Agricultural Wastes/Materials as Organic Fertilizer on Tropical Soils: A Soil Fertility Management Option

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ABSTRACT

Soil fertility management has been one of the major constraints in tropical agriculture due to several activities that occur in the soil, such as continuous cropping, leaching, erosion, soil acidity and nutrient uptake which cause depletion of soil organic matter and low crop yield. The role of organic fertilizer in maintaining soil fertility for crop production in the southeastern part of Nigeria was reviewed. The ultisols are the major soils used for the cultivation of crops in many parts of southeastern Nigeria. These soils are highly weathered and low in fertility. Despite the poor fertility attributes of the soil, it is continuously being used for crop production without regular application of organic amendments but inorganic fertilizer. Such practice encourages soil degradation. In this paper, agricultural wastes are considered an appropriate substitute for inorganic fertilizer in maintaining the fertility and health status of the soils. Agricultural waste otherwise known as agro-waste is comprised of animal waste (manure), crop residues (residual stalks, Straw, leaves, roots, husks, shells etc) and waste from aquaculture. The major sources of the organic fertilizer include; crop residue, green manure, poultry droppings, cattle dung, common or traditional compost, swine (pig) manure and urban wastes. These agricultural wastes are major sources of organic matter, if properly managed and treated could be the best substitute for inorganic fertilizer for farmers in the tropics. High cost of material for chemical fertilizer production affected the cost production, transportation, availability and cost of the mineral fertilizer which farmers have been depending on for their crop production not minding its consequences. The situation calls for a substitute which agricultural waste an organic fertilizer can do. Organic fertilizers not only supply nutrients to plants but play the key role of maintaining the physical, chemical and biological conditions of the soil.

Key words: agricultural waste, organic, inorganic, fertilizer, soil.

INTRODUCTION

Tropical soils have been noted for their extreme demand for fertility management compared to the soils of other parts of the world. The soils are majorly oxisols and ultisols which are commonly used for the cultivation of crops in many parts of southeastern Nigeria. The soils are highly weathered, acidic, and susceptible to erosion and generally low in fertility due to low organic matter content and CEC (Juo and Wilding, 1996). The soil is continuously being used for crop production without the application of adequate amendments, despite its poor fertility attributes. This has led to poor yield of crops and food insecurity. Research findings have shown declining yield with cropping and the long period of cropping which resulted into a deplorable state of soil organic matter (Adeoye *et al*., 2005; Adepetu *et al*., 1979) which is rarely remedied by using only mineral fertilizer. Also, mineral fertilizer is becoming unaffordable to most peasant farmers due deregulation of fertilizer prices and scarcity when available.

Khosro and Yousef (2012) reported that the most important constraint limiting crop yield in developing nations worldwide and especially among resource–poor farmers, is soil infertility. Therefore, maintaining soil quality can reduce the problems of land degradation, decreasing soil fertility, and rapidly declining production levels in large parts of the world that needed the basic principles of good farming practice. According to Mfilinge *et al*. (2014), low crop productivity is a general problem facing most farming systems in Sub - Saharan Africa. These low yields are pronounced in legumes and are often associated with declining soil fertility and reduced nitrogen fixation due to biological and environmental factors.

Conventional agriculture plays an important role in meeting the food needs of a growing human population, which has led to an increasing dependence on the use of chemical fertilizers and pesticides for increased productivity (Santos, 2012). Chemical fertilizers are industrially made substances which are composed of known quantities of nitrogen, phosphorus and potassium. However, the total dependence on chemical fertilizers by southeastern farmers for crop production is no longer feasible following the outbreak of the global pandemic caused by corona virus otherwise known as COVID-19 which brought about the total shutdown of industries, factories, transportation systems and inter-state movement in Nigeria. This situation made the supply of inorganic fertilizer inadequate and very costly that majority of the poor farmers could not access it for the 2020 farm season which would definitely affect agricultural production during the said period if there is no alternative.

The use of organic fertilizers as an alternative is particularly important in most parts of Africa, where low availability of nutrients is a serious constraint for food production (Brouwer and Powell, 2008). Long before the introduction of mineral fertilizers, the early farmers had already learned to make use of organic materials for improving the growth and yield of their crops, usually the staple and vegetable crops. The use of manure is beneficial to the resource poor farmers especially the crop-livestock farmers because of its low cost and availability. The positive role of organic manure in crop production and soil fertility management cannot be over emphasized (Tandon, 1992).

Agricultural wastes could be defined as the by-products of agricultural activities which are not the primary products of agricultural production but are still part of the results of agricultural activities. These wastes are usually in the form of crop residues either from the field or kitchen (residual stalks, straw, leaves, roots, husks shells etc) and animal waste (manures) (Sabiiti, 2011). Agricultural wastes are widely available, renewable and virtually free; hence they can be an important resource for some other users (Sabiiti, *et al*, 2005). Industrially, these wastes can be converted into heat, steam, charcoal, ethanol, bio-diesel as well as raw materials for certain production (animal feed, composting, energy and biogas construction etc). However, many of the agricultural wastes are still largely under-utilized and left to rot or openly burned in the field, especially in developing countries like Nigeria. These wastes are known to contain high levels of essential nutrients like Nitrogen, Potassium, Phosphorus, Sulphur, and Calcium that would improve soil fertility and increase crop yields such as maize, yam, cassava, groundnut, vegetables and others that could fetch high prices and hence enhance food security. This alternate method of utilization by farmers for agricultural production could also reduce the rate of accumulation with the subsequent reduction on environmental pollution thus improving environmental health (Sabiiti, 2005). There is a need for a greater awareness of the public and farmers of the benefits of proper management and utilization of organic wastes in agriculture, to reduce the level of nuisance problems, decrease in land values as well as environmental degradation (Westerman and Bicudo, 2005).

The goal should be to make properly managed agricultural waste a resource that can be utilized and not just discarded. Adopting appropriate conversion technologies, animal and crop waste can be turned into useful resources (Sabiiti, 2011). This paper aims to call for proper management and conversion of agricultural wastes into organic fertilizer a subtitute for inorganic fertilizer in the post-COVID-19 era in Nigeria.

AGRICULTURAL WASTES

The by-products of agricultural activities are usually referred to as "agricultural waste" because they are not the primary products. The impact of agricultural waste on the environment depends not only on the amounts generated but also on the disposal methods used. Some of the disposal practices pollute the environment. For example, agricultural waste burning is a common practice in undeveloped countries, but it is a source of atmospheric pollution. Agricultural waste burning releases pollutants such as nitrous oxide, carbon (iv) oxide, nitrogen (iv) oxide and particles like smoke carbon (Ezcurra *et al.,* 2001). These pollutants are accompanied by the formation of ozone and nitric acid (Hegg *et al.*,1987) hence contributing to acid deposition (Lacaux *et al*.,1992) thereby posing serious risk to human and ecological health. Environmental pollution from animal waste (faeces, urine, and respiration and fermentation gases) is a global concern and is much more acute and serious in countries with high concentrations of animals on a limited land base for manure disposal. Animal wastes are excreted in solid, liquid and gaseous forms, respiration and fermentation gases are lost to the environment soon after being produced by the animal (Sabiiti, 2011).

After excretion, solid and liquid animal waste is subjected to microbial biomass and soluble and gaseous products. Some of these products have an impact on the environment, as well as water quality, soil deterioration and air pollution. Odour pollution among urban livestock farmers was reported to contribute highly to social tensions in Kampala, Uganda (Sabiiti, 2011).

Moreso, the application of excessive animal wastes on land as fertilizers and soil amendment is subject to surface run-off and leaching that may contaminate ground or surface water. The aim should be to make agricultural wastes a resource that can be utilized for agricultural production. Agricultural wastes can be used to enhance food security mainly through their use as organic fertilizer and soil amendment use as animal feed and energy production. They contain large amounts of organic matter, and many of them can be directly added to the soil without any risk. Turning these agricultural wastes (crop residue and animal manures) into organic fertilizers (through composition) is one of the waste treatment technologies that make it possible to use organic as a fertilizer even in populated areas (Sabiiti, 2011). Technology plays a key role in soil fertility improvement, and hence crop productivity (Hargreaves *et al*., 2008).

Composting also reduces the volume of the waste, hence solving major environmental problems concerning the disposal of large quantities waste, kills pathogens that may be present, decrease the germination of weeds in agricultural fields and reduces odour (Jakobsen, 1995). The compost can be sold for additional revenue or used on the same farm, both crop residues and animal waste can be used as animal feed. However, the nutrient content of animal waste depends on the animal species, type of feed, and bedding material used (Mackie, 1998). The rumen contains the microbial enzyme cellulose, which is the only enzyme to digest the most abundant plant product, cellulose (Sabiiti, 2011) with ruminants, nutrients in by-products are utilized and do not become waste disposal problem (Oltjen and Beckett, 1996). According to (Mackie *et al.*, 1998), besides generating revenue from the energy produced, waste-to energy schemes offer an alternative and environmentally acceptable means of waste disposal. Additionally, the schemes also provide a valuable by-product, a good quality, agricultural fertilizer that is nearly odourless.

Recently in Nigeria, research interest has been diverted to the use of organic wastes as source of nutrients (Uyovbisere and Elemo, 2000). This is as a result of scarcity and high cost of inorganic fertilizer. Intensification of the use of mineral fertilizer has been reported to cause soil acidity and environmental health hazard. This situation renders use of inorganic fertilizer in sustainable soil productivity counterproductive (Nwite *et al*., 2014).

Consequently, efforts must be geared towards finding a close substitute to fertilizer that would ensure slow and steady supply of soil nutrients. Uyovbisere and Elemo (2008) reported a superior effect of integrated nutrient management in increasing soil productively. Also, the potential of agricultural wastes to improve soil properties have long been recognized (Johnston, 1986).

Mbagwu and Ekwealo (1990) noted that the combination of wastes ensured well balanced nutrients supply and uptake by crops and led to higher yield. However, the use of organic fertilizer may be limited by economic implications which include; cost of transportation and labour for application due to its bulkiness (Daramola *et al.*, 2005).

AGRICULTURAL WASTE GENERATION AND SOURCES

Agricultural wastes are the residues from the growing and processing of raw agricultural products such as fruits, vegetables, poultry, livestock and crops. They are the non-product of outputs of production and processing of agricultural products that may contain material that can benefit man but whose economic values are less than the cost of collection, transportation and processing for beneficial use. Their compositions will depend on the system and type of agricultural activities and they can be in the form of liquid or solid, soft or hard (Obi *et al*., 2016).

Agricultural waste otherwise known as agro-waste is comprised of animal waste (manure), crop residues (residual stalks. Straw, leaves, roots, husks shells, etc). The waste generated is dependent on the type of agricultural activities carried out. Therefore, agricultural wastes are generated mainly from cultivation activities, livestock production, waste from aquaculture, etc. Generally, the sources of soil organic matter include organic material of plant and animal origin. They are available in abundance in the country and are regarded as agricultural wastes. They are described below;

(a) **Crop residues:** These are the remains of the crop plants after harvest during agricultural production. Plant nutrients may be recycled back into the soil in crop residues in agricultural farms (Giller *et al*., 1994). However, in most cases, these are often insufficient to maintain the soil organic matter and nutrient supply at an adequate content for productive agriculture. Although, where they are available, the crop residues are good mulches which help maintain a favourable soil moisture and temperature, and prevent the multiplication of weeds and the accumulation of salts on the surface of the soil. Moreso, if they are burnt to ash, their fibre and carbon will be completely destroyed and the ash will have little effect on the soil's physical and biological properties, although the inorganic nutrients still remain and the potassium content may increase (Adetunji, 2005).

(b) **Green manure:** This is a green or fresh plant material that is incorporated or ploughed into the soil, usually at the flowering stage when its nitrogen content is highest and allowed to decompose in order to supply nutrients to the subsequent crop. Green manure is an important source of nitrogen. Three general sources of green manure exist, they are; (i) grain legume e.g cowpea, soybean, pigeon pea etc., (ii) woody (perennial) legumes e.*g Gliricida sepium, Senna siamea, Leucaena leucocephale*, etc, these are usually used for alley cropping systems, where they serve as more or less permanent barriers to run-off, besides providing prunnings as manure for the main crop, (iii) the third source are the non-grain legumes such as centrosema, crotalaria, sesbania and stylosanthes. Some of these are pasture crops, but because of their high nitrogen content, they are also used as green manure. They adapt well in acidic soils and are tolerant to poor drainage conditions and low soil fertility (Adentuji, 2005).

(c) **Poultry (Droppings) Manure:** Research has shown that the nutrient content of poultry manure is usually much higher than that of swine manure (Adetunji, 2005). Meanwhile its higher content of Zinc, and antibiotics and its lower content of fibrous materials, discourage direct applications of fresh poultry manure to the soil. Poultry manure is best utilized when mixed with cattle or swine manure, rice straw, rice hull, sawdust and any other fibrous materials and must be fermented thoroughly before it is used.

(d) **Cattle dung/Manure:** Cattle dung or manure is a good animal manure since there are no pollution problems of heavy metals and antibiotics in using it. It has a reasonably high content of nitrogen (N), potassium (K) and fibrous materials. However, when using cattle manure to avoid nutrient deficiency or imbalance, phosphorus (P) should be supplied from other sources preferably from inorganic fertilizers in order to make up the shortage of phosphorus (P) in the cattle manure (Adetunji, 2005). Cattle manure had higher nutrient residual effect in the soil which may be attributed to the slow release of its nutrients elements which is made up of both macro and micro nutrients to the soil (Adekunle *et al.*, 2005)

(e) **Common/Traditional compost:-** This organic manure is made by the combination of carbonaceous materials such as rice, straw, corn, sorghum stalks , corn cobs,rice hull and tree leaves with nitrogenous

materials such as cattle, swine and poultry manures including a small quantity of field soil for fermentation. Common compost is the best organic manure if properly prepared since it contains reasonable levels of nitrogen (N), phosphorus (P), potassium (K), silica and large quantity of carbon to improve the physical, chemical and biological properties of the soil. Composting is a bioxidative process which results in a stable organic product.

Composting normally provides a fast, simple and safe approach to the bulk treatments of organic wastes in comparison to chemical fertilizers, compost have relatively low amounts of nitrogen, phosphorus and potassium. However, it has a long term effect, the total amount available over time is greater than immediately available. Some nutrients are held in humus like compounds which decompose very slowly, so that their effects on soil continue for years after application.

(f) **Swine (Pig) manure:** This is organic manure, obtained from pigs. The nutrient content of swine manure is slightly higher than that of cattle but its higher copper content and lower content of fibrous materials discourage repeated and long term application of swine manure. According to Hsieh and Hsieh (1990) it is the best to dilute this manure by mixing it with rice hull, saw dust, rice straw and other fibrous materials which must be fermented before use.

(g) **Urban wastes:** Today, urban wastes are found everywhere in abundance, especially in major towns and cities. They are a ready source of organic materials for organic fertilizer. However, there are problems associated with the use of urban waste. Since it may contain heavy metals, parasites, and other pathogens that would not be of any benefit to the soils and plants or even the consuming public. Treatment is necessary for urban wastes to be used on agricultural land and its application managed properly. Also, to effectively use urban wastes the problem of bulkiness and high handling cost must be overcome. Therefore, its abundance and usefulness should make it a good alternative to fertilizers especially in this period that inorganic fertilizers are unavailable and insufficient to farmers.

Scientific and hygienic waste disposal is a serious concern (Abu Qdais and Al-Widyan 2016) in developing countries, especially in urban areas, where the population density is high and the availability of land for waste processing and disposal is limited. Collected waste is often dumped in open land or used for landfilling. This leads to severe environmental hazards (Du *et al.,* 2014). Due to the scarcity of land, existing dumping yards are sometimes overfilled. Although incineration is increasingly being used for waste disposal (Dube *et al.*, 2014), it cannot be advocated widely due to the associated toxic gas emissions (Kim and Kim 2010).

Now that this organic waste cannot be utilized as fuel because of its high moisture and low calorific value (Rana *et al.,* 2013), the plant nutrient content makes it ideal for recycling as manure for crop production. The conversion of solid waste to organic fertilizer is a desirable option, in light of reports that severe depletion of soil organic matter is a major cause of declining crop productivity (Lal, 2015). The use of organic fertilizers not only reduces the quantity of the organic fraction that ends up in landfills (Lim *et al.*, 2016), but also reduces the use of inorganic fertilizers (Lim *et al.,* 2015). Aerobic and anaerobic composting practices are popular in the country, but they are slow processes, limiting the turnover rate of waste recycling and disposal. Waste has to be collected from sources and transported to the composting yards, and large-scale dumping near the units for long period's leads to severe environmental pollution. In addition, improper separation of the inert materials, such as plastics and glass, may degrade the quality of the final compost for agricultural purposes (Wu *et al.*, 2014). In Nigeria, agriculture is the basic means of livelihood for people in most areas, especially the rural areas and we solemnly depend on them for food (Ifokwe,1998).

According to Khosro and Yousef (2012) the most important constraint limiting crop yield in developing nations worldwide and especially among resource–poor farmers, is soil infertility. Therefore, maintaining soil quality can reduce the problems of land degradation, decreasing soil fertility, and rapidly declining production levels in large parts of the world that needed the basic principles of good farming- practice. Mfilinge *et al*. (2014) said that low crop productivity is a general problem facing most farming systems in Sub- Saharan Africa. These low yields are pronounced in legumes and are often associated with declining soil fertility and reduced nitrogen fixation due to biological and environmental factors. Biological nitrogen fixation (BNF), a key source of nitrogen for farmers using little fertilizer, constitutes one of the potential solutions and plays a key role in the sustainable production of legumes and even non legumes. The continuous cultivation of the same piece of land year in year out due to increased population has resulted to in a decline in soil fertility such that even with the application of chemical inorganic fertilizer, little is obtained in return.

The use of chemical fertilizers causes air and ground water pollution as a result of the eutrophication of water bodies (Youssef and Eissa,2011). According to Chun-Li *et al*. (2014) though the practice of using chemical fertilizers and pesticides accelerates soil acidification, it also poses the risk of contaminating ground water and the atmosphere. It also weakens the roots of plants thereby making them to be susceptible to unwanted diseases. Organic manure sometimes called biofertilizer has been identified as an alternative to chemical fertilizer to increase soil fertility and crop production in sustainable farming (Chen, 2006). These potential biological fertilizers would play the key role in the productivity and sustainability of soil and also protect the environment as eco-friendly and cost effective inputs for the farmers (Khosro and Yousef, 2012). Organic farming is one of such strategies that not only ensures food safety but also adds to biodiversity of soil (Raja, 2013) and therefore are bountiful in nature (Itelima *et al.*, 2018).

It has been shown that the overall yield of crops is determined by the combined effect of light, air, water, micro and macro nutrients, and pH. However, as the soil is continuously cultivated, nutrients in the soil progressively diminish because the rate at which they are removed is greater than the rate at which they are being replaced (Wander, 2010). According to Wander (2010), apart from being taken up by plants, there are many other ways in which nutrients are lost from the soil. These include leaching, improper irrigation, over tillage, and bush burning. Loss of soil fertility is the primary cause of poor crops and the solution to this problem is by the use of an environment friendly organic fertilizer. In recent years, agrochemicals such as chemical pesticides and chemical inorganic fertilizers are extensively applied to obtain high yield. Intensive application of agrochemicals leads to several agricultural problems and poor cropping systems. Some farmers use more chemical fertilizers than the recommended levels for many crops. This practice accelerates soil acidification but also has the risk of contaminating underground water and the atmosphere, and also weakens the roots of plants and making them to be easy prey to unwanted diseases (Chun-Li *et al*.,2014).

Treatment: Agricultural wastes should be treated by composting before its application to the soil. This stabilizes the wastes into a relatively odorless mass and helps to kill disease organisms.

SPECIFIC ADVANTAGES OF ORGANIC FERTILIZERS FROM AGRICULTURAL WASTE OVER INORGANIC FERTILIZERS.

Inorganic fertilizers have become very popular in Nigeria and throughout the world because they are easily affordable and have the advantage of fast action owing to their prompt release of nutrients. However, there has been much research on the demerits of inorganic fertilizers and this has shown that they have disadvantages that cannot be overlooked. Most of the problems associated with harvested crops and some of the pollution of our natural environment occurred as a result of inorganic fertilizer use (Rosen and Horgan, 2009). These findings have led to the need for the provision of an environment friendly and low cost fertilizer known as organic fertilizer as a substitute. The world's demand for fertilizer has risen greatly in the past few decades. According to Fertilizer Suppliers Association of Nigeria (FESPAN) (2007), Nigeria's fertilizer demand is estimated to be 12 million metric tons per annum. Apart from the high cost, and inadequate supply, especially in the face of COVID 19 pandemic inorganic fertilizers when applied incorrectly, excessively or inadequately have negative effects. Many of the fertilizers imported some years ago into the country were wasted as farmers refused to purchase them. When interviewed, yam farmers complained that the fertilizers were responsible for the early decay of harvested yam tubers. According to Ifokwe (1998), it is also no secret that crops cultivated with inorganic fertilizers have less flavor, taste, and aroma than those cultivated without inorganic fertilizers. Excessive fertilizer application leads to salt burn and in most cases leads to the death of young plants (Laboski, 2011). Because they are non-biodegradable, long term use of inorganic fertilizers result in the accumulation of harmful substances and acidification of the soil thereby causing a decrease in the fertility of the soil (Taylor, 1997). Due to their high solubility in water, inorganic fertilizers applied to the soil could be leached deep into the soil (where plant roots cannot reach) and into underground water causing pollution (Ifokwe, 1998). According to Ifokwe (1998), different types of fertilizers are suitable for different soil types. To get fertilizers which will suit a particular soil, the soil needs to be analyzed. According to him, most of the fertilizers imported into the country are not suitable for our soil thereby giving negative rather than positive results; besides one requires a good knowledge before applying it but today, every illiterate farmer applies fertilizers without understanding how it works and its side effects. All these problems can however be avoided by the use of indigenous fertilizers which is environment friendly. According to Ifokwe (1998) the organic fertilizers also known as bio-fertilizers can achieve all that is achievable with inorganic fertilizers and even more without any side effects.

Organic fertilizers are environment friendly and do not cause pollution when properly managed unlike inorganic fertilizers which often ‘run off’ into water bodies causing eutrophication and ‘blue baby syndrome’ (acquired methemoglobinemia) when the nitrate level is above 10 mg/L(Knobeloch *et al.*,2009). The issue of excessive application does not arise in the use of bio-fertilizers and special skills are not required for its application (Ifokwe, 1998). Organic fertilizers have long lasting effects due to their slow nutrient release. The nutrients from bio-fertilizers are released to plants slowly and steadily for more than one season. As a result, long term use of bio-fertilizer leads to the buildup of nutrients in the soil thereby increasing the overall soil fertility. In addition, bio-fertilizers have been found to help control of plant diseases such as pythium root rot, rhizoctonia root rot, chill wilt and parasitic nematode (Mahimaraja *et al.*,2008). Research has shown that some organic fertilizers particularly those made with degraded tree barks and roots release chemicals that inhibit some plant pathogens. Disease control with organic fertilizer has been attributed to four possible mechanisms: Successful competition for nutrients by beneficial microorganisms present in the fertilizer, production of antibiotics by the beneficial microorganisms, successful predation against pathogens by beneficial microorganisms, activation of disease resistant genes in plants by the microorganisms(Abdul Halim ,2009).

Organic manure acts as a soil conditioner adding organic matter to the soil which helps to bind the soil particles together preventing soil eructing, desertification, and erosion while increasing the water retention capacity of the soil (Swathi, 2010). It enriches the soil with beneficial microorganisms while boosting the already existing ones unlike chemical inorganic fertilizers which acidify the soil making it hard for microorganisms to survive (Swathi, 2010). Bio-fertilizers contain a wide range of nutrients which are often absent in inorganic fertilizers (these include trace elements). Studies have shown that application of nitrogen fertilizer in some weather conditions cause emission of nitrous oxide which has a global warming effect potential 296 higher times than that of an equal mass of carbon dioxide (Grabber and Galloway,2008) Santos (1992), reported that, regarding the analytical part of its composition, the organic fertilizer has macro and micronutrients that can be assimilated by plants, such as: nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, sodium, iron, chlorine, silica, molybdenum, boron, copper, zinc and manganese.

Methane emissions from crop fields (notably rice paddy fields) are increased by the application of ammonium based fertilizers whereas the composting of animal waste in a confined place or in an anaerobic condition (an important process in the production of bio-fertilizer), reduces the addition of methane to the atmosphere as these add methane to the atmosphere when left to decay on their own. Organic fertilizer when compared to raw (undegraded) organic manure has the advantage of easier assimilation by plants and also the odor reduces after degradation (Swathi,2010). Again, the risk with raw organic manure is that it may contain pathogens such as *Salmonella* Spp. which may contaminate crops such as leafy vegetables and lead to the ingestion of the pathogen when the product is consumed. Organic fertilizer also contains useful microorganisms which may not be present in organic (degraded) fertilizer (Khosro and Yousef, 2012). These organic fertilizers can be produced from cheap waste materials which are abundant in Nigeria and the cost of production is low compared to inorganic fertilizers which required high energy. Organic fertilizers are obtained from animal sources such as animal manure or plant sources like green manure (Ritika and Uptal, 2014). .The production of organic fertilizer from agricultural waste is a modern technology which is a part of the application of biotechnology in agriculture.

The production of organic fertilizers is a result of the fermentation process, i.e. the activity of microorganisms in the decomposition of organic matter and the complexation of nutrients, which can be obtained by simply mixing water and fresh manure (Timm *et al.*, 2004). Organic fertilizers have bioactive compounds resulting from the biodigestion of organic compounds of animal and plant origin. Its contents include living or latent microorganism cells with aerobic and anaerobic metabolisms and fermentation (bacteria, yeasts, algae and filamentous fungi), in addition to organomineral metabolites and chelates in aqueous solutes (Pinheiro and Barreto, 1996). Santos and Akiba (1996), observed that the metabolites are compounds of proteins, enzymes, antibiotics, vitamins, toxins, phenols, esters and acids, including those with phyto-hormone activity, produced and released by micro-organisms.

The conversion of proper managed agricultural wastes to fertilizer sources for commercial farming is feasible in this era of technology. Considering the high level of the essential nutrients like nitrogen, potassium, phosphorus that would improve soil productivity and crop yields,there is no doubt that agricultural production would flourish with fertilizer from agricultural wastes.

Our dependence on chemical fertilizers and pesticides has encouraged the thriving of industries that are producing life-threatening chemicals which are not only hazardous for human consumption but can also disturb the ecological balance. In fact, attention is now shifting from consuming food grown with chemical fertilizers to food grown with organic fertilizers because of the harmful effects that these foods have in the body when consumed. Organic fertilizers can help solve the problem of food need of the ever increasing global population. It is important to realize the useful aspects of organic manure so as to apply it in modern agricultural practice. The application of organic fertilizers containing beneficial microbes promotes to a large extent, crop productivity. According to Khosro and Yousef (2012), these potential biological fertilizers would play a key role in the productivity and sustainability of soil and protect the environment as eco-friendly and cost effective inputs for the farmers. Using the biological and organic fertilizers, a low input system can help to achieve sustainability of farming.

CONCLUSION

Agricultural wastes are residues from the growing and processing of raw agricultural products; they are non-product outputs of production and processing and may contain material that can benefit man. These residues are generated from number agricultural activities and they include cultivation, livestock production and aquaculture. These wastes when managed properly through the application of the knowledge of agricultural waste management systems can be transformed into beneficial materials for commercial agricultural production. It is important to note that proper waste collection, storage, treatment, conversion to organic fertilizer and utilization is a panacea to a healthy environment. Proper waste conversion and utilization will assist in developing our agricultural sector and provide viable organic manure resources for many farmers for agricultural production in our society.

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Recent Research Focus of Biochar in Nigeria (Review)

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ABSTRACT

Increase in the availability of feedstocks in Nigeria as well as initial good results obtained from the use of biochar (BC) across the world are seemly encouraging BC recognition and use in Nigeria recently. However, these development and trend in the utilization of BC in Nigeria had not been properly reviewed. This paper aims to present recent utilization of BC in various agro-ecological zones of Nigeria between 2019 and 2023. From the reviewed papers, 71, 14, 10 and 5 % of researchers in Nigeria focused more on utilization of BC as soil amendment for improving soil quality, remediation, adsorbent and fuel purposes, respectively. Results obtained showed that biochar was mainly utilized in improving the quality of soil possibly dictated by the problematic Nigerian soil and quest to increase food production with increasing population. The current distribution of research shows some geographical variation, with higher concentrations in the derived savanna and humid forest zones. Notably, research is lacking in the northern and southern Guinea savanna zones, as well as the Mid-altitude, Sahel, and Sudan Savanna zones. These areas, particularly those with low organic soil content, could potentially benefit significantly from biochar application.Future research should focus on quantifying biochar use across zones, understanding the factors influencing its distribution, and exploring its potential for broader applications. This will help optimize biochar use for sustainable agriculture and environmental improvements in Nigeria.

Keywords: Agro-ecological zones, biochar applications, soil quality, biochar.

1.0 INTRODUCTION

Pyrolysis involves heating biomass in the absence of oxygen, resulting in the formation of BC, a complex and heterogeneous substance (Wilson, 2014). BC generally lowers soil acidity and increases buffering capacity; increases dissolved and total organic C, CEC, available nutrients, water retention, and aggregate stability; and reduces bulk density (El-Naggar *et al*., 2019). BC can increase microbial activity, accelerate nutrient cycling, and reduce leaching and volatilization of nitrogen (Lehmann & Joseph, 2015). BC positively affects soil properties, nutritional qualities, microorganisms, and agricultural output (Akhil *et al*., 2021). BC helps to improve soil quality and reduce pollutants and is crucial for decreasing greenhouse emissions, thus mitigating global climate change (Bolan *et al*., 2022). The utilization of BC enhances soil fertility by minimizing nitrogen leaching into groundwater, enhancing cation exchange, mitigating soil acidity, and improving water retention capacity (Hamidzadeh *et al*., 2023).

There are certain difficulties with BC that need to be resolved (Zubairu *et al*., 2023). BC amendments reduced the activities of soil enzymes associated with C cycling by 6% (Zhang *et al*., 2019). Due to the fact that poisons have a tendency to adhere to charcoal, an increase in the amount of toxins in food is also a challenge (Sohi *et al*., 2009). Due to the alkaline nature of BC, the application of very high doses causes certain plants to grow more slowly, resulting in reduced yields (Prapagdee *et al*., 2017). When BC is mixed into soils or later eroded, tiny particles of BC that are discharged into the air can potentially cause considerable regional and global warming (Zhang *et al*., 2019).

BC (BC) exhibits recalcitrant properties, which are crucial for soil conditioning, determining nutrient availability and fertility, and reducing N_2O, CO_2, and CH_4 gas emissions, as well as sorbing inorganic and organic contaminants (Niazi *et al*., 2018). BC is made up of volatile and condensed aromatic organic substances (Brewer *et al*., 2011) and elements of an inorganic source (Cantrell *et al*., 2012). BC properties are highly dictated by the pyrolysis temperature. BC produced at high temperature usually has a higher cation exchange capacity (CEC) (Singh *et al*., 2010), porosity, inner surface area, adsorption capacity, organic C content, and pH (Rajapaksha *et al*., 2015). The types of soil and BC determine the potential importance of BC application to soil (Butnan *et al*., 2015). The range of carbon in BC is 50–90%, with volatile substances about 40%, water 1–15%, and mineral substances about 5% when the biomass type and the parameters of thermal processing applied are considered (Mondal, 2020). The volatile matter, fixed carbon, ash, and moisture levels of biomass, respectively, range from 65 to 90, 3 to 26, 1 to 15, and 0 to 10% (Li *et al*., 2022). BC's polarity, aromaticity, and stability are dependent on the carbon-to-oxygen and hydrogen-to-carbon ratios (Li *et al*., 2022). Due to its high aromaticity and low polarity, BC is resistant to microbial degradation. This resistance is based on the ratios of hydrogen to carbon and oxygen to carbon (Liew *et al*, 2022). The protein and macromolecular amino acid composition of the feedstock determines the nitrogen content of the BC, with organic waste having the highest nitrogen content followed by agricultural residues and woody biomass (Pariyar *et al*., 2020).

Thermochemical conversion is a common technique for BC production (Yaashikaa *et al*., 2020). Thermochemical conversion method includes pyrolysis, hydrothermal carbonization, gasification and torrefaction (Pang, 2019). These processes recycle CO_2 released during combustion, which originates from atmospheric carbon captured through photosynthesis, potentially leading to neutral or negative carbon emissions (Routa *et al*., 2012). To achieve maximum BC yield, the production technique must be suitable for the type of biomass, and optimal process conditions like heating rate, temperature, and residence time are essential (Yaashikaa *et al*., 2020). Moreover, biomass combustion generates fewer harmful gas emissions, such as nitrous oxides (NOx) and sulphur dioxide (SO_2), compared to most fossil fuels, as biomass contains lower levels of sulfur and nitrogen (Vassilev *et al*., 2010). These advantages position biomass as a promising renewable energy source.

BC, derived from biomass, has garnered significant attention in the scientific community due to its versatile properties and wide-ranging applications (Das *et al*., 2021). The utilization of BC has been acknowledged by modern science and technology, offering numerous advantages (Hamidzadeh *et al*., 2023).BC, a by-product of biomass thermochemical conversion, has gained increasing attention for diverse applications. BC finds application in various areas worldwide, including agriculture (Afzal *et al*., 2017), removal of heavy metals like Cr(VI) (Liu *et al*., 2020), Hg(II) (Tang *et al*., 2015), As(V) from the effluent (Wang *et al*., 2015), organic pollutant (Qu *et al*., 2021), catalytic activity (Wang *et al*. 2020), energy production (Rago *et al*., 2020), reduction of CO_2 (Liu *et al*., 2018). A common application involves using BC as a soil amendment to mitigate greenhouse gas emissions and enhance soil quality. BC also serves as a precursor for catalysts and contaminant adsorbents (Qian *et al*., 2015). However, in Nigeria, BC utilization is still in its nascent stages compared to other non-African countries, necessitating further research and exploration.

1.2 Methodology

This paper was coined by summarizing recent papers on biochar use in Nigeria obtained from Google scholar in the last five years. Papers focusing on biochar use for the purposes of soil quality, adsorbent, fuel/power and remediation were used for this review. Papers were randomly chosen between the periods of 2019-2023 obtained from the search results. Results were summarized using Table and Figures.

1.3 USES OF BIOCHAR

Recent investigations have underscored the manifold benefits associated with the utilization of biochar (BC) in soil management, encompassing the mitigation of global warming by means of carbon sequestration and the augmentation of soil vitality and yield (Routa *et al*., 2012).By sequestering carbon within the soil for extended periods, BC incorporation as a soil amendment directly curtails greenhouse gas emissions, concurrently fostering soil fertility and overall soil well-being. Enhanced soil fertility induces heightened plant growth, leading to increased CO_2 assimilation. This virtuous cycle reduces the necessity for excessive fertilization, subsequently diminishing carbon emissions linked to fertilizer production, transportation, and application. Moreover, the introduction of BC into the soil matrix has the potential to mitigate emissions of other potent greenhouse gases such as N_2O and CH_4, which possess greater global warming potential than CO_2. Implementing BC derived from approximately 50% of global crop residues and 67% of global forestry residues as pyrolysis feedstocks for soil enrichment could result in an annual reduction of approximately 0.9 Gt in carbon emissions (Meyer *et al*., 2011). BC production through pyrolysis, as an alternative to direct combustion, holds the capacity to offset up to 12% of annual anthropogenic carbon emissions through soil amendment (Lehmann *et al*., 2006).BC properties such as negative charge density, high surface area are used to improve soil quality (Yadav et al., 2023). Because of this, it helps to improve soil quality and reduce pollutants and is crucial for decreasing greenhouse emissions, thus mitigating global climate change (Lehmann et al., 2021). This application of BC to soil influences the function and habitat of mycorrhizal fungi and overall soil organisms which stimulate the soil quality (Kannan et al., 2020).The incorporation of BC into soil not only amplifies agricultural productivity through heightened soil fertility, pH regulation in acidic soils, and enhancement of soil cation exchange capacity (CEC) (Kookana, 2011), but it also fosters soil microbial activity and nutrient retention (Lehmann *et al*., 2011). Elevating soil CEC augments soil fertility by averting nutrient runoff and establishing a nutrient reservoir accessible to plant root systems. BC, containing essential nutrients like nitrogen (N), phosphorus (P), and potassium (K), contributes nutrients directly to the soil. Furthermore, the augmentation of nutrient retention capabilities indirectly enhances soil fertility (Sohi *et al*., 2010).BC's role in nutrient conservation within soil serves to mitigate the risk of surface water eutrophication. Research conducted by Laird *et al*. (2010) illustrates that the introduction of BC significantly curbs nutrient leaching in Midwestern agricultural soil, thereby safeguarding water sources from nutrient contamination (Poerschmann *et al*., 2013). In the Amazon region, heightened soil nitrogen retention, facilitated by BC, has been linked to augmented nutrient uptake by crops (Steiner *et al*., 2008). BC's influence on fostering fungal growth and enhancing soil microbial activity has also been observed (Steiner *et al*., 2007).BC can ameliorate the negative impcts of salt affected soil on soil quality such as soil aggregation and stability (Alkharabsheh*et al*., 2021).BC's capacity to remediate pollutants from water and sediment further contributes to environmental amelioration. Studies have demonstrated BC's proficiency as a sorbent for certain soil pollutants (Ahmad *et al*., 2014). Leveraging its extensive surface area and microporosity, BC exhibits effective adsorption of organic contaminants from water sources. BC produced at temperatures exceeding 400 °C, due to its greater surface area, displays superior adsorption capacity compared to BC generated below 400 °C.

Additionally, BC has been shown to immobilize heavy metals in soil (Houben *et al*., 2013). The extensive surface area and microporosity of BC play a pivotal role in sequestering these toxic substances, altering their bioavailability and ecotoxicological effects. Oxygenated functional groups on BC's surface contribute to its mechanism of adsorbing metal contaminants (Uchimiya *et al*., 2011). Notably, BC derived from cottonseed hulls with high oxygen content exhibited significant uptake of heavy metals (copper, nickel, cadmium, and lead) from soil.Gonzalez (2013) has asserted that BC-derived activated carbon exhibits notable CO_2 adsorption capabilities (up to 4.8 mmol/g at 1 atm and 0 °C). Under conditions simulating real flue gas, BC's CO_2 adsorption capacity at typical temperatures was determined to be around 0.6-0.7 mmol/g (González, 2013). Surface area and micropore volumes have been identified as critical factors influencing hydrogen adsorption, with activated carbon featuring small pores showcasing significant hydrogen uptake capacities (Kacprzak *et al*., 2014).

Fuel cells, when supplied with suitable fuels like hydrogen, offer heightened efficiency and reduced greenhouse gas emissions in comparison to conventional power generation methods. Recent studies (Elleuch *et al*., 2013) propose BC's potential as a Direct Carbon Fuel Cell. Research by Kacprzak *et al*. (2014) scrutinized the impact of various carbonaceous fuels on direct carbon fuel cell performance, including commercial graphite, carbon black, diverse BC types, and more.Scientists have investigated using biochar made from various biomass sources as electrodes in microbial fuel cells and other energy storage devices (Bataillou et al., 2022). Zhang et al. (2020) used cedar wood to produce biochar and reported that biochar produced at higher temperatures (600–900 °C) has low electrical resistivity and high surface area with ordered honeycomb structure compared to biochar produced at a lower temperature (400 °C). Zhang et al. (2017) carbonized cotton via pyrolysis to prepare carbonized cotton electrode for battery. The electrode exhibited an energy efficiency of 73.5% and a discharge capacity of 366 mAh at a current density of 100 mA cm^{-2}.Khan et al. (2019), identified several key properties that make porous carbon materials ideal for battery electrodes: high thermal stability, large surface area, a network of pores, good electrical conductivity, and resistance to chemical breakdown. These characteristics all contribute significantly to the performance of batteries. According to Ahuja et al. (2024), different cathode materials were compared, and biochar turned out to be significantly cheaper than those made from metals.Further, Patwardhan et al. (2022) mentioned that metal-based cathode catalysts i.e. platinum, Fe-AAPyr (aminoantipyrine), Fe- Mebendazole, and MnO_2 are 115, 2.4, 2.5, and 2.9 folds costlier than biochar.Supercapacitors, as energy storage devices, have garnered attention for their high power density, extended life cycles, and rapid charge/discharge capabilities, suitable for applications like electric vehicles and electronic devices (Xiao *et al*., 2012). The microstructure of their conductors greatly influences supercapacitor performance. Carbon materials with substantial surface areas and porous structures are the favored constituents for supercapacitor construction (Liu *et al*., 2012). Recent investigations have explored BC derived from diverse biomass sources, such as paper, cardboard, and woody biomass, as promising supercapacitor electrode materials, offering both cost-effectiveness and satisfactory performance (Basri *et al*., 2013). Supercapacitor electrodes constructed from BC derived from woody biomass byproducts exhibited a potential window of approximately 1.3 V, along with rapid charge/discharge behavior (Jiang *et al*., 2013).

Nigeria's expansive tropical rainforest serves as a rich source of biomass materials (Olorunfemi *et al*., 2019), with climatic variations across the country enabling diverse crop cultivation, thereby enhancing the availability of potential BC feedstocks. Recent research endeavors within Nigeria have focused on exploring BC's role in soil fertility and crop performance enhancement. While literature provides insights into BC's properties and its conventional application as a soil amendment, limited attention has been dedicated to its novel applications. This paper offers an overview of recent research in BC utilization within Nigeria, encompassing research published between 2019 and 2023.

1.4 RECENT STATE OF BIOCHAR USE IN NIGERIA

Nigeria possesses seven distinct agro-ecological zones, as identified by Oluwaseyi (2017): Sahel Savanna (SHS), Sudan Savanna (SS), Northern Guinea Savanna (NGS), Southern Guinea Savanna (SGS), Mid-altitude (MA), Derived Savanna (DS), and Humid Forest (HF). These zones support the growth of diverse crops, generating ample biomass suitable for the production of biochar (BC). Analyzing the applications of BC is crucial for shaping its prospects in Nigeria. Recent research has seen a surge in interest due to its promising outcomes. Exploring its present research focus and utilization is paramount. In a two-year field study by Oladele (2019) who investigated how incorporating rice husk biochar affects rain-fed upland rice yield and soil biochemical properties.Biochar application, particularly at the highest rate (12 t ha^{-1}), significantly increased soil enzyme activity (invertase, alkaline phosphatase, urease, catalase) - especially in the top soil layer, soil organic carbon, available nitrogen, available phosphorus, total nitrogen, and soil moisture content (all in the top 0-0.1 m) and rice performance (yield by 46%.) (Table 1). Utilizing BC, further studies by Oladele *et al*. (2019) investigates the effects of combining biochar and inorganic fertilizer on rain-fed upland rice grown in Sub-Saharan Africa (Ondo sate of Nigeria). Field experiments showed that co-applying biochar and fertilizer significantly increased rice yield by up to 140%, grain nutrient recovery by 191%, and improved soil health in the top 10 cm. This improvement in soil health included reduced bulk density, increased water holding capacity, and enhanced chemical properties like N, P, K, and organic carbon. Researching further within the context of soil quality, Olakayode *et al*. (2020) investigated how biochar application affects dispersible clay content and various chemical properties in contrasting soil types (a sandy loam and a loamy sand). Milled biochar was incorporated into the soil samples (0 kg/ha, 450 kg/ha, 900 kg/ha, and 1344 kg/ha). Following incubation for 12 weeks, the results revealed that biochar application at the two highest rates (450 kg/ha and 1344 kg/ha) significantly improved several aspects of the soil chemistry in the sandy loam. These improvements included increases in soil pH, organic carbon content, and available phosphorus. Interestingly, biochar application at a rate of 900 kg/ha specifically led to a significant reduction in dispersible clay content.

Biochar has a low nutrient content and decomposes very slowly. While beneficial for soil health in the long term, it doesn't provide a quick boost for crops. To address this, Adekiya *et al*. (2020) conducted a two-year study (2017-2018) to evaluate how hardwood biochar, Poultry manure (PM) combined with faster release nutrient source (NPK), could impact ginger growth and yield. Interestingly, NPK fertilizer alone did not significantly improve soil physical properties and showed minimal impact on soil pH, organic matter content, calcium, and magnesium levels. While BC+ Poultry Manure led to better soil physical characteristics, BC+NPK yielded increases of 49.2% and 50.3% in 2017 and 2018, compared to biochar alone. They attributed this superior performance of BC+NPK to its readily available nutrients, especially nitrogen and potassium, which are essential for ginger rhizome development.

Further testing of BC by Adamu and Junaidu (2021), 0, 4, and 16 tons/ha softwood prune BC and micronutrient supplements at a rate of either 1 or ½ litre/ha were utilized. Sixteen (16) tons/ha of biochar resulted in significant increases in several soil quality measures such as rise in soil organic carbon content, a boost in organic matter content, an increase in cation exchange capacity (CEC), a rise in nitrogen content, and a slight increase in soil pH. This enhanced soil environment may lead to better okra growth and yield in future growing seasons.

In sperate studies by Agbede (2021) who investigated tillage practices, biochar, poultry manure, and NPK fertilizer, both individually and combined in indicated that reduced tillage in combination with NPK fertilizer, biochar and poultry manure prove to be an effective and sustainable management strategy for improving soil quality and carrot yield than conventional tillage in combination with NPK fertilizer, biochar and poultry manure. Mixture of biochar and poultry manure increased fresh carrot root yield by 76%, respectively. From this BC appears to be a promising tool for improving soil health and fertility in the long term. However, for optimal plant growth, it may be most beneficial to combine biochar with a fast-releasing nutrient source, especially for crops requiring a quick nutrient supply. In a study by Oyeyiola and Adeosun (2022), the effectiveness of urea-spiked poultry manure BC, pyrolyzed at 350 °C, was examined for its potential to ameliorate simulated sodic soils at Ladoke Akintola University of Technology's Teaching and Research Farm. The co-pyrolysis of poultry manure BC with urea proved most effective in reducing exchangeable sodium and exchangeable sodium percentage in soils. Conversely, poultry manure BC that was not co-pyrolyzed with urea exhibited the highest reduction in soil pH.

Abanum *et al*. (2022) conducted a screen house experiment at the University of Abuja to investigate the impact of organic materials as soil amendments on cashew seedling growth. Cocoa pod husk BC was found to be promising for cashew nursery and field trials post-transplanting. Isimikalu *et al*. (2022) carried out a field experiment in Illorin, within Nigeria's Southern Guinea Savanna region, to evaluate the influence of soil temperature and moisture on soil organic carbon mineralization. Synthetic (NPK) and organic (BC produced at approximately 350 °C) amendments were applied to a maize cropping system. Sole BC treatment exhibited a significant positive correlation with organic carbon mineralization under Typic Ustorthent.In another study, Okuo *et al*. (2022) investigated the effects of Blighia sapida-derived BC, pyrolyzed at 350 °C in a microwave furnace, on the mobility and bioavailability of heavy metals in lead-acid battery-contaminated soil. Their findings revealed that increasing the percentage of Blighia sapida BC amendment led to a decrease in heavy metal content, effectively mitigating heavy metal mobility, bioavailability, and toxicity in the polluted soil.

Okoro and Nwachukwu (2021) conducted a pot experiment in Ebonyi, Abakaliki, focusing on the effects of BC derived from empty oil palm bunches (pyrolyzed at 320 °C) and composted poultry manure on immobilization and migration of heavy metals. After a 6-week planting period, significant variations in heavy metal concentrations were observed due to BC application. Sodah et al. (2022) conducted field experiments to assess the impact of varying BC application rates on soybean nodulation and yield in Lafia, within Nigeria's Southern Guinea Savanna. The results indicated that BC positively and significantly influenced soybean nodulation and yield. Solomon (2022) studied nitrate leaching in soils of different textural classes in Adawama state of Nigerian Savanna. BC derived from maize cob, rice husk, cow dung, and chicken litter, pyrolyzed at 600 °C, was applied. Application of rice husk BC and cow dung BC at different rates significantly reduced nitrate leaching in sandy loam and loamy soils, respectively.

Table 1. Recent Biochar uses in Nigeria

Feedstock	Temperature (^{0}C)	Type of Experiment	Utilization	Location/Agro-ecological zones	Scope	Effect	Author(s)
Rice husk	350	Field	Soil quality	Ondo/HF	Sole BC	Improved soil quality and rice yield by 46%	Oladele (2019)
Rice husk	350	Field	Soil quality	Ondo/HF	BC + Inorganic fertilizer	140% rice yield increase and overall soil improvement	Oladele *et al*. (2019)
-	.	Laboratory	Soil quality	Osun/DS	Sole BC	Improved sandy loam organic C, available P	Olakayode *et al*. (2020)
Hardwood	580	Field	Soil quality	Ondo/HF	BC + NPK	BC+NPK yielded increases of 49.2% and 50.3% in two separate years and improved soil properties	Adekiya *et al*. (2020)
Softwood prune branches	-	Field	Soil quality	Nassarawa/DS	BC + Micronutrients	Improved soil quality specifically with 16 tons/ha	Adamu and Junaidu (2021)
Hardwood	580	Field	Soil quality	Ondo/HF	Tillage + BC+ Poultry Manure +NPK	BC, poultry manure, tillage combinations increase carrot yield by 76% and improves soil quality	Agbede (2021)
Poultry manure	350	Laboratory /Incubation	Soil quality	Oyo/DS	BC + urea	Reduce Na and exchangeable Na and reduced pH in soil	Oyeyiola and Adeosun (2022)
Cocoa pod husk	-	Pot	Soil quality	Abuja/DS	Sole BC	Improved cashew in nursery	Abanum *et al*. (2022)
-	350	Field	Soil quality	Kwara/Derived Savanna	NPK+BC	Positive result on Maize crop performance	Isimikalu*et al*. (2022)
Blighia sapida	350	Pot	Soil remediation	Edo/HF	Heavy metal remediation	Reduced heavy metal mobility	Okuo *et al* (2022)

Oil palm bunch	320	Pot	Soil remediation	Ebonyi/HF	Heavy metal immobilization	Demonstrated the capacity to reduce bioaccumulation of lead and zinc in okra plant	Okoro and Nwachukwu (2021)
-	-	Field	Soil quality	Nassarawa/DS	Nodulation	Increased nodule number, weight and yield of soybean	Sodah *et al*. (2022)
Maize cob, rice husk, cow dung and chicken litter	600	Laboratory	Soil quality	Adamawa/SGS	Nitrogen leaching	Reduced N leaching	Solomon (2022)
Empty maize cob and empty oil palm bunch	320	Pot	Soil remediation	Ebonyi/HF	Heavy metal remediation	reduce bioaccumulation of lead and zinc in okra plant	Okoro *et al*. (2022)
	~350	Field	Soil quality	Kwara/DS	Effect on rice yield	higher rice yields	Isimikalu *et al*. (2022)
Parkia biglosa, *Khaya senegalensis*, *Prosopis africana*, and *Terminalia glaucescens*	580	Field	Soi quality	Ondo/HF	Poultry Manure + BC	improved the quality of degraded acidic soil and sweet potato tuber yield	Agbede and Oyewumi (2022a)
-	>450	Laboratory	Fuel	Ebonyi/HF	Production of biofuel from *Spirogyra porticalis*, *Nymphaea alba* L, rice husk and BC	*S. porticalis* and *Nymphaea* L energy production advantageous than BC	Anyanwu *et al*. (2022)

Eggshell BC	500	Laboratory	Soil quality	Osun/DS	Calcium carbonate and waste materials (eggshell powder and eggshell BC) calcium carbide waste, and wood ash liming potential on the soil pH	Significant increase in soil pH and concentrations of some basic cations were observed after the addition of the waste materials including BC from eggshell.	Azeez *et al*. (2022)
chicken feather-based metal oxide-rich	417.2	Laboratory	adsorbent	Kwara/DS	Evaluation for adsorption use	**Was found to be mesoporous in nature, which shows that it can be used in an adsorption process**	Adeniyi *et al*. (2023)
maize stalk	500	Laboratory	Adsorbent	Bauchi/NGS/MA	sulfate sorption and desorption kinetics of BC	**rate of desorption of adsorbed sulfate desorption was not primarily controlled by the BC**	Aliyu *et al*. (2023)
-	-	Field and pot	Soil quality	Oyo/DS	compost, BC and micronutrients on an alfisol	**Optimum growth and economically higher yield for tomato crop was obtained with BC and compost.**	Adetayo *et al*. (2023)

Sahel Savanna (SHS), Sudan Savanna (SS), Northern Guinea Savanna (NGS), Southern Guinea Savanna (SGS), Mid-altitude (MA), Derived Savanna (DS) and Humid Forest (HF), Biochar (BC)

Okoro *et al*. (2022) conducted a pot experiment aimed at assessing the impact of composted poultry manure and pyrolyzed empty maize cob biochar (BC) and empty oil palm bunch BC (pyrolyzed at 320°C) on the bioaccumulation of heavy metals (lead and zinc) in Okra plants. Additionally, they examined the influence of artisanal mineral mining activities on the environment using ecological risk indices in Amagu, Abakaliki, and Southeastern Nigeria. Their results indicated that the combined application of composted poultry manure with empty maize cob BC and empty oil palm bunch BC exhibited the ability to decrease the bioaccumulation of lead and zinc in Okra plants.

Isimikalu *et al*. (2022) conducted two field experiments over two years in the Kwara State southern Guinea savanna agroecological zone of Nigeria, utilizing biochar (BC) derived from rice husk through pyrolysis in a top-lift reactor at approximately 350°C. The incorporation of BC resulted in higher rice yields during both years, with an average yield increase of around 55% at 15 t/ha compared to the control group.To assess carbon sequestration and maize growth in the sandy clay soil of Gombe, Sudan Savanna zone of Nigeria, Mustapha *et al*. (2022) applied maize stalk biochar produced at 400°C. The utilization of biochar was found to enhance soil organic carbon, total nitrogen, and accessible phosphorus content. It also improved soil bulk density and water-holding capacity. However, there was no significant impact observed on maize production and growth.

In a field experiment conducted in Owo, Ondo State of Nigeria, Agbede and Oyewumi (2022a) observed that the application of poultry manure alone, combined with hardwood biochar from various sources (Parkia biglosa, Khaya senegalensis, Prosopis africana, and Terminalia glaucescens) at an average temperature of 580°C, improved the quality of degraded acidic soil and enhanced sweet potato tuber yield. Similar positive outcomes were replicated in sandy and loam soil conditions (Agbede and Oyewumi, 2022b).In a laboratory study, Anyanwu *et al*. (2022) investigated the potential of Spirogyra porticalis and Nymphaea alba Linn for producing biodiesel, bioethanol, and biogas, in comparison with other feedstocks such as rice husk and biochar carbonized at temperatures exceeding 450°C. Their findings indicated that biofuel production from Spirogyra porticalis and Nymphaea alba L offered distinct advantages over other feedstocks, including biochar.

Azeez *et al*. (2022) conducted a laboratory incubation experiment at Obafemi Awolowo University, Ile-Ife, Osun, Nigeria, to assess the effects of calcium carbonate addition and various waste materials (eggshell powder, eggshell biochar prepared via pyrolysis at 500°C, calcium carbide waste, and wood ash with liming potential) on the soil pH and other chemical properties of chemically degraded sandy loam soils. The addition of these waste materials, including eggshell biochar, led to a notable increase in soil pH and the concentrations of certain basic cations.In Illorin, Kwara, Nigeria, Adeniyi *et al*. (2023) produced metal oxide-rich biochar derived from chicken feathers using a top-lit updraft reactor at a peak temperature of 417.2°C. The resulting biochar was characterized as mesoporous in nature, suggesting its potential applicability in adsorption processes.

Aliyu *et al*. (2023) carried out a laboratory study to investigate sulfate sorption and desorption kinetics in soil parent materials amended with maize stalk biochar pyrolyzed at 500°C in the Sudan savannah region of Bauchi, Nigeria. They concluded that the desorption rate of adsorbed sulfate was not primarily controlled by the biochar.In Ibadan, Adetayo *et al*. (2023) conducted a study on the growth and yield response of tomato (Solanum lycopersicum L.) influenced by compost, biochar, and micronutrients on an alfisol. Optimal growth and higher yields for the tomato crop were achieved using 30 kg/ha of biochar and 45 kg/ha of compost.

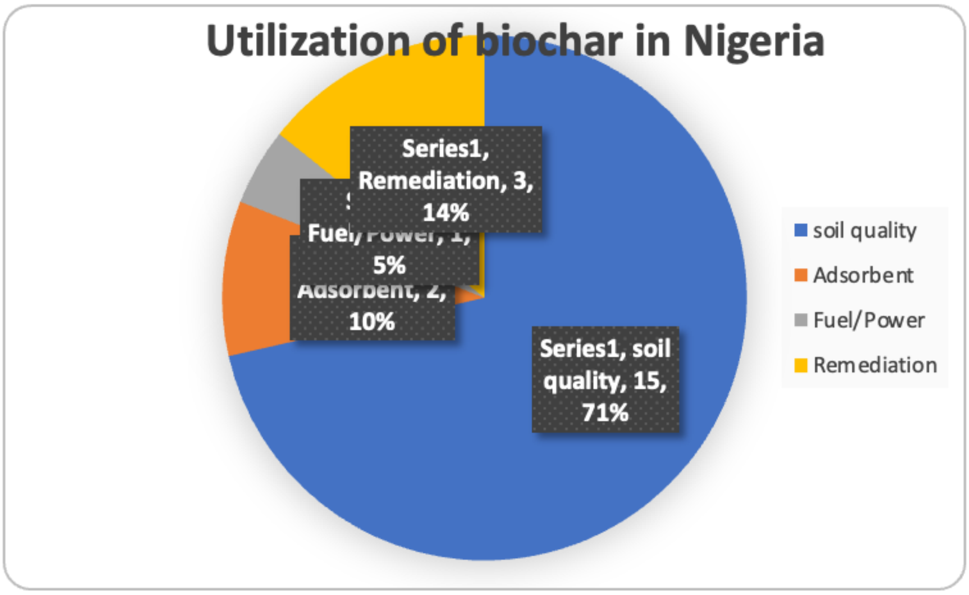

Fig. 1. Utilization of BC in Nigeria

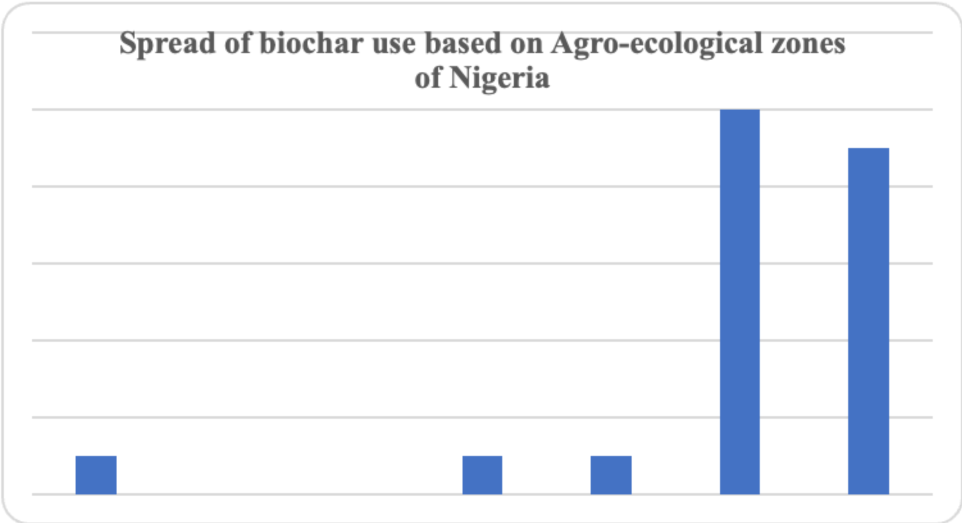

Fig. 2. Spread of BC use based on Agro-ecological zones of Nigeria

1.5RESULT AND DISCUSSION

Worldwide, biochar (BC) research is getting more ground due to its potential benefits. Biochar research in Nigeria is experiencing a period of rapid growth, fueled by its potential to benefit both agriculture and environmental health. The majority of current research (71%) (Fig. 1) focuses on biochar's ability to improve soil quality. Biochar's properties, such as increasing soil organic matter, improving the availability of key nutrients like nitrogen and phosphorus, and enhancing water retention capacity, make it a valuable tool for long-term soil improvement. This research is spread across all seven ecological zones of Nigeria suggesting its potential for nationwide impact on agricultural productivity.

While soil quality currently dominates biochar research, other promising applications are starting to emerge such as the remediation of polluted land. Biochar shows promise for immobilizing heavy metals in contaminated soils, making them less harmful for plant growth and overall environmental health. Although currently a smaller research focus (14%), it holds significant potential for environmental restoration efforts. Early research is exploring using biochar as adsorbent (10%) in cleaning water from pollutants. Further investigation could unlock new applications for biochar. Carbon materials with substantial surface areas and porous structures are the favored constituents for supercapacitor construction (Liu *et al*., 2012). BC was reported to have high surface area (Rajapaksha *et al*., 2015), but few was done in Nigeria (5%) to utilize this. While limited research is currently focused on biochar for energy production (5%), its high surface area suggests potential for supercapacitors (devices for storing electrical energy).

The current distribution of biochar research shows some interesting geographical patterns. Research is more concentrated in the derived savanna and humid forest regions compared to other zones. This may be due to factors like the specific challenges and opportunities these areas face in terms of soil quality and environmental pollution. Notably, the northern and southern Guinea savanna zones, as well as the Mid-altitude, Sahel and Sudan Savanna, haven't received much research attention (Fig. 2). This doesn't necessarily mean biochar isn't being used there, but it highlights the need for further investigation to understand its potential impact in these areas. The Sahel and Sudan savanna zones, with their naturally low organic soil content, could benefit significantly from biochar application. However, research data suggests no reported studies in these areas yet.

1.6 RECOMMENDATION

Based on the findings from the reviewed papers, I would like to make the following recommendations:

1. Promote Research Diversity: While the majority of research on biochar use in Nigeria has focused on improving soil quality, it is essential to encourage a more diverse range of research topics. Expanding studies in areas like soil remediation, adsorbent applications, and fuel/power generation can lead to a more comprehensive understanding of the potential benefits of biochar in various contexts.

2. Target Understudied Zones: The lack of reported research in the Southern Guinea Savanna (SGS), Sudan Savanna (SS), and Mid-altitude (MA) agro-ecological zones despite their need for soil improvement due to low organic content is a significant concern. Researchers should be encouraged to explore these areas to address the specific challenges faced by farmers in these regions.

3. Awareness and Education: Efforts should be made to raise awareness among researchers, policymakers, and farmers about the benefits of biochar. Education and training

programs can help disseminate knowledge and promote the adoption of biochar in regions where it is underutilized.

4. Collaboration and Funding: Encourage collaboration between researchers, institutions, and government agencies to facilitate research in the less studied agro-ecological zones. Additionally, seek funding opportunities specifically targeted at biochar research in areas where it is needed the most.

5. Long-Term Impact Assessment: Conduct long-term studies to assess the sustained impact of biochar applications in different agro-ecological zones. Understanding the long-term effects can provide valuable insights into the suitability and benefits of biochar in various environments.

6. Policy Support: Advocate for policies that promote the responsible and sustainable use of biochar in agriculture. Government support can play a crucial role in facilitating the adoption of biochar practices.

7. Knowledge Sharing: Encourage the sharing of research findings and best practices among researchers, farmers, and policymakers to promote the effective and responsible use of biochar across Nigeria.

By implementing these recommendations, we can contribute to a more balanced and effective utilization of biochar throughout Nigeria, addressing specific agricultural needs in different regions and promoting sustainable soil management practices.

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Influence of Chicken Feather Biochar on the Growth and Yield Indices of Maize (*Zea mays*) in the Derived Savannah Agro-Ecological Zone of Nigeria

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ABSTRACT

The study was carried out to assess the effects of chicken feather biochar on the growth and yield indices of potted maize (*Zea mays L.*) plants in the derived savannah agro-ecological zone of Nigeria. The experiment was sited at the Department of Soil Science, University of Nigeria, Nsukka. The chicken feather biochar rates used were 0g/4kg soil, 10g/4kg soil, 20g/4kg soil, 30g/4kg soil and 40g/4kg soil representing 0, 5, 10, 15 and 20 t/ha respectively. The experiment was laid out in a completely randomized design (CRD) with four replications. Data were collected on plant height (cm), stem girth (cm), number of leaves, number of cobs/plant and grain yield/plant (kg) after harvest. Results showed that the application of chicken feather biochar significantly ($p < 0.05$) increased plant height, stem girth, number of leaves and yield at the different rates of application. The 15 and 20 t/ha significantly ($p < 0.05$) increased plant height and stem girth from 8 weeks after biochar application/planting. The highest values of plant height (63.10 cm, 70.43 cm respectively) were recorded in 20 t/ha application rate at 8 and 12 weeks after planting. Number of leaves was not significantly ($p > 0.05$) influenced by chicken feather biochar rates. However, at 4, 8 and 12 weeks after planting (WAP), 15 t/ha produced highest number of leaves (7.33, 9.33 and 13.33 respectively). At 8 and 12 WAP, 20 t/ha increased stem girth significantly ($p < 0.05$) and recorded high values of 3.37 cm and 3.47 cm respectively. The yield indices (number of cobs and grain yield/plant) differed significantly ($p < 0.05$) among the rates of application. The 20 t/ha gave the highest mean values of the yield indices (1.5 and 0.35 kg respectively). Amendment of the soil with 20 t/ha chicken feather biochar gave the highest values of the growth and yield indices in maize and can, therefore, be recommended for maize production especially in the derived savannah agro-ecological zone of Nigeria.

Keywords: Chicken feather Biochar, growth and yield indices, maize, *Zea mays*, derived savannah

INTRODUCTION

Maize (*Zea mays* L.) is one of the most extensively cultivated tropical grains. It thrives in well-drained sandy loam or loamy soil. The ultisols of southeastern Nigeria agro-ecology are low in mineral reserves and the inherent poor soil fertility is one of the major causes of the declining yield of maize crop in Nigeria (Okoroafor et al., 2013; Adejumo et al., 2016). In addition to increasing soil acidity, low cation exchange capacity, low base saturation, nutrient depletion through erosion and leaching have also decreased the productive potential of the cultivated areas in southeast Nigeria (Onwudike, 2015). Enhancing food production on intensively cultivated soils of derived savannah agro-ecological zones of Nigeria by increased nutrient input and recycling will be necessary to provide food security for Nigeria's rapidly expanding population. Deliberate initiatives to encourage the use of plant and animal residues for crop production can help achieve this. Soil enhancement using organic wastes such as biochar has become a viable option to manage fertility and acidity problems. Biochar is the product of incomplete combustion of biomass in the absence of oxygen and studies have shown that it increases soil pH (Martinsen et. al., 2015), growth and yield of crops (Agegnehu et al., 2016; Rafique et al., 2020). Different studies have reported the positive effects of biochar application on agronomic performance of tropical soils (Zhu et al., 2014; Cely et al., 2015; Jin et al., 2015; Sikder and Joarder, 2019).

Globally, feathers are produced in large quantities annually as a by-product of poultry processing. Feathers could account for about 6 % of the live weight of the mature chicken. They are rich in a keratinous protein, which is a fibrous and insoluble protein (Fakhfakh et al., 2011). Feathers have multiple aesthetic and industrial uses. However, since animal derived biochars have been found to improve the soil properties such as pH, CEC, water holding capacity, organic matter and contain elements such as nitrogen, phosphorus, calcium, magnesium, chicken feathers can be used as alternative to organic manure and liming materials (Singh et al., 2010). The efficacy of chicken feather-based biochar as an organic amendment should therefore be assessed. The derived savannah agro-ecological zone of Nigeria typically experiences specific environmental conditions, such as seasonal variations in rainfall and temperature (Ibebuchi and Abu, 2023), which can impact maize growth. Understanding how chicken feather biochar interacts with these environmental factors to influence maize growth can provide valuable insights for sustainable agricultural practices in the region. Research findings from such studies could inform farmers and policymakers about the potential benefits of incorporating chicken feather biochar into agricultural practices to enhance maize production while promoting soil health and fertility. Additionally, the study may highlight the importance of utilizing locally available agricultural waste products, like chicken feathers, to produce biochar, thereby contributing to waste management and resource sustainability efforts in the tropics. The objective of this study was to determine the maize crop responses to different rates of chicken feather biochar application.

2. MATERIALS AND METHODS

2.1. Soil and its characteristics

The pot experiment was carried out in the glass house of the Department of Soil Science. Topsoil (0-15 cm) was collected from the Teaching and Research Farm of the Department of Soil Science, University of Nigeria, Nsukka, which lies between Latitude $06^0$25`N and Longitude $07^0$24`E and at an altitude of approximately 400m above sea level. A fallow portion of the farm was identified, cleared and samples were collected. The soil was weathered, brownish red and a coarse-textured ultisol, with a sandy loam textural class, strongly acidic pH, with moderate soil organic carbon (SOC) and available phosphorus, low total N and very low exchangeable potassium (Ebido et al., 2021).

2.2. Biochar production

Chicken feathers were collected from the Abattoir in Nsukka town. The feathers were pyrolysed (heating with limited oxygen) using an improvised kiln of a 10 kg capacity cylindrical drum, punctured at the sides and externally heated over a closed-chamber furnace at a temperature of 550-600°C. Before heating, the chicken feathers were put inside the drum and sealed tightly with a lid. To guarantee even burning of the chicken feathers, the drum was rotated continuously. After 45 to 60 minutes, the smoke that emerged from the pierced areas turned bright green, indicating entire burning of the feathers.

2.3. Experimental Procedure, Treatment and Design

The air-dried topsoil used for the experiment was sieved with 2-mm sieve into plastic pots. Twenty plastic pots of 4 kg soil capacity were used for the experiment. The topsoil and the biochar were thoroughly mixed in the pots and watered with two litres of water before planting. Planting was done immediately after watering. Subsequently, the planting media in the pots were watered routinely every two days with 50 cl of water. The treatments were five rates of the chicken feather biochar i.e. 0, 10, 20, 30 and 40 g 4 kg soil^{-1}, equivalent to 0, 5, 10, 15 and 20 t ha^{-1}, respectively (with average soil bulk density of 1,000 kg m^{-3}). The experiment was laid out in a screen house in a completely randomized design (CRD) with four replications.

2.4. Planting Operation and Data Collection

Hybrid maize (*Zea mays* L.) variety (Oba super II) obtained from Department of Crop Science, University of Nsukka, was used as a test crop. Two maize seeds were sown directly in each pot at a depth of 3 cm, and constantly kept moist but not waterlogged throughout the experimental period which lasted for three months. Weeding was carried out manually by hand rouging at monthly intervals. Data were collected on the following parameters;

Plant height: One plant from each pot was tagged and sampled while 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 weeks after planting (WAP).

Stem diameter: Stem diameter was measured at stem base point immediately above the soil surface, of the selected plant and used to compute the stem diameter values for each pot at 4, 8 and 12 WAP.

Number of leaves per plant: The number of fully opened, mature and non-senescence leaves was counted for each of the selected plants and used to compute the values for each pot at 4, 8 and 12 WAP.

Yield and Yield Components: The maize cobs were harvested at 12 WAP and the mean number of cobs/plant was recorded in the selected plant, as well as the fresh weight of the grains/plant.

2.5. Statistical analysis

The agronomic data collected were subjected to one-way analysis of variance (ANOVA) for experiments in CRD, using a linear model procedure with the help of the software SAS Discovery Edition 4. The least significant difference (LSD) test was used to separate means that were significant at 5% probability.

3. RESULTS AND DISCUSSION

3.1. Effects of Chicken Feather Biochar on Maize Growth

There were general increases in growth parameters of maize grown on soil amended with chicken feather biochar throughout the growing period compared to control (Table 1). Chicken feather biochar had high significant ($P < 0.05$) effect on the growth of maize which could be as a result of the inherent nutrients in the chicken feathers. The reports of Lehmann et al. (2006) and Singh et al. (2010) showed that biochar derived from animal products are richer in nutrients. These significant influence on maize growth parameters by chicken feather biochar was in accordance with the findings of Onwuka and Nwangwu (2016), who reported that poultry derived biochar had higher significant ($p < 0.05$) effect on okra growth compared to other animal sources of biochar.

There were variations among application rates,with 20 t/ha recording the highest mean values for plant height (56.34 cm) and stem girth (3.01 cm) while 15 t/ha recorded the highest values of the number of leaves (10.00). Amongst the different rates of biochar application, it was observed that the growth performance of maize increased with increase in rates of biochar application with 20 t/ha having highest values. This was in agreement with the works of Chan et al. (2008) which showed that crop growth and yield increased with increasing rates of biochar application.

Table 1: Main Effects of Biochar Rates on Maize Growth

Biochar rates (t/ha)	**Growth Parameters**		
	PH	**NL**	**SG**
0	43.08	8.22	2.28
5	36.94	7.78	2.06
10	39.61	7.78	2.09
15	54.26	10.00	2.67
20	56.34	9.22	3.01
$LSD_{(0.05)}$	7.45	1.7238	0.4404

t/ha=tonnes per hectare, PH: plant height, NL: number of leaves, SG: stem girt

3.3. Effects of Chicken Feather Biochar on the Plant Height of Maize at Different Sampling Periods

The results presented on Table 2 showed the mean plant height of potted maize at 4, 8 and 12 WAP. Plant height was significantly ($P < 0.05$) affected by the different application rates at the sampling periods of 8 and 12 WAP. The chicken feather biochar applied at 20 t/ha had the highest effects with values of 35.50 cm, 63.10 cm and 70.43 cm at 4, 8 and 12 WAP respectively, which agreed with the findings of Jeffery et al. (2011) who reported a high percentage increase of crop growth indices with biochar application at different rates. The significant increase in plant growth at 20 t/ha could be as a result of the high nutrients (potassium, phosphorus and nitrogen) release potential of biochar at that rate with time in accordance with the earlier report of Hossain et al. (2020). The control (0 t/ha) recorded the lowest mean plant height at 4 and 8 WAP, while 10 t/ha produced the least values of plant height at 12 W

Table 2: Effect of Biochar Rates on the Plant Height (cm) of Maize on the Field for 12 Weeks after Planting (WAP)

	Weeks After Planting (WAP)		
Biochar rates (t/ha)	**4**	**8**	**12**
0	21.39	40.70	48.20
5	29.20	46.30	53.73
10	29.43	41.60	47.80
15	35.20	58.13	69.43
20	35.50	63.10	70.43
$LSD_{(0.05)}$	NS	15.678	14.425

WAP: Weeks After Planting, t/ha=tonnes per hectare

3.4 Effect of Chicken Feather Biochar on Number of Leaves of Maize at Different Sampling Periods

Table 3 shows the mean number of maize leaves at 4, 8 and 12 WAP. There were no significant differences (P < 0.05) amongst the rates except at 4 WAP.. It was observed that 15 t/ha chicken feather biochar gave the highest mean number of maize leaves with values 7.33, 9.33 and 13.33 across the sampling periods; 4, 8 and 12 WAP respectively. This was followed by the 20 t/ha while (control) gave the least mean number of maize leaves. The results obtained amongst the treatment rates agree with the findings of Barrow (2012) and Ippolito et al. (2012) who reported that biochar contained essential nutrients necessary for plant growth although the resulting nutrient levels depended on the feedstock.

Table 3: Effect of Biochar Rates on the Number of Leaves in Maize on the Field for 12 Weeks after Planting (WAP)

	WEEKS AFTER PLANTING (WAP)		
Biochar rates (t/ha)	**4**	**8**	**12**
0	4.67	7.67	10.00
5	5.67	7.67	10.00
10	5.67	8.33	11.67
15	7.33	9.33	13.33
20	6.00	9.00	12.67
$LSD_{(0.05)}$	1.4854	NS	NS

WAP: Weeks After Planting, t/ha=tonnes per hectare

3.5. Effect of Chicken Feather Biochar on the Stem Girth of Maize at Different Sampling Periods

The results on Table 4 of maize stem girth at 4, 8, and 12 WAP showed significant differences (P < 0.05) among the biochar rates except at 4 WAP. The 20 t/ha biochar application increased the mean stem girth across the sampling periods (4, 8 and 12 WAP) by 40.13 %, 58.22 % and 52.86 % respectively, followed by 15 t/ha. It's noteworthy that the soil media amended with 15 and 20 t/ha of chicken feather biochar had increased the stem girth of the maize more than the other rates. This agrees with the reports of Zhu et al. (2015) who opined that biochar is an exceptional amendment material because of its high phosphorous and potassium contents which are readily available to the plants with no negative effects on the soil structure compared with mineral fertilizers which destroy the soil structure. This increase in the growth indices of maize plant might be linked to the steady nutrient release by the biochar into the soil media and availability of the nutrients for plant uptake and growth.

Table 4: Effects of Biochar Rates on the Stem Girth (cm) of Maize on the Field for 12 Weeks after Planting (WAP)

	Weeks After Planting (WAP)		
Biochar rates (t/ha)	**4**	**8**	**12**
0	1.57	2.13	2.27
5	1.77	2.10	2.30
10	1.90	2.53	2.73
15	2.00	2.93	3.13
20	2.20	3.37	3.47
$LSD_{(0.05)}$	NS	0.9831	0.831

WAP: Weeks After Planting, t/ha=tonnes per hectare

Effects of Chicken Feather Biochar Rates on the Yield Components of Maize

The results of Table 5 show the mean number of maize cob and weight of fresh maize (kg) after harvesting. It revealed that 20 t/ha chicken feather biochar gave the highest mean number of maize cobs/plant (1.50) and weight of fresh maize (0.35 kg) after harvest, followed by 15 t/ha while control (0 t/ha) had no yield. This shows that animal sources of biochar have higher nutrient contents and stabilised organic materials that help improve the fertility status of the soil thereby improving growth. Therefore, it was observed that 20 t/ha biochar significantly improved crop yield. Although the optimum rate of biochar to be applied depends on the specific soil type and crop management, observations of crop growth after applying biochar have shown consistent positive results (Marjenah et al., 2016). This result agrees with the work of Major et al. (2010) who reported that application of biochar improves soil fertility status which in turn improves plant growth.

Table 5: Effects of Chicken Feather Biochar Rates on the Yield Components of Maize

Biochar Rates	**Mean No of maize cobs/ Plant**	**Mean weight of maize cobs (kg)/plant**
0 t/ha	0.00	0.00
5 t/ha	0.55	0.09
10 t/ha	0.55	0.10
15 t/ha	1.00	0.24
20 t/ha	1.50	0.35
$LSD_{(0.05)}$	0.56	0.23

t/ha=tonnes per hectare

CONCLUSION

The study revealed increase in the growth and yield indices of maize plant with increasing rates of chicken feather biochar application. The 20 t/ha gave the highest values of the growth and yield indices. However, there was steady increase in the plant height, stem girth and number of leaves all through the growth period. The observed significant increases in growth and yield of the maize plant as a result of the soil amendment with the chicken feather biochar could be attributed to the high nutrient release from the biochar to the soil especially at 20 t/ha. Thus, chicken feather biochar could be considered as an effective amendment for optimum growth and yield of maize especially at higher rate of 20 t/ha. Further research is imperative to study the efficacy of chicken feather biochar on other crops.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to TETFund, University of Nigeria, Nsukka, for sponsoring this research with Research project no. 35 and reference code TETF/DR&D/CE/UNI/NSUKKA/BR/2020/VOL.1.

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Effects of Poultry and Bat Manure Amendments on Some Soil Fertility Properties in Mokwa Southern Guinea Savannah Zone of Nigeria

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ABSTRACT

Use of organic manure as soil amendment is receiving attention by famers in Nigeria and across the globe as an alternative to nutrient sources for crop production and soil quality improvement. The study was carried out at the Niger State College of Agriculture, Mokwa, Orchard in 2021 cropping season to evaluate the physical and chemical properties of soils cultivated to Corchorus olitorius (Ayoyo) with organic manure amendment in 2020 cropping year. The study investigated seven (7) previous year's treatment plots that included Control (0 t ha^{-1} manure), Poultry manure (3, 6 and 9 t ha^{-1}) and bat manure (3, 6 and 9 t ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated three times. Data were collected on soil N, P, OC, OM, Exchangeable Bases, Exchangeable acidity and CEC as well as particle size distribution for the determination of textural class. The texture of the soil was consistently Loamy Sand in all the treatment plots. Except for the pH values that were significantly (P>0.05) reduced by both manure types with the highest reduction (5.5) observed in 3 t ha^{-1} bat manure treated plots, the values recorded for N, P, OC, OM, Exchangeable bases, Exchangeable Acidity and CEC generally increased as the rate of poultry and bat manure increased from 3 to 9 t ha^{-1}. The largest increase in these parameters was generally recorded in 9 t ha^{-1} bat manure treatments, which did not differ from those obtained in 6 t ha^{-1} bat manure treatment plots. It is therefore, suggested that the 6 t ha^{-1} bat manure be adopted for soil fertility and productivity improvements in Mokwa Southern Guinea Savannah Agro Ecological zone of Nigeria.

Keywords: Residual, Amendments, Poultry manure, Bat manure, Soil fertility.

Introduction

Farmers in Nigeria today have realized the need for soil amendments using organic resources that is available such as crop residues, farmyard manure and animal wastes (Iren *et al*., 2012 and John *et al*., 2013) There is increased pressure on agricultural lands to meet the increasing demand for food. Small scale farmers contribute mostly to food production in Nigeria and there has been a decline in soil fertility of small holder farms. Fertility restoration is very key to achieving and maintaining high crop productivity (Atoleye *et al*., 2014). Also, the long-term cultivation of land without organic input leads to a decrease in soil organic carbon (SOC), and total nitrogen (N) contents, and consequently in reduced crop yield. Organic fertilizers (manure, compost, and crop residues) are recommended for use in lands under intensive cultivation to maintain and improve soil structure, increase ware retention, capacity and facilitate the availability of nutrients for plants.

Addition of organic materials such as crop residues, animal manures, green manures to soils increases soil organic matter contents, improves soil fertility, soil physical characteristics and enhance microbial activities, ameliorates metal toxicity (Ano and Agwu 2005). It plays a crucial role in sustaining the fertility of the soil and crop production due to its effects on the soil physical, chemical and biological properties. Animal manure is considered a valuable nutrient source when applied to soil at rates commensurate with good agronomic practices.

In recent times, organic manures are used as alternative to mineral fertilizers. This is due to rising cost of mineral fertilizers, rapid nutrient loss of added fertilizers and adverse environmental impacts from inorganic fertilizers accumulation of nutrients in soils, particularly nitrogen, phosphorus and several micronutrients increases the potential for the degradation of surface and ground water resources, especially when manure application is nitrogen based.

The bat guano is being widely used as a natural fertilizer due to its high nitrogen content and also the guano shows some nematocidal effects. The bat guano is also very important for the growth of microflora as it contains all essential nutritive elements for their growth (Amanabo *et al.*, 2019). Unfortunately, despite the benefits of bat guano, desired attention has not been given to the guano.

The smallholder farmers in the Mokwa Southern Guinea Savannah agro-ecological zone have amended their soils with little brown bat droppings for several years. They reported that, at least 5 years' residual benefits to cultivated crops (vegetables, maize, millet, sorghum etc) before reapplication (Mohammed *et al.*, 2020). There is dearth of documented research information on the residual benefits of bat manure amendments as claimed by the farmers .in the study area.

The objective of the Study was therefore, to evaluate the residual effects of poultry and bat manure amendments on some soil fertility properties in Mokwa, Southern Guinea Savannah zone of Nigeria.

Materials and method.

Study Area

The trial was conducted in 2021 cropping Season at the Teaching and Research Orchard, Niger State College of Agriculture, Mokwa. The site is located at latitude 09^0 18'N and Longitude 05^0 4'E of the equator in the Southern Guinea Savannah zone of Nigeria. The average annual rainfall amount of the area is 1,177.9 mm per annum and temperature of 33.6 ^{0}C (CAM Metrological Unit, 2021).

Experimental Design and Treatments

The field was laid out as a factorial combination of poultry and little brown bat manures fitted in a Randomized Complete Block design (RCBD) consisting of seven (7) treatments and three replications. Poultry manure (PM) and bat manure (BM) were applied at different rates viz-a-viz; 0 t/ha, 3 t/ha, 6 t/ha and 9 t/ha poultry manure and 0 t/ha, 3 t/ha, 6t/ha and 9 t/ha bat manure.

Soil and manure analyses.

Soil sampling and analysis

Soil samples were taken from the experimental site before the commencement of the experiment in 2019 cropping year using soil auger at a depth of 0 - 15 cm. Ten (10) soil samples were randomly taken from each block, bulked and mixed thoroughly to obtain a composite sample. The composite soil sample was conned and quartered to obtain a sub-sample (two handfuls). Similarly, in 2021 cropping season, three (3) soil samples were collected from each of the twenty-one (21) treatment plots before planting activities commenced. The soils collected were also bulked, mixed thoroughly to obtain a composite sample. A sub sample of the composite soil sample was obtained and air dried. The air-dried soil was thereafter sieved using 2 mm sieve and used for soil physical and chemical properties analysis using standard methods described by Anderson and Ingram (1993). The particle size distribution was determined using hydrometer method. Soil pH was measured in 1:1 (soil: water) suspension using a glass electrode pH meter. Organic carbon was determined by Wet Oxidation method. Micro-Kjeldahl method was used to determine the total Nitrogen of the soil samples. Available Phosphorus was determined by Bray No. 1 method. Exchangeable cations were extracted with 1N ammonium acetate at pH 7.0. The concentrations of Ca and Mg were determined on an Atomic Absorption Spectrophotometer (AAS) and the concentrations of Na and K on a Flame Photometer. Cation Exchange Capacity (CEC) was extracted using the leachate from the washed soil sample with neutral ammonium acetate (IITA (1978).

Manure Analysis

The standard methods described by Anderson and Ingram (1993) were also used to determine the chemical properties of the manures. The pH, OC, N, P, Ca, Mg, K and Na contents in poultry and bat manures were the properties measured.

Droppings treatment and application in the first year of cropping

Both droppings used in this work were collected and air dried in the Soil Science Laboratory. The lumps in both droppings were broken to obtain ground manure.

Manures were uniformly applied according to treatment specifications and worked into the soil by light hoeing at one week before transplanting viz a viz control (No application), poultry droppings (2, 4 and 6 t ha^{-1}) and Little Brown Bat droppings (2, 4and 6 t ha^{-1}). Jute mallow (Ayoyo) seedlings were thereafter planted. Manures were incorporated into the soil 2 weeks before planting

Statistical Analysis

All data collected were subjected to the analysis of variance (ANOVA) and where significant. were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability using the General Linear Model (GLM) procedure of Version 9.3 (SAS, 2010).

Results

Soil Physical and Chemical Properties soil before the commencement of the experiments.

The physical and chemical properties of the soil at the experimental site prior to the commencement of the experiment in 2019 are presented in Table 1.

The soils at the study area were slightly acidic (6.5) and belong to the sandy loam textural class. Organic carbon (OC), total nitrogen (N), available phosphorus (P), Cation exchange capacity (CEC) and exchangeable cations were generally low (Table 1) according to the nutrient ratings of Esu (1991).

Table 1: Physical and chemical properties of the soil of experimental site prior to the commencement of the experiment.

Parameter	Value
Soil Particle Size	
Sand (%)	92
Silt (%)	4
Clay (%)	4
Textural Class	loamy Sand
pH (H_20)	6.5
Organic carbon g kg^{-1}	11.40
Available P mg kg^{-1}	13.23
Total N g kg^{-1}	0.11
Exchangeable Cations	
Ca (cmol kg^{-1})	2.69
Mg (cmol kg^{-1})	1.25
K (cmol kg^{-1})	0.24
Na (cmol kg^{-1})	0.32
Exchangeable acidity (EA) (cmol kg^{-1})	0.30
CEC (cmol kg^{-1})	6.60

Values represent means of triplicate determination of composite soil sample.

Chemical properties of poultry and bat manures.

The chemical properties of both organic amendments are shown in Table 2. The pH values of the manures were high (slightly to moderately alkaline). With the exception of EA and Na contents, the values of OC, OM, N, P, K, Ca, Mg and CEC obtained in bat manure were numerically higher than those recorded in poultry manure.

Table 2: Chemical properties of Poultry and Bat manures before soil amendment.

Parameter	Value	
	Poultry Manure (PD)	Little Brown Bat Manure (BD)
pH (H_20)	7.58	8.02
Organic carbon (OC) (%)	21.18	31.43
Organic matter (OM) (%)	36.62	54.34
Available P (%)	1.86	2.29
Total N (%)	3.30	7.99
Exchangeable Cations (%)		
Ca	1.13	2.08
Mg	1.30	2.37
K	1.68	1.85
Na	1.17	0.95
Exch. Acidity (EA) (%)	0.88	0.78
Cation Exch. Capacity (CEC) (%)	11.21	19.37

Values represent means of triplicate determination.

Both organic manures have considerably high contents of OM, OC, N, P, K, Ca and Mg (Table 2). This indicates higher potential for increasing soil OM, OC, N, P, Ca and Mg contents (Table 2).

Physical properties of soils after poultry and Bat manure amendments in 2021 cropping season.

Physical characteristics of the soil are presented in Table 3. The values of sand, silt and clay at the commencement of the investigation differ only marginally. The proportion of sand, silt and clay obtained among the treatments fall within the Loamy Sand textural class which was similar to the textural class of soil at the commencement of the trial in 2019. This indicated that application of poultry and bat manures did not affect the textural class Designation of the soil.

Table 3; Physical properties of soils in 2021 after organic matter application in 2019 cropping year.

Soil type	Initial	3 t/ha PM	6 t/ha PM	9 t/ha PM	3 t/ha BM	6 t/ha BM	9 t/ha BM	S.E
Sand	92.24	90.08	90.37	90.07	90.08	90.08	90.08	9.54
Silt	4.00	3.36	3.36	3.36	3.36	3.36	3.36	0.10
Clay	3.76	6.56	6.27	6.57	6.56	6.56	6.56	0.12
Textural Class	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand	Loamy Sand

Table 4: Chemical properties of soils amended with poultry and bat manures

`	pH (H_2O)	OC(g/kg)	OM (g/kg)	Avail. P(g/kg)	Total N(g/kg)
Initial	6.50a	11.40g	20.66g	13.23g	0.11d
Control	6.27b	11.43g	19.71f	19.90f	0.32c
3t/ha PM	5.96d	12.80f	22.06c	23.13e	0.35c
6t/ha PM	6.26b	20.19d	34.81d	26.53 d	0.56b
9t/ha PM	6.140c	19.79e	34.12e	30.43 b	0.55b
3t/ha BM	5.54e	24.11b	41.67b	23.72e	0.68a
6t/ha BM	5.57e	25.35a	43.70a	29.47c	0.69a
9t/ha BM	5.60e	25.42a	42.82a	34.54a	0.67a
S.E	0.04	0.02	0.09	0.02	0.02
Significant	*	*	*	*	*

* Significant at 5%, SE = Standard Error. Any two means having a common letter within the same column are not significantly different at the 5% level of significance

Effects of manures (PM and BM) application on Soil pH.

The pH values as influence by poultry and bat manure treatments are shown in Table 4. The poultry and bat manure treatments significantly decreased the pH values when compared with the values obtained in initial and control plots. Significantly the lowest pH value was recorded in 3 t/ha bat manure treated plots. This was however, not significantly different from 6 and 9 t/ha bat manure treatments. The pH values obtained from poultry manure treatments were significantly higher than that of bat manure treatments (Table 4). Irrespective of manure treatment rates and types, the initial pH values observed in this study was higher than those recorded in plots previously treated with organic manure (Table 6).

The largest decrease in pH (5.5) falls within the moderately acidic category of pH ranges listed by Esu (1991), which was within the tolerable range for many crops. Mohammed *et al*. (2020) reported that moderately acidic to slightly alkaline (5.5 to 7.3) is generally the most suitable range for most agricultural crops/plants growth (Table 6).

Effects of manures (PM and BM) application on soil OC and OM

Poultry and bat manures applied increased soil organic carbon and organic matter contents significantly when compared with those of the initial and control plots. Significantly highest value of 25.42 g/kg was recorded in 9 t/ha bat manure treated plots which was not significantly different from those of the 6 t/ha bat manure treatments that had 35.35 g/kg.

A similar trend was observed in the values of OM obtained. Significantly highest value of OM was observed in 9 t/ha bat manure treated plots. Table 6 revealed that significantly highest organic matter value of 34.00 g/kg was recorded in plots previously amended with organic manure, irrespective of manure type.

Effects of manures (PM and BM) application on soil total Nitrogen contents.

Results of residual soil total nitrogen contents before planting in 2020 cropping year are shown in Table 4. Significantly highest total N was observed in 6 t/h bat manure treatment plots, which was not significantly different from those of 9 and 3 t/ha treated plots.

All the bat manure treated plots produced significantly higher total N contents than the poultry manure amended plots. The residual value of 0.55 g/kg N recorded in plots amended with organic manure was higher than 0.11 g/kg N obtained as initial value before commencement of the work in 2019 cropping season (Table 6). However, this was not statistically significant.

Effects of manures (PM and BM) on Soil available phosphorus

Residual available P contents of the soil are presented in Tables 4 and 6. Significantly highest available P value was recorded in 9 t/ha bat manure treated plots. Among all the treatments, 34.54 mg/kg P was recorded in the 9 t/ha treated plots followed by 30.43 mg/kg P in the 9 t/ha poultry manure amended plots. Generally, the previously manure treated plots gave 33.96 mg/kg P which was significantly higher than the 13.23 mg/kg P obtained in plots not treated with manure (Table 6).

Exchangeable bases, exchangeable acidity and CEC contents of the soil.

The residual exchangeable bases and exchangeable acidity are presented in Tables 5 and 7.

General increase in the values of exchangeable bases, exchangeable acidity and CEC were observed as organic manures treatments increased from 3 to 9 t/ha (Table 5).

The values of Ca obtained increased from 3 t/ha to 9 t/ha in both poultry and bat treatment plots. Significantly highest Ca value was obtained in the 9 t/ha in both poultry and bat treatments. Significantly highest Ca was obtained in 9 t/ha bat manure treated plots among the treatments. This was however, not different from that of 6 t/ha bat manure amended plots (Table 5). In Table 7, the residual Ca content recorded in the organic manure amended plots (2.83) was only numerically higher than that of the initial value (2.69).

A trend in values that were similar to those obtained in Ca were observed in Mg, Na. CEC and EA as the poultry and bat manure treatments increased from 3 to 9 t/ha. Except for potassium (K) contents that increased numerically, the values of Mg, Na. CEC and EA increased significantly as poultry and bat manures increased from 3 to 9 t/ha (Table 5).

Table 5: Comparism of Soil Exchangeable Cations and Acidity of bat and poultry manures treated plots at harvest of Jute Mallow (Ayoyo) and initial.

TREATMENT	Ca cmol/kg	Mg cmol/kg	K cmol/kg	Na cmol/kg	EA cmol/kg	CEC cmol/kg
Initial	2.69d	1.25h	0.24	0.32e	0.30f	6.60h
Control	2.37e	2.24g	0.85	0.24f	0.91e	9.29g
3t/ha PM	2.45e	4.00f	0.97	0.34de	0.92e	9.34f
6t/ha PM	2.85c	4.56e	1.05	0.39c	0.97d	10.89c
9t/ha PM	2.98b	4.72d	2.52	0.40c	1.03c	10.66d
3t/ha BM	2.77cd	5.00c	1.03	0.37cd	0.97d	9.65e
6t/ha BM	3.18a	5.18b	1.15	0.50b	1.20b	12.37b
9t/ha BM	3.24a	6.24a	3.03	0.63a	01.28a	15.96a
S.E	0.03	0.08	1.04	0.02	0.08	0.10
Significant	*	*	NS	*	*	*

* Significant at 5%, SE = Standard Error. Any two means having a common letter within the same column are not significantly different at the 5% level of significance

Table 6: Comparison of the means of Soil pH, OC, OM, Total N, Available P and K and Na at Jute Mallow harvest and before Planting.

TREATMENT	pH (H_20)	OC g/kg	OM g/kg	Avail. P g/kg	Total N g/kg
Initial Value	6.40a	11.4a	20.0b	13.23b	0.11
Residual value	5.91b	19.79b	34.0a	33.96a	0.55
S.E	2.53	2.82	0.001	30.0	22.0
Significance	*	*	*	*	NS

* Significant at 5%, SE = Standard Error. Any two means having a common letter within the same column are not significantly different at the 5% level of significance

Table 7. Comparism of the means of soil Ca, Mg, EA and CEC at Jute Mallow harvest and before planting

TREATMENT	Ca cmol/kg	Mg (kg)	K cmol/kg	Na cmol/kg	EA (kg)	CEC (kg)
Initial value	2.69	1.25a	0.24	0.32	0.30b	6.60b
Residual value	2.83	5.28	5.40	0.41	1.04a	11.17a
S.E	25.0	7.0	36.0	35.0	5.0	12
Significance	NS	*	NS	NS	*	*

* Significant at 5%, SE = Standard Error. Any two means having a common letter within the same column are not significantly different at the 5% level of significance

On one hand, only the residual values of Mg, EA and CEC obtained in the organically amended plots were significantly higher than those of the initial values (Table 7). The values of Ca, Na and K obtained in the initial and manure amended plots were, on the other hand, not significantly different (Table 7).

Discussions

According to Ojeniyi (2000), organic manure/fertilizer can be used to maintain sustainable crop yield and soil fertility, improvement in nutrient recycling and enhance crop productivity. . The soil fertility parameters investigated in this study were generally improved by the application of both poultry and bat manures, probably due to the low soil fertility properties of the site prior to commencement of the experiment. The pH value of poultry manure recorded in this work was similar to those obtained by Law-Ogbomo *et al*. (2017) in poultry manure, while Amanabo *et al.* (2019) also had pH vaures in bat manure that is comparable to those obtained in our study. There was a generally reduction in soil pH value due to the residual effects of poultry and bat manure applications. The N, P, OC, Mg, K, Ca, Na had values of 10.20, 30.70, 33.66, 0.45, 0.53, 30.86, 0.24 respectively obtained by Law-Ogbomo *et al*. (2017) in poultry manure were numerically at par with those obtained in this study. On the other hand, Amanabo *et al.* (2019) recorded 33.0 g/kg, 8.0 g/kg, 8.75 g/kg, 3.17 cmol/kg, 11.94 cmol/kg, 3.76 cmol/kg and 2.82 cmol/kg in OC, N, P, Na, K, Mg, and Ca respectively in bat manure. These results were generally similar to those obtained in this study.

Generally, there was improvement in the soil fertility parameters investigated as the rates of poultry and bat manure applied increased from 3 to 9 t/ha which corroborates the findings of many researchers (Kirchmann and Witter, 2010, Mahmud *et al.*, 2009, Amanabo *et al.*, 2019, Akongwubel *et al.*, 2012 and Sanni *et al*., 2014). These increases might be attributed to the high OC, OM, N, P, K, Ca, Mg, K, Na and CEC contents in the poultry and bat manures applied. These values were generally high when compared with the critical level for soil fertility ratings reported by Esu (1991).

Generally, the largest values of OC, OM, P, N, Ca, Na, K, Na, EA and CEC obtained in plots amended with poultry and organic manure were highest in plot that received 9 t/ha treatments. This could be due to the large amounts of the organic manure applied. The values of soil OC, OM, P, N, Na, K and CEC in the previously amended soil with organic manures had values that were higher than the critical levels of soil fertility rating reported by Esu (1991). This indicated that the residual fertility status of the soil was high. However, the values of Ca , Na and EA fall below the critical levels of soil fertility ratings for crops (Esu, 1991).

Conclusion

Generally, the soil fertility parameters investigated in this study increased as the rates of organic manures amendments s increased from 3 to 9 t/h in both manure types. The highest increase was observed in 9 t/ha bat manure amendments which was not significantly different from the values obtained in plots that received 6 t/ha bat manure treatments. The residual soil fertility status of the soil was observed to be generally higher than those of the critical levels for soil fertility nutrient ratings. This indicated a considerable level of soil fertility status.

Recommendation

For sustainable soil fertility improvement in Mokwa Southern Guinea Savanna agro-ecological zone of Nigeria, 6 t/ha bat manure is recommended for adoption by small holder farmers.

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Effects of Integrated Soil Fertility Management on the Growth and Cob Yield of Maize/Soybean Intercropping System Ii Ogbomoso, Oyo State, Nigeria

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ABSTRACT

In the tropics, farmers dominantly practice intercropping systems, such as growing maize (*Zea mays*) and soybean (*Glycine max*) in mixtures. The productivity of this practice may however, be limited by poor soil fertility. Therefore, the performance of maize and soybean intercrop subjected to integrated soil fertility management was evaluated at the Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria in the main cropping season in 2023. The cropping system (main plot) and nutrient sources (subplot) were arranged as split-plot laid out in Randomized Complete Block Design with four replications. Data were collected on plant height, stem girth and maize cob yield. Data were subjected to Analysis of Variance and treatment means compared using Least Significance Difference at 5% probability level. Intercropping maize with soybean had no negative effect on the growth parameters of maize (height and stem girth) compared with sole maize. However, the soil amendments influenced the growth parameters differently. Combined application of NPK and poultry manure had significantly tallest plants (161.2 cm) at 10 weeks after sowing (WAS) and robust stem girth (65.0 mm) compared with the control (no soil amendments) which had plant height (126.8 cm) and stem girth (48.1 mm) respectively. In contrast to the observation for maize, intercropping improved the heights of soybean. Intercropped soybeans were taller (37.42 cm) than sole soybean (28.60 cm). Intercropping had no adverse effect on the stem girth of soybean. Combined application of NPK and poultry manure had significantly tallest soybean plants (39.3 cm) at 10 WAS while sole NPK had the shortest soybean (27.9 cm). Sole application of poultry manure had significantly highest value of stem girth (22.4 mm) while sole NPK treatment had the lowest value of stem girth (15.5 mm). Combined application of NPK and poultry manure had the highest maize cob yield (4229 kg/ha) which differs significantly from the control (1285 kg/ha) that had the lowest cob yield. There was no significant interaction between the cropping system and fertilizer treatments for all the growth and yield parameters for both maize and soybean. In conclusion, intercropping maize with soybean had no adverse effect on the growth of both crops and cob yield of maize. However, the soil amendments were superior to the control in their effects on growth of both crops and cob yield of maize. Combined application of NPK and PM outperformed their sole applications.

Keywords: Maize, Soybean, Intercropping, NPK mineral fertilizer, Poultry manure

Introduction

The intercropping of maize and legumes is widespread among smallholder farmers due to the ability of the legume to cope with soil erosion and with declining levels of soil fertility. The principal reasons for smallholder farmers to intercrop are flexibility, profit maximization, risk minimization against total crop failure, soil conservation and improvement of soil fertility, weed control and balanced nutrition (Kinama *et al.*, 2018). Other advantages of intercropping include potential for increased profitability and low fixed costs for land as a result of a second crop in the same field (Parajulee and Panta, 2021). Furthermore, intercrop can give higher yield than sole crop yields, greater yield stability, more efficient use of nutrients, better weed control, provision of insurance against total crop failure, improved quality by variety, also maize as a sole crop requires a larger area to produce the same yield as maize in an intercropping system (Manasa *et al*., 2018).

Poultry manure and NPK mineral fertilizers are commonly used in maize-based cropping systems to improve soil fertility and increase crop yields. However, there are varying opinions on the benefits and drawbacks of these two types of fertilizers, particularly in terms of their effects on carbon sequestration, soil chemical properties, and crop yields. Due to the high cost and unavailability of these fertilizer materials, the use of inorganic fertilizer on staple food crops like maize has generally been limited to a few farmers endowed with capital (Jjagwe *et al*., 2020) and with substantial off-farm income (Niang *et al*., 1998). The increasing use of mineral fertilizers, which resulted in the globalization of farming practices that necessitated the larger use of lands to provide the best crop yield, was fueled by rising hunger, due to constant increase in population.

Organic fertilizers are frequently advocated as alternatives to mineral fertilizers. The notion of sustainable agriculture has recently emerged as a system of ecological farming methods based on scientific breakthroughs to meet humanity's desire for healthy foods while also preserving the quality of the environment and natural resource base. Organic fertilizers, rather than mineral fertilizers, could represent an environmentally benign practice through sustainable farming methods. Indeed, organic fertilizers are made from organic resources (such as plant leftovers, animal manures, and food industry by-products) and are exposed to a variety of processes, including fermentation, drying, chopping, and composting (Dadi *et al.*, 2019, Jones and Jacobsen, 2002). There are signs that poultry manure and NPK fertilizer used under leguminous cover crops will improve soil fertility indices more than their sole application in the predominant coarse-textured soils in derived savanna of southwest Nigeria. The objective of this study was to investigate the effects of poultry manure and NPK mineral fertilizer on maize and soybean growth and cob yield of maize in a maize/soybean cropping systems.

2.0 Materials and Methods

Experimental Site

The study was conducted at the Teaching and Research Farm, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo state, Nigeria, during the 2023 growing season. Ogbomoso is located in the derived savanna agroecological zone by latitude $8^0 10'$ N and longitude $4^0 10'$ E.

Soil sampling and pre-planting analysis

Six samples were taken randomly in each plot using an alderman auger and then bulked to one sample to eliminate variability. A sub sample was taken and sent to the laboratory for analysis of N, P, K, Ca, Mg, Zn, CEC, organic C, total available P, total carbon, exchangeable bases, particle size distribution. Soil pH was measured using a pH meter in a 1:2 soil-water ratio (Black *et al*., 1965). Organic matter content was determined using the Walkley-Black test (1934). Nutrient levels were measured through laboratory analysis using methods such as the Kjeldahl method for total nitrogen (Kjeldahl, 1883), the Bray 1 method for available phosphorus (Bray and Kurtz, 1945), and the extractable ammonium acetate NH_4O_{AC} method for potassium (Pratt, 1965). Calcium and magnesium were measured using the atomic absorption spectrophotometric method (Chapman and Pratt, 1961) and the EDTA complexometric titration method (Lindsay and Norvell, 1978), respectively. Particle size distribution was determined through the hydrometer method (ASTM., 2010).

Treatments and experimental design

The experiment was a split-plot laid out in a Randomized Complete Block Design (RCBD) with cropping systems as the main factor and the nutrient sources as the sub-plot factor and was replicated four times. The cropping systems includes; sole maize, sole soybean and maize and soybean intercropping. The nutrient sources include; only poultry manure at 5 tonnes per hectare, only mineral fertilizer; NPK 20:10:10, single super phosphate and muriate of potash to supply 120 N, 60 P_2O_5 and 30 K_2O in kg/ha and combined half the rates of mineral fertilizer and poultry manure. Plots without any soil amendments were included for comparison. The 30 N, 60 P_2O_5 and 30 kg K_2O per hectare were applied at sowing using NPK (20:10:10) and SSP while 90 kg N as urea was side-dressed at four weeks after sowing.

Plot layout

The plots measured 4 × 4 m with 1.5 m gap between plots with spacing of 75 × 25 cm for sole maize to make a population 53,333 plants/hectare, 50 × 25 cm for sole soybean to make a population of 80,000 plants/hectare and the same planting distance used for sole maize was maintained for each crop under intercropping system.

Cultural practices

Two (2) seeds of maize and soybean were sown per hole and thinned to 1 plant per hill two weeks after sowing. Manual weeding was carried out when needed to remove unwanted plants from the treatment plots. A mixture of Atrazine and Gramozone was applied at 5 litres per hectare, to all treatment plots immediately after sowing as pre- and post-emergence herbicides. Also, control of armyworm was done using caterpillar force containing emamectin benzoate.

Data Collection

Data were collected on five randomly selected and tagged plants at two weeks interval from four (4) weeks after sowing (WAS) on plant height using metre rule, stem diameter using vernier caliper and converted to stem girth using the formula πd (π =3.14 and d= diameter measured). At maturity, maize cob was harvested and weighed.

Data Analysis

Data were subjected to analysis of variance (ANOVA) using PROC GLM SAS. Treatment means were separated by least significant differences (LSD) at $p \leq 0.05$.

3.0 RESULTS

Soil Properties before Planting

The soil was near neutral in pH, low in organic carbon, nitrogen, phosphorus and has medium content of exchangeable cations (Table 1).

Effect of intercropping system and fertilizer treatments on height, stem girth and cob weight of maize

Maize plant height was not significantly affected by the cropping systems at both sampling period while plant height differed significantly with fertilizer treatments. Application of combined poultry manure and NPK produced tallest height during the sampling period (14.25 and 161.15 cm at 4 and 10 WAS respectively). The control without any soil amendment had the shortest plants at these periods (8.95 and 126.8 cm, respectively). There was no significant interaction between the cropping system and fertilizer treatments on maize plant height at both 4 and 10 WAS (Table 2).

Cropping system had no significant effect on the stem girth of maize plants during the period of observation.

Combined application of NPK and poultry manure had significantly thickest stem girth with 27.4 and 68.6 mm (Fig. 1) at 4 and 10 WAS while maize with no soil amendment had the least stem girth (18.4 and 47.2 mm) at 4 and 10 WAS respectively.

Intercropping system had no negative effects on the field cob weight of maize. Combined application of NPK and poultry manure had significantly the highest maize cob yield (4229 kg/ha) and the control had the least cob yield (1285 kg/ha). Sole NPK and poultry manure had significantly higher cob yield than the control (Table 3).

Table 1: Results of Pre-cropping soil analysis

Parameters	**Values**
pH (H_2O)	6.38
Nitrogen (g/kg)	0.40
Organic carbon (g/kg)	5.0
Phosphorus (mg kg^{-1})	7.78
Exchangeable cations (cmol kg^{-1})	
Calcium	1.21
Magnesium	0.44
Potassium	0.13
Sodium	0.27
Exchangeable acidity	0.51
ECEC	3.33
Zinc (mg g^{-1})	2.03
Sand (g/kg)	852
Silt (g/kg)	78.2
Clay (g/kg)	69.8
Textural Class	Loamy Sand

Table 2: Effects of cropping systems and fertilizer treatments on plant height of maize (cm) at 4 and 10 weeks after sowing

	Fertilizer treatments				
Cropping systems	Control	NPK	PM	NPK+PM	Cropping system mean
	4 weeks after sowing				
Sole maize	9.25	12.15	12.53	13.7	11.91
Maize/Soybean intercrop	8.64	12.15	11.65	14.79	11.81
Fertilizer treatment mean	8.95	12.15	12.09	14.25	
$LSD_{0.05}$ CS	ns				
$LSD_{0.05}$ Fert	2.19				
$LSD_{0.05}$ CS*Fert	ns				
	10 weeks after sowing				
Sole maize	129.6	162.3	144.9	156.2	148.25
Maize/Soybean intercrop	123.9	151.5	139.65	166.1	145.29
Fertilizer treatment mean	126.75	156.9	142.23	161.15	
$LSD_{0.05}$ CS	ns				
$LSD_{0.05}$ Fert	14.88				
$LSD_{0.05}$ CS*Fert	ns				

$LSD_{0.05}$ =LSD at 5% probability level. CS=Cropping systems, Fert=Fertilizer treatments, CS*Fert=Interaction between cropping systems and fertilizer treatments.

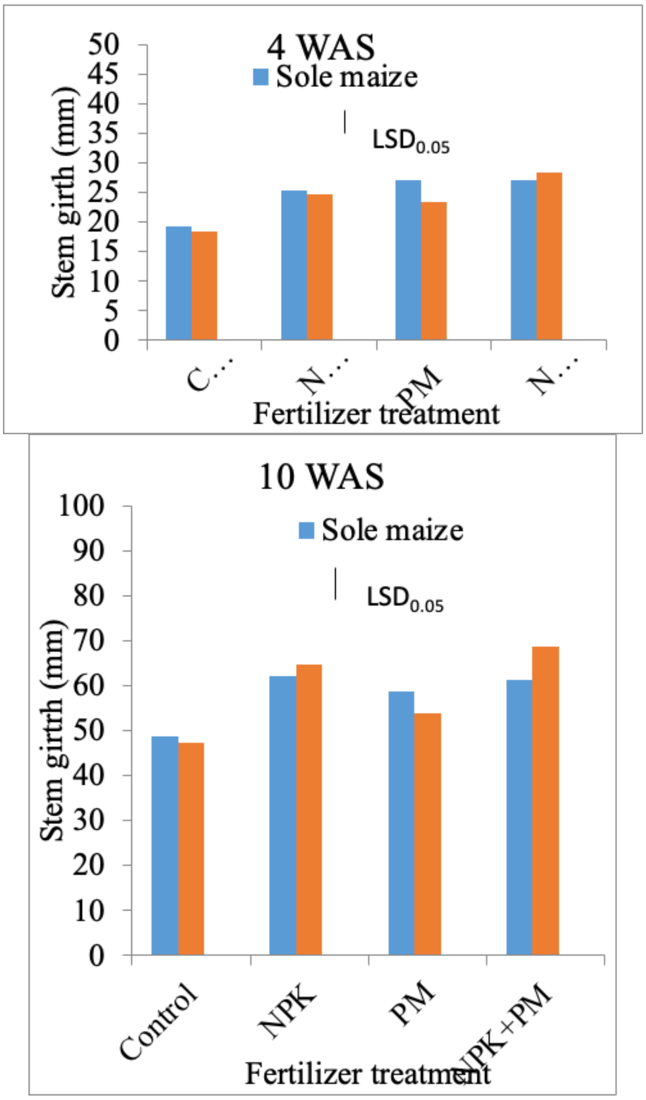

Figure 1: Effects of cropping systems and fertilizer treatments on stem girth of maize at 4 and 10 weeks after sowing

Table 3: Effects of cropping systems and fertilizer treatments on the cob weight (kg/ha) of maize

Cropping systems	Fertilizer treatments				
	Control	NPK	PM	NPK+PM	Cropping system mean
Sole maize	1483.25	3512.5	3100	3783.25	2969.8
Maize/soybean intercrop	1087.5	3087.5	1916.75	4675	2691.7
Fertilizer treatment mean	1285.4	3300	2508.4	4229.1	
$LSD_{0.05}$ CS	ns				
$LSD_{0.05}$ Fert	1095.8				
$LSD_{0.05}$ CS*Fert	ns				

$LSD_{0.05}$ =LSD at 5% probability level. CS=Cropping systems, Fert=Fertilizer treatments, CS*Fert=Interaction between cropping systems and fertilizer treatments.

Effects of cropping system and fertilizer management on height and stem girth of soybean

The height of soybean were significantly affected by the cropping system at 10 WAS. Intercropped soybean had the tallest plant (37.42 cm) while sole soybean had the shortest plant (28.60 cm) (Table 4). Application of combined NPK and poultry manure treatment had the tallest soybean (12.8 and 47.05 cm) at 4 and 10 WAS while sole NPK had the shortest soybean (10.72 and 25.58 cm) respectively. There was no interaction between cropping system and fertilizer treatments for soybean height at both sampling period.

The cropping system had no significant effect on stem girth of soybean during both periods of observation while stem girth was significantly influenced by fertilizer treatments. Combined poultry manure and NPK treatment had soybean plants with the thickest stem (9.74 cm) while the control with no fertilizer amendments had the lowest stem girth (8.36 mm) at 4 WAS (Fig. 2). At 10 WAS, plots that had poultry manure only produced the thickest stem girth (23.13 mm) while those with NPK only had the lowest stem girth (13.95 mm).

Table 4: Effects of cropping system and fertilizer treatment on plant height of soybean at 4 and 10 weeks after sowing

Cropping systems	Fertilizer treatments				
	Control	NPK	PM	NPK+PM	Cropping system mean
	4 weeks after sowing				
Sole maize	11.55	11.65	11.95	12.8	11.99
Maize/Soybean intercrop	11.05	10.72	12.15	12.7	11.66
Fertilizer treatment mean	11.3	11.2	12.05	12.75	
$LSD_{0.05}$ CS	ns				
$LSD_{0.05}$ Fert	1.13				
$LSD_{0.05}$ CS*Fert	ns				
	10 weeks after sowing				
Sole maize	25.93	25.58	31.45	31.45	28.6025
Maize/Soybean intercrop	0.05	30.12	42.48	47.05	37.425
Fertilizer treatment mean	28.00	27.85	36.965	39.25	
$LSD_{0.05}$ CS	3.41				
$LSD_{0.05}$ Fert	4.82				
$LSD_{0.05}$ CS*Fert	ns				

$LSD_{0.05}$ =LSD at 5% probability level. CS=Cropping systems, Fert=Fertilizer treatments, CS*Fert=Interaction between cropping systems and fertilizer treatments.

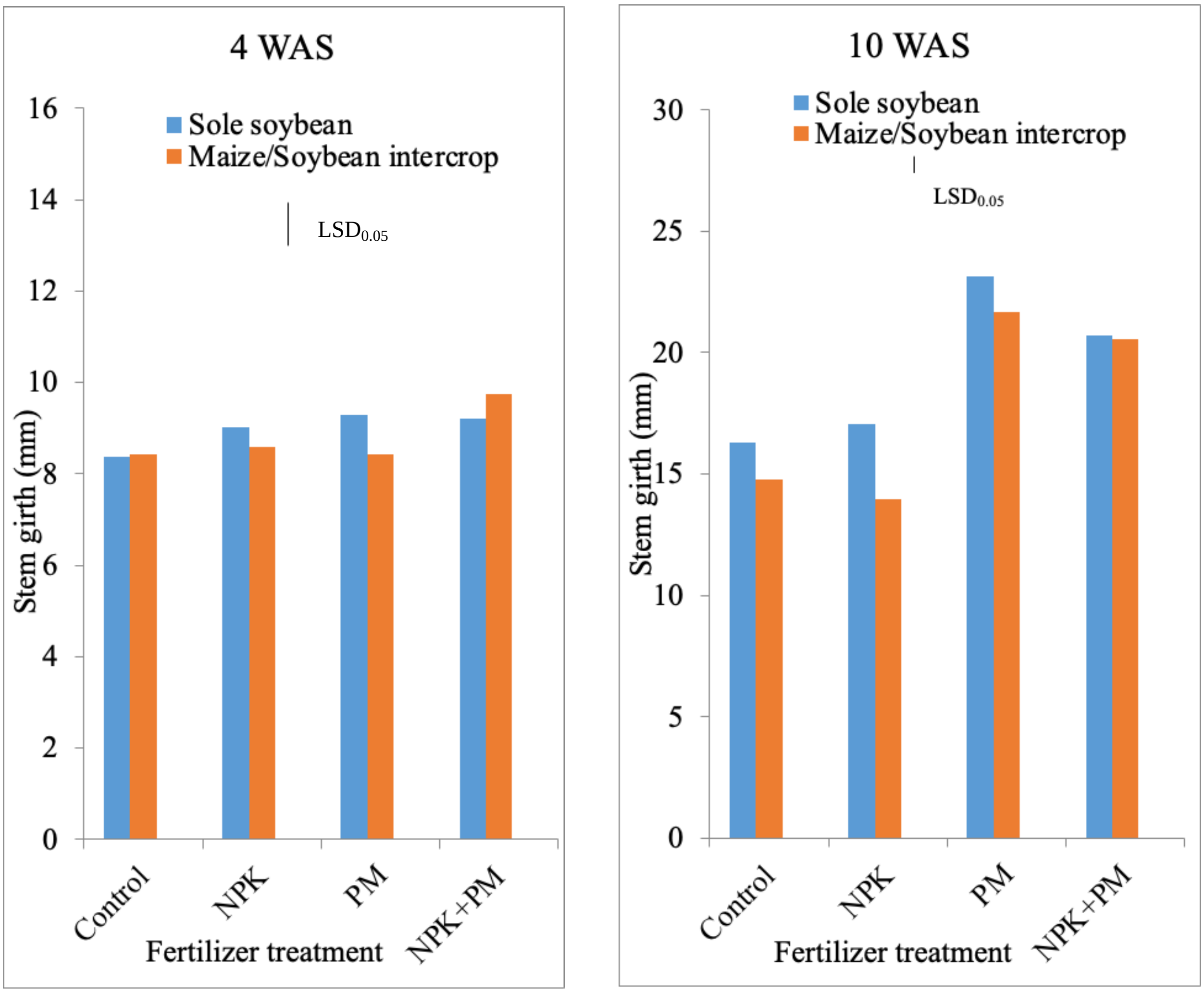

Figure 2: Effects of cropping systems and fertilizer treatments on the stem girth (mm) of soybean at 4 and 10 weeks after sowing

DISCUSSION

Few of the fundamental metrics for morphological observations are plant height and stem girth, which measure crop growth and development as well as the rate and stability of plant growth. It was observed that the intercropping system had no adverse effects on maize growth parameters and cob weight. This may be due to the presence of complementary resource utilization patterns between maize and soybean. Maize plants frequently engage in ferocious competition for resources like water, nutrients, and sunlight in monoculture. However, competition between maize plants is reduced when cultivated alongside soybeans, allowing individual plants to access more resources, such as sunshine (Zhang *et al*., 2017). Also, soybean and maize have differing nutritional requirements and root structures. Through symbiotic partnerships with nitrogen-fixing bacteria, soybeans may fix atmospheric nitrogen, lessening maize's competition for nitrogen. This finding is in contrast with the observation of Franco *et al*. (2018), who noted that intercropping increased the height, stem girth, and mobilization of photosynthates for the vegetative growth of maize plants as compared to monocropping of maize.

Similarly, Suarez *et al*. (2022), reported that as compared to maize planted in monocropping systems, intercropped maize with bean was taller and had a higher stem girth.

The outcomes demonstrated that maize plant height and stem girth were significantly impacted by fertilizer management. It was observed that the combined NPK and poultry manure treatment had the tallest maize plants followed by sole applications of NPK and poultry manure while the control plots had the shortest plant. The increased height obtained under the combined application of NPK and poultry manure, might be as a result of the complimentary release of essential nutrients to the plant and also the improvement in soil physical properties through the application of organic manure. These findings agreed with that of Almaz *et al*. (2018) who attributed the greater maize height to the gradual release of essential nutrients as required by the plant in a combined application of NPK and poultry manure.

Intercropping maize with soybean was observed not to have any effect on the cob yield. This is in contrast with the study of Wei *et al*. (2022) who reported that maize/soybean intercropping has a greater impact on crop yield. The yield of intercropping maize was equivalent to be 10% higher than the yield of monocropping, indicating that intercropping significantly increased the yield of maize. This changes might be attributed to the difference in plant spacing and climatic condition in the two experiment. The combined application of NPK and poultry manure was observed to have the higher cob yield than sole applications of the fertilizer which agreed with the report of Mahmood *et al*. (2017) who noted that combined application of both organic and inorganic sources of nutrients improved growth and yield and related parameters of maize and attributed that the combination of organic manures might have improved the nitrogen use efficiency, micro and macro nutrient recovery and help in P solubilization and its uptake by the plants and enhanced K availability that in turn resulted in better growth and yield of maize. Similarly, Mubeen *et al.* (2013) reported that the combined application of organic and inorganic fertilizers is considered a good option to enhance nutrient recovery, plant growth and ultimate yield otherwise higher N and P application rates are required to attain better yield in maize.

It was observed that intercropping and fertilizer management affected the height of soybean plants. The sole soybean plants were shorter than the intercropped soybean. This outcome might have been caused by maize shadowing impact, which decreased the soybean's ability to intercept light. Under low light, plants adapt to grow towards light which causes stem elongation and petioles (etiolation) and capture as much light energy as possible to optimize the photosynthesis yield. This helps plants to accelerate CO_2 fixation as well as the accumulation of carbohydrates to ensure a physiological growth rate of plants (Wu *et al*., 2017; Wimalasekera, 2019). Ijoyah *et al*. (2013) and Almaz *et al*. (2018) found taller soybean plants in the intercropped compared to the monocropped soybean which they ascribed to the increased population of plants in intercropping. The combined application of NPK and poultry manure had the tallest plant among the fertilizer management methods compared to the control. This was in agreement with the reports of Almaz *et al*. (2017), Vishal *et al*. (2019), Adekiya *et al*. (2020), and Batyrbek *et al*. (2012), who reported that the combined use of NPK and organic fertilizer had a good effect on crop growth.

Stem girth was not adversely affected by the intercopping system though sole soybean plants had a better stem girth to the intercropped soybean which could be as a result of shading which brings about stem elongation and inhibited the stem diameter growth. This is supported by a research carried out by Fan *et al*. (2018) who noted that the stem diameter and aboveground biomass accumulation was decreased during the intergrowth period compared with that of the sole cropping system. Poultry manure had the highest stem girth especially at 10 WAS this can be due to the gradual release of nutrients through mineralization to the soil for the needs of soybean. This combination can support consistent and sturdy stem growth in soybeans (Almaz *et al*., 2018).

The result of the study showed that the evaluated cropping systems and nutrient sources exhibited variation in the growth parameters of maize and soybean plants. Intercropping maize/soybean with combined application of poultry manure and NPK had a better performance on the observed crops and therefore can be recommended to farmers.

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Effect of Animal Manures Application on Available Phosphorus Using Bray II Extractant for a Degraded Ultisols in Southeastern Nigeria

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ABSTRACT
Phosphorus is the second most limiting nutrient in crop production. However, information on bray II phosphorus on a degraded Ultisols with applied animal manures is scarce. Therefore, field experiment was conducted to assess the effect of animal manures on bray II phosphorus of a degraded Ultisols. The experiment was laid out in a randomized complete block design with three replications. The experiment was subjected to statistical analysis (ANOVA). The treatments were poultry and sheep manures at the levels of 0, 30 and 60 % N. Post- treatment soil samples were collected at the soil depths of 0 – 5, 5 – 10, 10 – 20 and 20 – 40 cm at different weeks (1, 2, 3, 4, 6, 8 and 12) in early and late seasons of 2019 and 2020. The results showed that addition of poultry and sheep manure only increased bray II phosphorus concentrations with P_{30}, P_{60} and S_{30}, S_{60} rates relative to the control in most soil depths. Highest bray II phosphorus concentrations were with P_{60} (54.92 mg kg^{-1}) and S_{60} (54.98 mg kg^{-1}) at 5 – 10 cm in early season of 2019. Concentrations were better in 2019 than 2020. Consequently, integration of poultry and sheep manure applied best supports the bray II phosphorus with $P_{60}S_{60}$ in a degraded Ultisol.

Keywords: Bray II phosphorus, Ultisols, animal manures, degradation, nutrients.

1.0 INTRODUCTION

Phosphorus is the second most limiting nutrient in crop production and plays most critical roles in energy transfer and storage (Akinola, 2005; Muindi, 2019; Kashyap *et al*., 2021). It is a structural component of nucleic acids, nucleotides, and coenzymes (Hasmah *et al*., 2015). Availability of soil P is a function of its dynamics and can be improved by using organic amendments. Phosphorus does not occur abundantly in soils as N and K. It is very stable or insoluble, only a very small proportion exists in the soil solution. In acidic soils, continuous application of P could lead to the accumulation of Fe and Al - P. Phosphorus deficiency is the main limiting factor for crop production in acidic soils.

However, the greatest percentage of soil phosphorus is present in chemical forms that are not readily available to plants. Thus, plants cannot always get adequate supply of required phosphorus from the soil (Adepetu *et al*., 2014). It is not mobile in the soil with the availability being poor in wet soils. Available phosphorus constitutes soil P pool that is present in soil solution or readily exchangeable between soil solution and the solid soil phase (Azeez *et al*., 2013). Phosphorus promotes root growth, seed formation and development of flower (Mosaic, 2013). It has been defined as a fraction of total P that present in the soil, which could be absorbed by plants (Azeez *et al*., 2013). The unavailability of P in plants makes it the most limiting nutrient in the soil. The main reason for the limited bioavailability of soil P is its high immobilization (Sorption and precipitation) rate and its slow release into the soil solution. It is also involved in an array of processes in plants such as photosynthesis, respiration, nitrogen fixation, flowering, fruiting and maturation. It has poor solubility (Muindi, 2019; Alakeh *et al*., 2022).

As plants remove P from soil solution, it is replenished by the active P pool especially desorption of sorbed P from the soil minerals, the activity of soil organisms on soil P that was complexed with the positively charged soil organic matter and the application of organic amendments to the soil (Alakeh *et al*., 2022). Phosphorus exists in two forms as organic and inorganic in soils with each present in solid, liquid soil phases or interphase between solid and liquid phases. It is absorbed as orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) (Kashyap *et al*., 2021) by plants with its availability depended on high Ca^{2+} or Al^{3+} in the soil which may hinder P uptake by plants.

Organic P in Nigeria was found to range from 15 - 80 % of the total soil phosphorus in agricultural soil (McLaughlin *et al.* 1990; Adepetu *et al*., 2016). The exact amount of organic P in soils varies and greatly depends on vegetation cover of such soil, nature of the soil, land use history, and soil composition (Adepetu *et al*., 2016). Organic phosphorus occurs majorly as ester linkages on inositols with lesser amount in phospholipids, phytin and nucleic acid (Stevenson, 1986; Adetunji, 1994; Adepetu *et al*., 2014). There are other soil organic phosphorus compounds that have been identified and they include nucleic acid, lecithin, diesters and glycophosphate (Adepetu *et al*., 2014). The concentration and composition of soil organic P is affected by factors such as soil management practices, soil moisture conditions and changing weather condition. In tropical forest soils of Southwestern Nigeria, organic P fraction ranges between 20 and 79 % of the total soil P in the plough layer (Adepetu and Corey, 1975; Adepetu *et al*., 2016).

Once phosphorus enters the soil through manure or dead plant or animal debris (organic sources), it cycles between several soil pools via processes such as mineralization, immobilization, adsorption, precipitation, desorption, weathering, and dissolution. Because mineralization and immobilization processes are biological processes, they are highly influenced by soil moisture, temperature, pH, organic carbon to organic phosphorus ratio of crop residues, microbial population (Prasad and Chakraborty, 2019).Soils containing greater concentrations of iron and aluminum oxides have greater potential to adsorb phosphorus than soils with relatively low iron and aluminum oxides. Another soil property that favors phosphorus adsorption is the clay content. Soils with greater clay content have higher adsorption capacity than coarse textured sandy soils (Prasad and Chakraborty, 2019).

Manure is an excellent source of plant nutrients and land application of which animal waste is the most economical way of disposing it. Manure is composed of organic and inorganic P compounds, heavy metals, and recently, the sex hormones estradiol and testosterone. Animal diet and manure collection, treatment, and storage are all important factors that explain much of the variation found in total P values for manure. Manure also contains large amounts of organic P such as phospholipids and nucleic acids, which could be released to increase soil inorganic P concentrations by mineralization. Different P forms have different mobility.

Organic forms of P move to greater depths than soluble inorganic P, apparently because of their lesser reaction with soil colloids (Makris, 2003; Prasad and Chakraborty, 2019).

The importance of phosphorus as a yield limiting factor in Southeastern part of Nigeria soils is well established (Kashyap *et al*., 2021). Regardless of the forms of phosphorus, the nutrient is still unavailable in adequate amount needed by crops in Southeastern Nigeria. This study therefore, assessed the response of bray II phosphorus to different levels of poultry and sheep manures application as well as establishing its optimum application in an Ultisol of Southeastern Nigeria. The objective of this study was to investigate soil bray II phosphorus at different soil depths, weeks and seasons after manures incorporation.

2.0 MATERIALS AND METHODS

Field experiment was conducted at the Teaching and Research farm of Federal University of Technology, Owerri, Imo State. Owerri (Latitudes 5^0 05′ and 5^0 23′ N and Longitudes 7^0 02′ and 7^0 21′ E) on an elevation of 124 m above sea level in the humid rain forest agro-ecological zone of Nigeria. Its mean annual rainfall, daily temperature and monthly relative humidity were 2,500 mm, 32 °C and 85 % respectively (IPEDC, 2006). The study locations were georeferenced using a hand held Geographical positioning system (GPS) with the coordinates as; Latitude 5^0 22′ 55″ and N Longitude 6^0 59′ 44″ E, Latitude 5^0 22′ 23″ and N Longitude 6^0 59′ 26″ E, Latitude 5^0 22′ and 54″ N Longitude 6^0 59′ 32″ E and Latitude 5^0 22′ 48″ and N Longitude 6^0 59′ 29″ E for the first, second, third and fourth locations respectively.

Field study was conducted for four seasons in two years (2019 and 2020), with each year consisting of two seasons (early and late seasons) in each year. Treatments consisting of poultry and sheep manures were applied into plots constructed each measuring 3 × 3 m^2. Prior to application, the poultry and sheep manures were air dried and ground using a wiley mill. The treatment consisted of three rates of 0, 30 and 60 % N equivalent to 0, 1.08 and 2.16 and 0, 0.62 and 1.24 t ha^{-1} of poultry and sheep manures respectively were applied and thoroughly incorporated into the soils. The experimental design was a 3^2 factorial replicated three times in randomized complete block design.

Pretreatment soil samples were collected from 0 - 5, 5 - 10, 10 - 20 and 20 - 40 cm depths while post-treatment soil samples were collected per treatment plots from same depths as the former at various intervals (1, 2, 3, 4, 6, 8 and 12 weeks) in the early and late seasons of 2019 and 2020. These intervals consisted of weekly in the first month, fortnightly in the second and ones in the third month after treatment applications.

Both pre and post treatments soil samples collected were prepared by air drying, sieving using a 2 mm diameter mesh and the fine earth fractions stored ready for laboratory analyses. The poultry and sheep manures were oven dried for 103 °C for 12 hours and ground using wiley and digested using double acid.

However, the poultry and sheep manures, pre and post treatment soil samples were subjected to laboratory analyses using standard methods. Manure samples were analyzed for pH, EC, total N, total P, total K, Ca, Mg, Na and organic carbon. The pretreatment soil samples were analyzed for particle size fractions after dispersed with calgon (Gee and Or, 2002), pH in 1: 2.5 sample/ water ratio (Jackson, 1967) using the glass electrode of a pH meter, EC (Richards, 1954), Bray II P (Olsen and Sommer, 1982), OC (Nelson and Sommers, 1996). Meanwhile, post treatment soil samples were analyzed for bray II P.

All data collected were subjected to Analysis of Variance (ANOVA), means compared using Fisher's Protected Least Significant Difference Test at 5 % probability level. All analyses were computed using Genstat Statistical package (discovery edition 12 software) (Genstat 2012).

3.0 RESULTS

3.1 *Nutrient composition of the manures used for the study.*

The pH of poultry and sheep manures applied during this experiment was 7.8, Na contents were 0.89 and 0.79 g kg^{-1}, respectively. Concentrations of N, P and K were higher in poultry manure while Ca, Mg and organic carbon were higher in sheep manure. The EC values of both manures were above 3.2 dS m^{-1}. The N, P and K were better in poultry than sheep manure with the values of 89.66, 4.68 and 9.13 g kg^{-1} in poultry manure and 83.36, 4.22 and 8.93 g kg^{-1} for sheep manure.

Table 1: Nutrients composition of Manures Used for the Study.

Chemical	Manures Poultry	Properties Sheep
PH	7.8	7.8
EC (dS m^{-1})	14.23	9.45
Total nitrogen (g kg^{-1})	89.66	83.36
Total – phosphorus (g kg^{-1})	4.68	4.22
Total potassium (g kg^{-1})	9.13	8.93
Total sodium (g kg^{-1})	0.89	0.79
Total – calcium (g kg^{-1})	6.89	6.92
Total magnesium (g kg^{-1})	5.64	5.69
Organic carbon (g kg^{-1})	298.98	515.44
Carbon: Nitrogen	3.34	6.18
Exchangeable acidity ($cmol^{+}$ kg^{-1})	0.6	0.6

3.2 *Nutrient composition of pretreatment soils used for the study.*

In Table 4.2a, sand, silt and clay contents ranged from 682.00 – 701.00, 41.00 – 48.00 and 25.70 – 28.80 and 726.00 – 741.00, 18.00 – 26.00 and 23.80 – 25.30 g kg^{-1} in early and late seasons of 2019, respectively. In both seasons, distribution of the various soil particles were irregular with soil depths and with mean concentrations being an increasing order of sand > clay > silt, texture of the soils between sandy loam and loam sandy in early and late seasons, respectively. In Table 4.2b, ranges of sand, silt and clay were respectively 886.00 – 912.00, 42.00 – 72.00 and 28.00 - 62.00 (early season) and 884.00 – 902.00, 54.00 – 62.00 and 40.00 – 62.00 g kg^{-1} (late season), with their distributions down soil depths not sequenced for all fractions in the early season and increase for sand, decrease for silt and erratic for clay in late season. In both seasons and years, mean soil fractions decreased in the order sand > silt > clay with sand better than others.

From the result (Table 4.2a (2019)), soil pH and EC ranged respectively from 4.10 – 4.80 and 0.10 - 0.20 dS m^{-1} (early season) and 4.4 – 4.6 and 0.20 - 0.20 dS m^{-1} (late season) (Table 4.2a). While the ranges in 2020 (Table 4.2b) were 4.45 – 4.87 and 0.20 - 0.40 dS m^{-1} in the early season and 4.03 – 4.33 and 0.20 - 0.30 dS m^{-1} in the late season (Table 4.2a). Meanwhile, the mean pH of the soils were 4.45, 4.50, 4.65 and 4.17 in wet and dry seasons of 2019 and 2020 respectively, giving a range of 4.17 – 4.65. The electrical conductivity decreased with depth with mean values varying as 0.18 - 0.25 d Sm^{-1} in early and late seasons of 2019 and 0.25 – 0.33 d Sm^{-1} also in wet and dry seasons of 2020.

Table 2a: Physico- chemical characteristics of the soils used for the study in 2019.

	Wet Season 2019					Dry Season 2019				
	Soil Depths (cm)					Soil Depths (cm)				
Physico chemical properties	0 - 5	0 - 10	10 - 20	20 - 40	Mean	0 - 5	0 - 10	10 - 20	20 - 40	Mean
Sand (g kg^{-1})	682	680	701	684	686.8	726	741	738	728	733
Silt (g kg^{-1})	46	41	42	48	44.25	21	18	24	26	22.3
Clay (g kg^{-1})	27.2	27.1	25.7	28.8	27.2	25.3	24.1	23.8	24.6	24.5
Textural Class	sandy loam					Loamy sand				
pH	4.8	4.4	4.1	4.5	4.45	4.6	4.5	4.4	4.5	4.5
EC (d Sm^{-1})	0.2	0.2	0.2	0.1	0.175	0.3	0.3	0.2	0.2	0.25
Bray II P (mg kg^{-1})	41.82	40.56	42.15	40.93	41.37	36.4	38.8	37	38.1	37.6

Table 2b: Physico- chemical characteristicsof the soils used for the study in 2020.

	Wet Season 2020					Dry Season 2020				
	Soil Depths (cm)					Soil Depths (cm)				
Physico chemical properties	0 - 5	0 - 10	10 - 20	20 - 40	Mean	0 - 5	0 - 10	10 - 20	20 - 40	Mean
Sand (g kg^{-1})	906	904	912	886	902.00	886	884	894	902	891.50
Silt (g kg^{-1})	66	48	42	72	57.00	62	58	58	54	58.00
Clay (g kg^{-1})	28	52	42	62	46.00	52	62	40	48	50.50
Textural Class	Sand					Loamy sand				
pH	4.53	4.87	4.76	4.45	4.65	4.03	4.07	4.23	4.33	4.17
EC (d Sm^{-1})	0.4	0.4	0.3	0.2	0.33	0.3	0.3	0.2	0.2	0.25
Bray II P (mg kg^{-1})	41.8	40.6	42.2	40.9	41.37	36.4	38.81	36.98	38.11	37.58

Also, mean total P were 1.46 and 1.27 and 0.39 and 0.30 g kg^{-1} in early and late seasons with concentrations higher in early than late seasons and in 2019 than 2020. The distributions of soil total phosphorus were not sequenced for early and late seasons in 2019 while that of 2020 reduced as the soil depth increased. Equally, bray II P contents ranged from 40.56 – 42.15 with a mean of 41.37 and 36.42 – 38 – 81 with a mean of 37.52 mg kg^{-1} in early and late seasons of 2019 and 18.17 – 22.24 with mean of 26.02 and 22.23 – 28.11 (25.82 mg kg^{-1})in early and late seasons of 2020 respectively (Table 4.2b). Mean concentrations were higher in early than late seasons and 2019 than 2020 with distribution down soil depth being a decrease in both seasons and years.

3.3 *Soil Bray II Phosphorus*

Effects of manures (poultry and sheep manures only and integration of manures) on bray II phosphorus at various soil depths, manure rates, weeks after applications, seasons and years were presented in Table 3. Addition of poultry manure only increased bray II P concentrations with P_{30} and P_{60} rates in relation to the control in most soil depths, weeks after manure incorporation (WAMI), seasons and years. Highest and lowest bray II P concentrations were with P_{60} (54.92 mg kg^{-1}) at 5 – 10 cm in early season of 2019 at 12th

Table 3 Cont'd.

Years and Seasons	2019 a				2019 b				2020 a				2020 b			
Soil Depths	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Manure Rates	Third Week After Manure Incorporation															
P_0S_0	50.17	43.41	43.44	43.22	44.99	44.91	45.43	44.83	23.34	23.17	9.21	8.16	22.05	23.44	8.68	7.73
P_0S_{30}	51.61	44.44	43.13	43.46	46.67	46.64	47.16	46.73	27.86	23.64	12.91	10.68	27.86	25.23	12.43	14.39
P_0S_{60}	51.70	44.05	43.96	44.91	44.55	44.82	44.74	45.65	26.88	23.17	15.21	11.14	27.18	23.44	14.46	13.14
Mean	**51.16**	**43.97**	**43.51**	**43.86**	**45.40**	**45.46**	**45.78**	**45.74**	**26.03**	**23.33**	**12.44**	**9.99**	**25.70**	**24.04**	**11.86**	**11.75**
$P_{30}S_0$	51.15	44.94	44.93	44.95	46.59	46.36	47.40	46.92	19.66	16.36	13.26	10.23	29.97	29.47	12.86	11.95
$P_{30}S_{30}$	51.00	46.78	46.75	46.79	46.19	46.39	46.40	46.13	29.91	26.20	17.74	7.86	30.19	26.32	16.80	18.25
$P_{30}S_{60}$	50.79	46.89	46.88	46.91	45.84	45.78	45.76	45.86	30.14	27.92	18.50	8.63	27.49	26.53	17.72	13.75
Mean	**50.98**	**46.20**	**46.19**	**46.22**	**46.21**	**46.18**	**46.52**	**46.30**	**26.57**	**23.49**	**16.50**	**8.91**	**29.22**	**27.44**	**15.79**	**14.65**
$P_{60}S_0$	52.73	44.70	45.10	45.20	46.72	46.75	46.74	46.82	41.84	38.93	12.66	10.29	32.51	31.31	12.26	11.19
$P_{60}S_{30}$	50.57	45.17	44.56	44.60	45.42	45.40	45.61	45.35	30.34	27.36	17.67	7.80	30.57	27.60	16.74	13.38
$P_{60}S_{60}$	52.84	46.48	46.22	46.41	46.06	45.96	45.87	45.97	32.54	29.25	17.17	7.11	32.75	29.38	16.44	16.57
Mean	**52.05**	**45.45**	**45.29**	**45.40**	**46.07**	**46.04**	**46.07**	**46.05**	**34.91**	**31.85**	**15.83**	**8.40**	**31.94**	**29.43**	**15.15**	**13.71**
S_0	51.35	44.35	44.49	44.46	46.10	46.01	46.52	46.19	28.28	26.15	11.71	9.56	28.18	28.07	11.27	10.29
S_{30}	51.06	45.46	44.81	44.95	46.09	46.14	46.39	46.07	29.37	25.73	16.11	8.78	29.54	26.38	15.32	15.34
S_{60}	51.78	45.81	45.69	46.08	45.48	45.52	45.46	45.83	29.85	26.78	16.96	8.96	29.14	26.45	16.21	14.49
LSDs (0.05) P	*0.44*	*0.61*	*0.14*	*0.20*	*0.34*	*0.54*	*0.36*	*0.12*	*0.87*	*0.18*	*0.72*	*0.10*	*1.46*	*1.77*	*0.52*	*4.15*
" S	*0.44*	*0.61*	*0.14*	*0.20*	*0.34*	*0.54*	*0.36*	*0.12*	*0.87*	*0.18*	*0.72*	*0.10*	*1.46*	*1.77*	*0.52*	*4.15*
' P x S	*0.76*	*1.06*	*0.23*	*0.35*	*0.58*	*0.94*	*0.63*	*0.21*	*1.51*	*0.31*	*1.25*	*0.17*	*2.53*	*3.10*	*0.90*	*7.18*

Fourth Week After Manure Incorporation																
P_0S_0	48.27	49.85	50.23	50.13	48.94	48.27	49.01	48.30	22.24	25.40	13.65	13.49	19.66	20.07	19.13	16.61
P_0S_{30}	51.67	51.75	51.84	51.96	48.51	49.30	48.66	48.57	28.98	25.40	20.56	17.81	23.95	24.37	20.70	24.51
P_0S_{60}	51.46	51.51	51.46	51.39	49.16	48.68	48.71	48.71	30.31	26.63	15.77	14.77	27.93	24.76	25.74	24.40
Mean	**50.47**	**51.04**	**51.18**	**51.16**	**48.87**	**48.75**	**48.79**	**48.53**	**27.18**	**25.81**	**16.66**	**15.36**	**23.85**	**23.07**	**21.86**	**21.84**
$P_{30}S_0$	50.64	51.88	51.64	51.81	49.51	49.12	49.19	49.12	21.49	18.21	17.75	15.31	25.56	24.71	27.57	25.19
$P_{30}S_{30}$	52.55	52.70	52.72	52.77	49.77	49.83	49.21	48.66	29.51	26.60	16.97	12.54	29.52	28.36	23.53	22.52
$P_{30}S_{60}$	51.34	51.68	51.66	51.64	49.00	48.45	47.80	48.13	32.72	29.83	16.43	15.78	24.72	28.12	26.70	25.88
Mean	**51.51**	**52.09**	**52.01**	**52.07**	**49.43**	**49.13**	**48.73**	**48.64**	**27.91**	**24.88**	**17.05**	**14.54**	**26.60**	**27.06**	**25.93**	**24.53**
$P_{60}S_0$	51.30	52.34	52.36	52.27	50.10	50.28	50.37	50.45	38.85	38.86	13.85	11.68	29.71	33.65	23.58	21.53
$P_{60}S_{30}$	52.49	52.44	52.61	52.42	50.43	50.45	50.49	50.52	33.93	29.99	15.88	14.73	26.03	27.96	25.94	24.67
$P_{60}S_{60}$	50.30	50.34	50.50	50.12	49.21	49.23	48.29	49.49	33.69	29.45	14.73	13.68	27.18	29.61	24.67	23.89
Mean	**51.36**	**51.71**	**51.82**	**51.60**	**49.91**	**49.99**	**49.72**	**50.15**	**35.49**	**32.77**	**14.82**	**13.36**	**27.64**	**30.41**	**24.73**	**23.36**
S_0	50.07	51.36	51.41	51.40	49.52	49.22	49.52	49.29	27.53	27.49	15.08	13.49	24.98	26.14	23.43	21.11
S_{30}	52.24	52.30	52.39	52.38	49.57	49.86	49.45	49.25	30.81	27.33	17.80	15.03	26.50	26.90	23.39	23.90
S_{60}	51.03	51.18	51.21	51.05	49.12	48.79	48.27	48.78	32.24	28.64	15.64	14.74	26.61	27.50	25.70	24.72
LSDs (0.05) P	*0.90*	*0.27*	*0.18*	*0.09*	*0.54*	*0.13*	*0.67*	*0.53*	*2.57*	*2.56*	*0.10*	*1.12*	*2.80*	*3.07*	*2.31*	*2.63*
" S	*0.90*	*0.27*	*0.18*	*0.09*	*0.54*	*0.13*	*0.67*	*0.53*	*2.57*	*2.56*	*0.10*	*1.12*	*2.80*	*3.07*	*2.31*	*2.63*
' P x S	*1.55*	*0.46*	*0.31*	*0.15*	*0.94*	*0.23*	*1.15*	*0.92*	*4.45*	*4.43*	*0.16*	*1.93*	*4.85*	*5.32*	*4.00*	*4.55*

a = wet season, b = dry season, 1 = 0-5 cm, 2 = 5-10 cm, 3 = 10-20 cm, 4 = 20-40 cm depths, P = poultry, S = sheep and P x S = poultry and sheep manure interaction.

Table 3: Bray II P at various Soil Depths and Weeks After Manure Incorporation (WAMI) in Wet and Dry Seasons of 2019 and 2020.

Years and Seasons	2019 a				2019 b				2020 a				2020 b			
Soil Depths	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Manure Rates	First Week After Manure Incorporation															
P_0S_0	50.40	50.37	46.35	47.54	45.24	44.50	44.59	44.06	34.46	30.50	13.45	6.94	24.69	27.21	23.38	9.44
P_0S_{30}	49.25	49.75	48.98	48.58	46.73	46.73	46.76	45.25	38.24	30.69	23.99	10.76	28.23	29.56	25.53	13.48
P_0S_{60}	51.28	51.52	48.78	48.82	47.73	47.36	47.42	45.54	36.50	32.06	15.88	11.55	26.36	31.85	25.68	11.26
Mean	**50.31**	**50.55**	**48.04**	**48.31**	**46.57**	**46.20**	**46.26**	**44.95**	**36.40**	**31.08**	**17.77**	**9.75**	**26.43**	**29.54**	**24.86**	**11.39**
$P_{30}S_0$	52.17	51.63	46.83	49.82	47.71	46.89	48.65	47.17	38.86	33.71	12.77	9.28	28.68	30.14	24.14	9.12
$P_{30}S_{30}$	52.36	52.73	48.03	47.84	50.49	50.12	50.16	45.89	37.92	33.48	21.44	14.58	27.72	33.21	22.57	14.29
$P_{30}S_{60}$	51.74	52.51	48.23	46.93	47.36	48.67	46.93	46.05	38.87	34.06	24.00	14.65	28.67	33.79	23.93	14.36
Mean	**52.09**	**52.29**	**47.70**	**48.20**	**48.52**	**48.56**	**48.58**	**46.37**	**38.55**	**33.75**	**19.40**	**12.84**	**28.36**	**32.38**	**23.55**	**12.59**
$P_{60}S_0$	48.96	49.21	47.32	49.13	46.53	45.91	45.88	46.33	40.86	36.44	32.57	26.85	30.69	32.97	32.58	10.09
$P_{60}S_{30}$	52.86	52.74	49.13	47.26	49.19	48.91	48.91	46.32	47.62	42.49	13.66	10.70	37.42	35.71	23.48	10.47
$P_{60}S_{60}$	50.09	50.40	49.02	46.21	46.48	46.12	46.29	47.32	47.75	42.30	27.46	8.78	37.55	41.03	27.34	15.14
Mean	**50.64**	**50.78**	**48.49**	**47.53**	**47.40**	**46.98**	**47.03**	**46.66**	**45.41**	**40.41**	**24.56**	**15.44**	**35.22**	**36.57**	**27.80**	**11.90**
S_0	50.51	50.40	46.83	48.83	46.49	45.77	46.37	45.85	38.06	33.55	19.60	14.36	28.02	30.11	26.70	9.55
S_{30}	51.49	51.74	48.71	47.89	48.80	48.59	48.61	45.82	41.26	35.55	19.70	12.01	31.12	32.83	23.86	12.75
S_{60}	51.04	51.48	48.68	47.32	47.19	47.38	46.88	46.30	41.04	36.14	22.45	11.66	30.86	35.56	25.65	13.59
LSDs (0.05)																
P	*0.17*	*0.31*	*0.11*	*0.08*	*1.03*	*0.34*	*0.34*	*0.26*	*0.14*	*1.43*	*0.21*	*0.26*	*0.26*	*3.48*	*1.80*	*2.86*
" S	*0.17*	*0.31*	*0.11*	*0.08*	*1.03*	*0.34*	*0.34*	*0.26*	*0.14*	*1.43*	*0.21*	*0.26*	*0.26*	*3.48*	*1.80*	*2.86*
' P x S	*0.30*	*0.53*	*0.20*	*0.13*	*1.79*	*0.59*	*0.59*	*0.44*	*0.23*	*2.48*	*0.37*	*0.45*	*0.45*	*6.03*	*3.11*	*4.96*

Second Week After Manure Incorporation																
P_0S_0	50.50	51.10	50.11	51.32	45.13	45.11	43.59	43.78	26.85	24.16	12.57	12.55	21.76	24.77	13.08	9.66
P_0S_{30}	51.51	51.33	51.50	52.56	46.03	46.16	45.68	45.80	31.85	35.94	24.08	19.73	26.99	24.26	12.47	12.43
P_0S_{60}	51.62	51.25	51.49	51.98	45.69	45.76	45.11	45.21	32.64	29.75	19.18	15.57	32.39	29.87	19.25	15.64
Mean	**51.21**	**51.23**	**51.03**	**51.95**	**45.62**	**45.68**	**44.79**	**44.93**	**30.45**	**29.95**	**18.61**	**15.95**	**27.05**	**26.30**	**14.93**	**12.58**
$P_{30}S_0$	51.26	50.85	50.80	51.84	46.72	46.64	43.84	43.79	39.33	38.78	17.45	23.24	29.16	29.65	15.48	13.10
$P_{30}S_{30}$	51.06	50.96	50.87	51.63	48.04	48.00	43.92	43.88	35.28	32.73	29.10	25.42	25.82	31.18	18.97	15.39
$P_{30}S_{60}$	50.63	50.35	50.46	52.04	44.95	45.02	46.51	46.52	30.91	28.31	25.56	15.50	29.59	28.37	17.43	15.41
Mean	**50.98**	**50.72**	**52.42**	**51.84**	**46.57**	**46.55**	**44.76**	**44.73**	**35.17**	**33.27**	**24.04**	**21.39**	**28.19**	**29.73**	**17.29**	**14.63**
$P_{60}S_0$	52.73	52.48	50.32	52.63	45.82	45.83	44.36	44.55	38.59	37.27	22.61	20.65	28.65	27.54	15.18	10.47
$P_{60}S_{30}$	50.46	50.09	52.39	52.16	46.31	46.41	46.10	46.10	27.87	21.56	10.10	10.76	27.73	24.70	13.36	10.70
$P_{60}S_{60}$	52.69	52.35	52.00	52.33	44.58	44.75	44.59	44.68	41.64	39.69	12.34	13.69	31.52	32.94	12.51	13.60
Mean	**51.96**	**51.64**	**51.57**	**52.37**	**45.57**	**45.66**	**45.02**	**45.11**	**36.03**	**32.84**	**15.02**	**15.03**	**29.30**	**28.39**	**13.68**	**11.59**
S_0	51.50	51.48	50.41	51.93	45.89	45.86	43.93	44.04	34.92	33.40	17.54	18.81	26.52	27.32	14.58	11.08
S_{30}	51.01	50.79	51.59	52.12	46.79	46.86	45.23	45.26	31.67	30.08	21.09	18.64	26.85	26.71	14.93	12.84
S_{60}	51.65	51.32	51.32	52.12	45.07	45.18	45.40	45.47	35.06	32.58	19.03	14.92	31.17	30.39	16.40	14.88
LSDs (0.05)																
P "	*0.42*	*0.25*	*0.23*	*0.08*	*0.07*	*0.19*	*0.79*	*0.81*	*1.54*	*0.14*	*0.12*	*2.15*	*1.81*	*2.04*	*1.90*	*2.13*
S	*0.42*	*0.25*	*0.23*	*0.08*	*0.07*	*0.19*	*0.79*	*0.81*	*1.54*	*0.14*	*0.12*	*2.15*	*1.81*	*2.04*	*1.90*	*2.13*
' P x S	*0.73*	*0.43*	*0.39*	*0.13*	*0.12*	*0.32*	*1.36*	*1.41*	*2.67*	*0.24*	*0.21*	*3.73*	*3.14*	*3.53*	*3.29*	*3.68*

a = wet season, b = dry season, 1 = 0-5 cm, 2 = 5-10 cm, 3 = 10-20 cm, 4 = 20-40 cm depths, P = poultry, S = sheep and P x S = poultry and sheep manure interaction.

Table 3 Cont'd.

Years and Seasons	2019 a				2019 b				2020 a				2020 b			
Soil Depths	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Manure Rates	Sixth Week After Manure Incorporation															
P_0S_0	46.00	44.90	44.23	47.82	42.33	42.38	42.41	44.33	35.90	29.67	22.39	4.91	24.75	21.92	15.93	10.22
P_0S_{30}	47.00	44.91	44.87	50.38	45.28	45.35	45.32	45.63	34.92	31.75	27.29	7.28	24.59	28.60	23.98	14.19
P_0S_{60}	47.18	44.89	44.91	50.13	44.13	43.99	44.14	45.04	48.64	40.85	29.55	9.67	38.49	32.59	26.22	13.06
Mean	**46.73**	**44.90**	**44.67**	**49.44**	**43.91**	**43.91**	**43.96**	**45.00**	**39.82**	**34.09**	**26.41**	**7.29**	**29.28**	**27.70**	**22.04**	**12.49**
$P_{30}S_0$	47.00	46.75	46.64	48.94	42.63	42.70	42.72	44.55	39.41	36.70	27.39	4.85	29.57	28.67	20.98	14.31
$P_{30}S_{30}$	47.90	45.37	45.22	48.32	43.69	43.70	43.66	44.93	33.42	30.92	24.74	7.46	26.57	29.82	19.77	11.21
$P_{30}S_{60}$	48.19	45.86	45.86	49.22	44.04	44.13	44.05	43.80	38.89	34.36	28.64	8.77	28.65	32.00	25.13	15.07
Mean	**47.70**	**45.99**	**45.91**	**48.83**	**43.45**	**43.51**	**43.48**	**44.43**	**37.24**	**33.99**	**26.92**	**7.03**	**28.26**	**30.16**	**21.96**	**13.53**
$P_{60}S_0$	47.00	46.73	46.84	46.97	45.62	45.62	45.75	46.39	46.17	36.36	28.72	8.85	35.08	31.58	22.93	15.25
$P_{60}S_{30}$	48.00	45.92	45.99	48.03	43.53	43.54	43.55	46.21	41.43	41.22	26.72	6.85	31.64	32.93	23.06	13.17
$P_{60}S_{60}$	48.88	46.46	46.36	49.18	44.13	44.16	44.15	44.21	40.42	38.04	26.30	6.36	30.64	31.78	23.39	9.98
Mean	**47.96**	**46.37**	**46.40**	**48.06**	**44.43**	**44.44**	**44.48**	**45.60**	**42.67**	**38.54**	**27.25**	**7.35**	**32.45**	**32.10**	**23.13**	**12.80**
S_0	46.67	46.13	45.90	47.91	43.53	43.57	43.63	45.09	40.49	34.24	26.17	6.20	29.80	27.39	19.95	13.26
S_{30}	47.63	45.40	45.36	48.91	44.17	44.20	44.18	45.59	36.59	34.63	26.25	7.20	27.60	30.45	22.27	12.86
S_{60}	48.08	45.74	45.71	49.51	44.10	44.09	44.11	44.35	42.65	37.75	28.16	8.27	32.59	32.12	24.91	12.70
LSDs (0.05)																
P	*10.77*	*0.33*	*0.08*	*0.10*	*0.19*	*0.18*	*0.21*	*0.18*	*0.13*	*1.42*	*0.71*	*0.09*	*0.70*	*2.61*	*3.27*	*2.53*
" S	*10.77*	*0.33*	*0.08*	*0.10*	*0.19*	*0.18*	*0.21*	*0.18*	*0.13*	*1.42*	*0.71*	*0.09*	*0.70*	*2.61*	*3.27*	*2.53*
' P x S	*18.66*	*0.58*	*0.15*	*0.17*	*0.33*	*0.32*	*0.36*	*0.31*	*0.23*	*2.46*	*1.23*	*0.16*	*1.21*	*4.53*	*5.66*	*4.39*

Eighth Week After Manure Incorporation																
P_0S_0	50.99	50.71	50.03	50.82	46.01	47.26	47.22	47.05	29.97	27.20	21.18	12.81	22.06	21.68	16.15	9.51
P_0S_{30}	51.76	51.73	51.64	52.81	47.24	48.93	49.21	47.47	29.80	29.92	25.51	17.17	24.38	25.62	24.15	14.45
P_0S_{60}	52.89	52.83	50.92	50.67	48.18	48.83	49.12	48.05	43.47	38.12	29.34	19.33	31.78	29.88	24.50	18.36
Mean	**51.88**	**51.76**	**50.86**	**51.43**	**47.14**	**48.34**	**48.52**	**47.52**	**34.41**	**31.75**	**25.34**	**16.44**	**26.07**	**25.73**	**21.60**	**14.11**
$P_{30}S_0$	54.98	54.85	52.82	51.66	46.38	47.90	48.93	48.65	28.36	28.34	25.85	17.19	23.93	23.80	21.85	14.61
$P_{30}S_{30}$	53.29	53.31	51.98	50.32	47.16	49.18	47.32	46.89	35.33	33.69	24.50	14.52	27.33	29.23	20.41	11.58
$P_{30}S_{60}$	55.66	55.77	50.66	51.45	48.35	48.89	48.49	49.27	35.74	32.93	28.44	18.37	25.77	28.69	25.11	15.70
Mean	**54.64**	**54.64**	**51.82**	**51.14**	**47.30**	**48.66**	**48.25**	**48.27**	**33.14**	**31.65**	**26.26**	**16.69**	**25.68**	**27.24**	**22.46**	**13.96**
$P_{60}S_0$	52.20	52.20	50.86	52.73	46.82	48.62	47.91	48.12	41.86	37.25	27.45	18.48	32.28	31.15	22.57	15.23
$P_{60}S_{30}$	55.51	52.22	52.67	52.11	45.15	49.01	49.05	49.85	35.67	32.01	26.49	16.45	26.76	27.43	21.61	13.54
$P_{60}S_{60}$	56.15	56.35	51.63	50.93	46.29	49.28	48.88	49.11	37.01	36.34	26.10	16.19	26.87	28.57	22.04	15.28
Mean	**54.62**	**53.59**	**51.72**	**51.92**	**46.09**	**48.97**	**48.61**	**49.03**	**38.18**	**35.20**	**26.68**	**17.04**	**28.64**	**29.05**	**22.07**	**14.68**
S_0	52.72	52.59	51.24	51.74	46.40	47.93	48.02	47.94	33.40	30.93	24.83	16.16	26.09	25.54	20.19	13.12
S_{30}	53.52	52.42	52.10	51.75	46.52	49.04	48.53	48.07	33.60	31.87	25.50	16.05	26.16	27.43	22.06	13.19
S_{60}	54.90	54.98	51.07	51.02	47.61	49.00	48.83	48.81	38.74	35.80	27.96	17.96	28.14	29.05	23.88	16.45
LSDs (0.05)																
P	*0.57*	*0.58*	*0.12*	*0.21*	*0.08*	*0.09*	*0.06*	*0.14*	*2.44*	*2.01*	*1.21*	*0.49*	*3.20*	*2.36*	*1.51*	*1.16*
"																
S	*0.57*	*0.58*	*0.12*	*0.21*	*0.08*	*0.09*	*0.06*	*0.14*	*2.44*	*2.01*	*1.21*	*0.49*	*3.20*	*2.36*	*1.51*	*1.16*
' P x S	*0.99*	*1.01*	*0.20*	*0.36*	*0.14*	*0.15*	*0.10*	*0.24*	*4.23*	*3.48*	*2.09*	*0.86*	*5.55*	*4.08*	*2.61*	*2.02*

a = wet season, b = dry season, 1 = 0-5 cm, 2 = 5-10 cm, 3 = 10-20 cm, 4 = 20-40 cm depths, P = poultry, S = sheep and P x S = poultry and sheep manure interaction.

Table 3 Cont'd.

Years and Seasons	2019 a				2019 b				2020 a				2020 b			
Soil Depths	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Manure Rates	Twelfth Week After Manure Incorporation															
P_0S_0	50.26	51.22	50.33	51.13	49.53	49.76	48.26	48.26	28.33	26.97	20.94	12.99	18.33	17.36	15.12	10.98
P_0S_{30}	52.94	51.89	52.31	51.04	49.61	49.92	51.25	51.22	29.46	29.66	25.41	17.48	21.03	21.26	19.80	15.49
P_0S_{60}	52.19	51.36	51.62	51.23	51.14	51.11	50.20	49.86	43.17	37.95	29.19	19.63	29.21	28.25	26.21	18.06
Mean	**51.80**	**51.49**	**51.42**	**51.13**	**50.09**	**50.26**	**49.90**	**49.78**	**33.65**	**31.53**	**25.18**	**16.70**	**22.86**	**22.29**	**20.38**	**14.84**
$P_{30}S_0$	52.31	54.82	51.00	52.68	49.89	50.02	51.28	51.11	35.16	28.18	25.78	17.49	25.64	19.28	19.54	14.98
$P_{30}S_{30}$	51.89	53.24	51.34	50.91	50.35	50.21	50.68	50.67	28.08	33.49	24.24	14.77	18.80	23.56	17.72	13.51
$P_{30}S_{60}$	51.88	55.10	51.45	52.86	50.48	50.48	49.36	49.16	35.44	37.15	28.24	18.67	25.41	22.99	21.78	16.41
Mean	**52.03**	**54.39**	**51.26**	**52.15**	**50.24**	**50.24**	**50.44**	**50.31**	**32.89**	**32.94**	**26.09**	**16.98**	**23.28**	**21.94**	**19.68**	**14.97**
$P_{60}S_0$	51.95	52.07	51.64	52.14	50.44	50.16	49.75	49.67	41.75	37.15	27.25	18.68	32.14	27.88	20.90	15.56
$P_{60}S_{30}$	51.85	55.90	50.90	50.82	51.14	51.06	48.96	48.92	35.47	31.84	26.29	16.72	25.76	22.15	19.60	14.24
$P_{60}S_{60}$	53.31	56.79	52.02	50.34	49.58	49.53	50.63	50.39	36.76	36.18	26.15	16.49	27.27	26.45	23.21	15.31
Mean	**52.37**	**54.92**	**51.52**	**51.10**	**50.39**	**50.25**	**49.78**	**49.66**	**37.99**	**35.06**	**26.56**	**17.30**	**28.39**	**25.49**	**21.24**	**15.04**
S_0	51.51	52.70	50.99	51.98	49.95	49.98	49.76	49.68	35.08	30.77	24.66	16.39	25.37	21.51	18.52	13.84
S_{30}	52.23	53.68	51.52	50.92	50.37	50.40	50.30	50.27	31.00	31.66	25.31	16.32	21.86	22.32	19.04	14.41
S_{60}	52.46	54.42	51.70	51.48	50.40	50.37	50.06	49.80	38.46	37.09	27.86	18.26	27.30	25.90	23.73	16.59
LSDs (0.05)																
P	*0.04*	*0.07*	*0.30*	*0.11*	*0.40*	*0.05*	*0.28*	*0.17*	*2.39*	*2.03*	*1.21*	*0.47*	*2.39*	*2.46*	*2.57*	*1.51*
"																
S	*0.04*	*0.07*	*0.30*	*0.11*	*0.40*	*0.05*	*0.28*	*0.17*	*2.39*	*2.03*	*1.21*	*0.47*	*2.39*	*2.46*	*2.57*	*1.51*
' P x S	*0.07*	*0.12*	*0.45*	*0.19*	*0.69*	*0.09*	*0.48*	*0.29*	*4.15*	*3.51*	*2.10*	*0.81*	*4.15*	*4.26*	*4.46*	*2.61*

a = wet season, b = dry season, 1 = 0-5 cm, 2 = 5-10 cm, 3 = 10-20 cm, 4 = 20-40 cm depths, P =poultry, S = sheep and P x S = poultry and sheep manure interactions.

WAMI and P_{30} (7.03 mg kg^{-1}) at 20 – 40 cm in early season of 2020 at 6th WAMI. Trends in concentration with soil depth were a decreasing sequence for most manure rates at various seasons, years and periods of the application. Averaged over soil depths and poultry manure rates, concentrations in early and late seasons varied as 49.58 and 47.01 mg kg^{-1} (2019) and 27.11 and 25.05 (2020) in 1st WAMI, 51.58 and 45.42 (2019) and 25.68 and 21.14 mg kg^{-1} (2020) in 2nd WAMI, 46.69 and 45.99 mg kg^{-1} (2019) and 19.85 and 20.89 mg kg^{-1} (2020) in 3rd WAMI, 51.50 and 49.22 mg kg^{-1} (2019) and 22.15 and 25.07 mg kg^{-1} (2020) in 4th WAMI, 46.91 and 44.22 mg kg^{-1} (2019) and 27.38 and 23.83 mg kg^{-1} (2020) in 6th WAMI, 52.50 and 48.86 mg kg^{-1} (2019) and 27.73 and 22.61 mg kg^{-1} (2020) in 8th WAMI, 52.13 and 50.11 mg kg^{-1} (2019) and 26.07 and 20.87 mg kg^{-1} (2020) in 12th WAMI. This shows fluctuations of decrease followed by increase amongst weeks after incorporation in early season of 2019, decrease from 1st to 2nd followed by increase from 3rd to 4th and another decrease in the 6th followed by another increase from 8th to the 12th week in late season of 2019, a decrease from the 1st to the 3rd followed by an increase from the 4th to the 8th before another decrease in the 12th WAMI in 2020. In both years, concentrations were better in early (50.13 and 25.14 mg kg^{-1}) then, late (47.14 and 22.78 mg kg^{-1}) seasons, averaged over depth, rates and weeks after application. Concentrations were better in 2019 than 2020 averaged over season, depth, rates and weeks after application.

Furthermore, highest and least bray II P concentrations were with S_{60} (54.98 mg kg^{-1}) at 5 – 10 cm in early season of 2019 at 8th WAMI and S_0 (6.20 mg kg^{-1}) at 20 – 40 cm in early season of 2019 at 6th WAMI. In each season, years and weeks after applications, trends for most rates was a decrease down soil depths with that for others being inconsistent.

Averaged over rates and soil depths, concentrations in early and late seasons were 49.58 and 47.00 mg kg^{-1} (2019) and 27.12 and 25.05 mg kg^{-1} (2020) at 1st WAMI, 51.44 and 45.50 (2019) and 25.65 and 21.06 mg kg^{-1} (2020) in 2nd WAMI, 46.69 and 45.98 (2019) and 19.85 and 20.89 mg kg^{-1} (2020) in 3rd WAMI, 51.50 and 49.22 (2019) and 22.15 and 25.07 mg kg^{-1} (2020) in 4th WAMI, 46.91 and 44.22 mg kg^{-1} (2019) and 27.38 and 23.83 mg kg^{-1} (2020) in 6th WAMI, 52.50 and 48.06 mg kg^{-1} (2019) and 27.73 and 22.61 mg kg^{-1} (2020) in 8th WAMA and 52.13 and 50.11 mg kg^{-1} (2019) and 27.74 and 20.87 mg kg^{-1} (2020) in 12th WAMI.

However, concentrations in bray II P at various weeks after incorporations showed fluctuations starting from increase from 1st to 2nd followed by decrease in 3rd with another increase in the 4th and decrease in the 6th WAMI and such order up till the 12th WAM, during early season of 2019, a decrease from the 1st to the 3rd and increase in the 4th followed by another decrease in the 6th and subsequent increase from the 8th to the 12th WAMI in the dry season of 2019, a decrease from 1st to the 3rd followed by increase from the 4th to the 12th WAMI in the wet season of 2020 and a decrease from the 1st to the 3rd followed by increase in the 4th and a subsequent decrease from the 6th to the 12th WAMI. More so, concentrations were better in the early (50.11 and 25.37) than late seasons (47.16 and 22.77 mg kg^{-1}) of 2019 and 2020 and with 2019 better than 2020.

Table 3 also presented that integration of manures differed amongst seasons, years, weeks after application and soil depths. Highest concentration was with $P_{60}S_{60}$ (56.79 mg kg^{-1}) at 5 – 10 cm in early season of 2019 at the 12th WAMI while the lowest was with $P_{30}S_0$ (40.85 mg kg^{-1}) at 20 – 40 cm depth in early season of 2020 at the 6th WAMI. The distributions down soil depths were a decrease for most rates at various seasons, years and periods after application. Also, concentrations were better in early than dry seasons of both years and with 2019 than 2020.

Generally, best bray II P decreased with the integration of manures (56.79) > sheep (54.98) > poultry (54.92 mg kg^{-1}).

4.0 DISCUSSION

4.1 *Nutrients composition of the manures used for the study.*

The poultry and sheep manures were mildy alkaline (Pam and Brian, 2007) and this would promote soil pH on application as they were within the range of 7.4 – 7.8 described as mildy alkaline by Pam and Brian (2007). It has been noted that application of organic manure can improve the soil pH (Hargreaves *et al*., 2008; Iren *et al*., 2014; Li *et al*., 2018).

The EC values of both manures were classified as very strongly saline by LAS (2014). Its higher value in poultry manure than sheep manure could be due to the high soluble salt contents and as such might have increased salt contents of applied soils. Other researchers have also noted high EC values of poultry manure than cattle and goat manures (Azeez and Van Averbeke, 2010[a]; 2010[b]; Usman, 2015; Saka *et al*., 2017). The high sodium content of poultry manure than sheep manure could be responsible for its high EC value. It is also well known that poultry manure has higher nutritional value than sheep manure (Abdelrazak, 2002).

Nutrient concentrations especially total N, P and K were better in poultry than sheep manure and this corroborated the work of Usman (2015), who stated that the fertility status of the soil proved to be beneficial, with poultry manure than any other organic manure in his research. Hence, manure also contains large amounts of organic P such as phospholipids and nucleic acids, which could be released to increase soil inorganic P concentrations by mineralization (Shen *et al*., 2011).

Moreover, variations in composition of poultry and sheep manures could be due to differences in dietary intake. During this experiment, sheep diet was composed of roughages while poultry consisted mainly of concentrates. Sheep manure application improves soil properties through improving physiochemical and biological conditions of the soil (El Gammal and Salama, 2016; Zhang, 2017). The impact of diet in the manures was demonstrated by the high organic carbon and C: N contents of sheep compared with poultry manure due to its carbonaceous nature (Osama *et al*., 2016). Manures contributed to the reduction in fixation of phosphorus and significantly improved soil nutrient status and increase in plant P tissue concentration.

4.2 *Nutrients composition of the soils used for the study.*

In Table 4.2a, sand, silt and clay contents in both seasons, distributed irregularly with soil depths and with mean concentrations being an increasing order of sand > clay > silt, texture of the soils between sandy loam and loam sandy in wet and dry seasons, respectively. The textures of the soils were expected to enhance the release of the orthophosphates and K to the soils. In Table 4.2b, sand, silt and clay were distributed down soil depths and irregular for all fractions in the early season and increase for sand, decrease for silt and irregular for clay in late season. In both seasons and years, mean soil fractions decreased in the order sand > silt > clay with sand better than others. Generally, texture of the soils in both years (2019 and 2020) and seasons (early and late), was dominantly sandy, probably due to the nature of the parent material which is Coastal plain sand (Uzoho, 2010). However, the sand fractions are dominated by such minerals as haematite, goethite, gibbsite and with quartz dominating the clay mineralogy (Uduak *et al*., 2012). Sandiness of the soils signifies high tendency of nutrient leaching and poor soil fertility. It has been noted that the coarser the soil fractions, the higher the water and nutrient transmissible pores and the greater the tendency for nutrient leaching (Ezeaku, 2006). Mixing manure with sandy soils help to retain moisture levels.

However, the values for soil pH indicated that they were slightly to moderately acidic (Adaikwu and Ali, 2013; Ukaegbu, 2020) with the degree greater down soil depth, probably due to its poor organic matter content. It has been reported that the poorer the soil organic matter, the higher the soil acidity (Hargreaves *et al*., 2008), decaying organic matter produces H^+ which is responsible for acidity. In both season and years, values of the soil pH were below 5.0. This shows that the soils may suffer from aluminum toxicity since this occurs in soils with pH less than 5.0 and increases as pH decreases (Neenu and Karthika, 2019). However, lower values than pH 5 suggested that all volatile fatty acids were evaporated and this would be constrained by high acidity and poor fertility status (Obiefuna *et al*., 2012).Moreover, low soil pH might also allow the base cations to leave the exchange sites and released into the soil solution to become exchangeable cations for plant to make use of them or they leached away from the soil. In both seasons in 2019, the pH decreased down soil depth up till 10 – 20 cm probably due to depressed organic matter content that has been noted in soil which is increasingly related to its pH (Prasad and Chakraborty, 2019). While that of 2020 were irregular. As the soils were acidic, P can be dominantly adsorbed by Al or Fe oxides and hydroxides. Thus, P can be first adsorbed on the surface of clay minerals and Fe or Al oxides by forming various complexes (Prasad and Chakraborsty, 2019). The electrical conductivity indicates low salt content of the soils and this might not constitute a threat to its productivity. Equally, bray II P contents were high. Available P has been classified as low (< 8), medium (8 – 20) and high (> 20 mg kg^{-1}) (Adaikwu and Ali, 2013) and low (< 15), medium (15 – 25) and high (> 25 mg kg^{-1}) (Enwezor *et al*., 1990).

4.3 *Soil Bray II Phosphorus*

The values of the bray II P in 2019 were high while 2020 were moderate as it was stated by Chukwu, Ezenwa, Osund and Asiedu (2007) that ≥ 25 mg kg^{-1} was high for available P in Southeastern Nigerian soils and were higher than the critical level of 12 mg kg^{-1} reported by Abegaz *et al*. (2016) and 10 – 16 mg kg^{-1} stated by Adeoye and Agboola (1985).

Generally, best bray II P decreased with the integration of manures (56.79) > sheep (54.98) > poultry (54.92 mg kg^{-1}). Highest concentrations with manure integration have been ascribed to its high effect on priming of mineralization. The best concentration at varying weeks after application for the different manures could be due to the existence of favorable condition for mineralization at such periods with most being in the early season and 0 – 5 cm soil depth due to the availability of moisture and oxygen for residual oxidation of the manures. The relative increase in available P is due to the addition of manures, this could create a shield or manure blockage and thus preventing the fractional sites onto which the P is fixed to the metallic components from fixing soil P and would result into more P being available in the solution pool or the available P pool. According to Hylander and Neribara (2023), bray II P values increased for several minutes after addition of the extractant to nonallopanic Andisol.

5.0 CONCLUSION AND RECOMMENDATION

Organic amendments, in particular poultry and sheep manures can represent the sustainable tool to improve soil fertility in intensive agriculture. Generally, addition of poultry and sheep manures on the soils improved the soil bray II phosphorus compared with control and this was due to nutrients present in the manures applied. However, integration of poultry and sheep

manures incorporated led to increase in the soil bray II P more than the single applications in the early and late seasons of 2019 and 2020. Highest application of manures interaction improved soil bray II P with the trend of $P_{60}S_{60}$> $P_{60}S_{30}$> $P_{30}S_{30}$> $P_{30}S_{30}$. Furthermore, relative to soil depths bray II P decreased as the depth increased. Across the weeks, highest soil bray II P were obtained at fourth week in 2020 and eight week in 2019 at all depths in relation to other weeks in both years. More so, highest soil bray II P were obtained between soil depths of 0 – 5 and 5 – 10 cm after manures application. Early seasons aid mineralization better than late seasons.
To increase soil bray II phosphorus, addition of poultry, sheep and integration of poultry and sheep manures are recommended. For long – term sustainability, replacement of P removed by crops is necessary. The knowledge acquired during this study can be brought together to develop a decision support systems for soil bray II P management under intensive cropping systems in Southeastern Nigeria. Phosphorus needs to be added to the soils because it is the limiting nutrients in sandy soils. The nutrients decreased as soil depth increased, thus this would not have harmful effect on water and the environment.

ACKNOWLEDGEMENTS

We acknowledged the reviewers, editor and those who contributed to the success of the work. Meanwhile, the statements, opinions and views are for the authors.

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Evaluation of Different Levels of Phosphorus Fertilizer Towards Enhancing Nodulation and Grain Yield in Cowpea (*Vigna unguiculata* (L.) Wap-)

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ABSTRACT

The experiment was conducted during the wet season of 2021 and 2022 at Binyaminu Usman polytechnic research farm, Hadejia. to assess the effect of different levels of phosphorus fertilizer towards enhancing nodulation and grain yield in cowpea (SAMPEA-11). The treatments consist of four levels of phosphorus (0, 30, 50 and 70kg Pha^{-1}) in the form of single super phosphate (SSP) laid out in a randomized complete block design (RCBD) with three replications. All growth and yield parameters (Plant height, number of branches, number of nodules, pod number and grain yield) were recorded, the data were subjected to analysis variance using Genstat, and means were separated with SNK. The result indicates that 70kg of phosphorus fertilizer has the highest number of plant height, number of branches, pod number, number of nodules and grain yield. This rate (70kgPha^{-1}) of phosphorus fertilizer is therefore recommended for enhancing nodulation and grain yield of cowpea.

Keywords: Cowpea, Phosphorus, Nodulation and Yield

Introduction

Cowpea (*vignaunguiculata* as a grain legume is an important source of food, income and livestock feed and forms a major component of tropical farming system because of its ability to improve marginal lands through nitrogen fixation and as cover crop (sanginga*et al;* 2003). It is a valuable and dependable commodity that earns income for many smallholder farmers and traders in sub Saharan African (langylintuo*et al.*, 2003). Cowpea can be grown under rain fed conditions as well as by using irrigation or residual moisture along river or lake flood plains during the dry season, provided that the range of minimum and maximum temperature is between 28^{O}C and 30^{O}C (night and day) during the growing season. Cowpea performs well in agro ecological zone where the rainfall range is between 500 and 1200mm/year (madamba*et al*, 2006). Among the factors responsible forsuch low yield is edaphic factor (soil physiochemicalcharacteristics) particularly phosphorus (P) deficiency whichis the most limiting soil fertility factor for cowpea production (IITA., 2003). This occurs as a result of either inherent lowlevels of P in the soils or depletion of the nutrient throughcultivation.

Phosphorus is among the most needed elements for cropproduction in many tropical soils. However, many tropicalsoils are inherently deficient in P (Osodeke, 2005) andnitrogen (Haruna and Aliyu, 2011). The deficiency can be soacute in some soils of the Savannah zone of Western Africaresulting in cessation of plant growth as soon as the P storedin the seed is exhausted (Mokwunye and Bationo, 2002). Cowpea does not require too much nitrogen fertilizer becauseit fixes its own nitrogen from the air using the nodules in itsroots. However, in areas where soils are poor in nitrogen, thereis a need to apply a small quantity of about 15 kg of nitrogenas a starter dose for a good crop. If too much nitrogen fertilizeris used, the plant will grow luxuriantly with poor grain yield.

Cowpea requires more phosphorus than nitrogen in the formof single super phosphate (Nkaa*et al*., 2014). Phosphorus plays key roles in many plant processes suchas energy metabolism, nitrogen fixation, synthesis of nucleicacids and membranes, photosynthesis, respiration and enzymeregulation. Phosphorus is critical to cowpea yield because it isreported to stimulate growth, initiate nodule formation as wellas influence the efficiency of the rhizobium legume symbiosis (Nkaa*et al*., 2014). It is required in large quantities in youngcells such as shoot and root tips to increase metabolism andpromote rapid cell division. It also aids in flower initiation, seed and fruit development (Ndakidemi and Dakora, 2007). According to Oti*et al*. (2004), phosphorus decreases zincconcentration in the cowpea grain, thereby affecting itsnutritional quality. It is required for the physiologicalprocesses of protein synthesis and energy transfer in plants (Nkaa*et al*., 2014). Application of phosphorus has beenreported by several authors to improve yield of cowpea. Seedyield is, therefore, governed by number of factors which havea direct or indirect impact. Among these factors are yieldcomponents such as number of pods per plant, number ofseeds per pod and 100-seed weight over a given land area (Cobbinah*et al*., 2011).

In Nigeria under farmers practice, legumes usually receive little mineral phosphorus fertilizer, they therefore rely partly on the natural available soil phosphorus and other nutrients for nitrogen fixation and growth, and this resulted to low yields (Singh *et al*, 2011 and Nkaa*et al*, 2014).

In consideration of the abovementioned problems, this study was conducted to determine the optimum level of phosphorus in the form of single super phosphate that will enhance the growth and yield of cowpea in the study area.

Materials and Methods

Experimental site: The experiment was conducted during the wet season of 2021 and 2022 at Binyaminu Usman polytechnic research farm, Hadejia.It is situated at a latitude of 11º 35 to 11º N, 37¹ N and longitude of 10º 04¹ to10º 11¹E. The variety usedwasSAMPEA 11, which has good seed quality and resistance to nematode and tolerance to major insect pest. The research consists of four treatment laid out in a randomized complete block design (RCBD) replicated three times. The treatments consist of four levels of phosphorus (0, 30, 50 and 70 kg Pha^{-1}) in the form of single super phosphate (SSP). Each gross plot consisted of $17.1m^2$ measuring 3.8m x 4.5m and net plot measured 6.75m2 (4.5m x 1.5m).

Two seeds were manually sown per hole at the depth of 3cm and spacing of 30 cm between stands. Phosphorus fertilizer was applied during land preparation before planting. The application was according to treatments. Two hoe weeding were carried at 2 and 4 weeks after sowing to control weeds.

Data collection and analysis

Data were collected on **Growth parameter**: plant height, number of branchesper plant and number of nodules at 3, 6 and 9 WAS, while grain yield wasdetermined at harvest. Plant height, number of branches perplant and number of leaves were determined at 3, 6 and

9WAS. The number nodules were recorded from each plot, the plants to beuprooted were watered up to saturation point. The plants werethen uprooted with the help of a dibber, the root systemwashed gently in clean standing water. The nodules were thenseparated and counted per plant. Nodules were cut opened todetermine apparent effectiveness, using a razor blade and handlens. Nodules with pink or reddish colour were consideredeffective and fixing nitrogen, while those with green orcolourless were identified as ineffective nodules.

Harvesting was done at physiological maturity when about 85% of pods had turnedbrown and more than 75% of leaves had senescenced. It was done within one square meter area of plants from the central rows on each plot. Five plants were taken from each plot (harvested area). The pods, number of seeds per pod were counted, Average seed weight was determined by randomly counting 100 seeds from the threshed and oven dried. These were weighed to represent the 100-seed weight. Seed yield per hectare was determined by threshing the harvested plants from the net plot. These were put in labeled envelopes, oven dried at 80°C for 48 h and thenweighed. The resulting weights, in grams per meter square, were then extrapolated to kilogram per hectare basis to get the average seed yield per hectare.

All the crop data collected was subjected to analysis of variance (ANOVA) using GenStat 17th edition, the treatment means were separated by Least Significant Difference (LSD) at 5% probability levelwithSNK.

Results and Discussion

Soil Analysis

The soil was slightly alkaline sandy loams with low available P, total N, exchangeable cations and low CEC (Table 1). The available P varied between 2.85 and 2.91 mgkg^{-1}, which are lower than 7.0 mgkg^{-1} established by Aune and Lai (1995) as the critical soil available P level required for proper growth and development of cowpea.

Effect of phosphorus levels on plant height

Effect of phosphorus levels on plant height is presented in Table 2, at various growing seasonin 2021 and 2022 wet season. In 2021, at 3 and 6 WAS,application of Phosphorus fertilizer produced nosignificant ($P<0.05$) effect on plant height. Significant effect of phosphorus fertilizer was observed only at 9WAS, the tallest plant was recorded from application of 70 kgPha^{-1} while the application of 0 and 30 kgPha^{-1} produced the Shorter plant. In 2022 there is no significant ($P<0.05$) statistical differences on plant height at all the sampling periods with regards to phosphorus fertilizer application. The role of phosphorus in celldivision could be responsible for the increase in the plantheight at 9WAS in 2021. This finding is in conformity with that of Ayodeleand Oso, (2014) who reported that application of 20kgPha^{-1}significantly increased plant height and leaf area index.Sanginga*et al*., (2013) observed that plant height and number of leaves per plant were significantly enhanced byphosphorus application.

Effect of Phosphorus levels on number of branches per plant

Table 3 showed effect of phosphorus levels on number ofbranches per plant of cowpea variety SAMPEA 11 at varioussampling period in 2021 and 2022 wet seasons. In 2021 at 6WAS, application of 50and 70 kgPha^{-1}recorded significantly ($P<0.05$) higher number of branches perplant when compare with control. At 6 WAS, eachincrease in phosphorus from 0 to 70 kgPha^{-1} resulted insignificant increase in number of branches. In 2022 at

6WAS, application of 70Kgha-1 of Phosphorus producedsignificantly ($P<0.05$) highest number of branches per plantwhile when compare with control. At 6 WAS, number ofbranches per plant increased significantly ($P<0.05$) withincrease in phosphorus application from 0 to70kgPha^{1}. At 3WAS and 9WAS, 30-70 kgPha^{-1}recorded similar result. The positive effect of phosphorus onnumber of branches per plant could be due to the significantrole of the element on cell division and elongation whichresulted in the production of more lateral buds thatdeveloped into branches. Nkaa*et al*,.(2014) reported thatphosphorus fertilizer application to cowpea varieties hadpositive effect on number of leaves and branches per plant.Ayodele and Oso (2014) also reported that total number ofbranches per plant increased with phosphorus application upto 40 kgPha^{-1}. Number of reproductive branches per plant(flower bud-bearing) was positively affected by phosphorusapplication up to 40 kgPha-1 (Muhammed *et al.*, 2013).Another contributing factor that probably enhanced numberof branches per plant could be the soil texture of the plotwhich is sandy loam. This textural class facilitated soilmoisture holding capacity that reserved adequate water forthe crop usage especially in photosynthesis, translocation of assimilate and other physiological processes.

Effect of phosphorus levels on Nodulation

Effect of phosphorus levels on number of nodules was presented in Table 4. Significance difference was observed in number of nodules as the result of application of Phosphorus fertilizer in 2021 and 2022 growing season. Increase in nodulation with increase in the level of phosphorus fertilizer application 30-70 kgPha^{-1} was observed at 6 WAS and 9WAS of the sampling period at 2021 and 2022 growing season. In 2021, the highest number of nodules was recorded from application of 50 and 70 kgPha^{-1} at 6WAS and 9WAS, the least number of nodules was obtained from application of 0 to 30 kgPha^{-1}, No significance $P>0.05$difference in number of nodules recorded at 3 WAS in 2021. Similarly, in 2022 the highest number of nodules was recorded from application of 70 kgPha^{-1} at 6WAS and 50 and 70 kgPha^{-1} 9WAS, the least number of nodules was obtained from application of 0 to 30 kgPha^{-1}. No significance $P>0.05$statistical differences recorded in number of nodules at 3 WAS in 2022 growing season of the study area.

Effect of phosphorus levels on Grain yield

Table 5 shows effect of phosphorus levels on yield ofSAMPEA 11 cowpea variety. In 2021, application of 70kgPha-1 produced significantly ($P<0.05$) the highest grainyield while the lowest yields was recorded from control followed by 30 and 50 kgPh^{-1}. In2021, application of 50 and 75 kgPha^{-1} producedsignificantly ($P<0.05$) the highest yield while 0 kgPha^{-1}produced the lowest yield. The positive response ofgrain yield to phosphorus application could be due thesignificant role of the element on enhancing thephotosynthesis apparatus such number of leaves per plant. The soil pH (7.3) of the experimental sitewhich was slightly alkaline could also be responsible for thehigher yield. Haruna and Usman (2013) reported getting higher yield at 30 kgPha-1 while Singh *et al*., (2011) recorded the highest yield at 60 kgPha-1. According toEcocrop (2009), best yield of cowpea was obtained undersoil pH of 5 -7 while other agronomic practices were carriedout as recommended. Results of the research conducted atSadore in South of Niamey, Niger republic during 2012 and2013 wet seasons revealed that application of 60 kgha-1 ofphosphorus significantly increased cowpea yield by 30.8%(Shagari, 2014).

Table 1: Physio-chemical properties of soil samples of experimental site in 2021 and 2022.

Soil properties	2021	2022
Physical properties		
Sand %	66.36	58.24
Silt %	9.32	8.53
Clay %	24.32	33.23
Soil textural class	Sandy loam	Sandy loam
Chemical properties		
pH H_2O	7.2	7.3
Total Nitrogen (gkg^{-1})	1.15	1.32
Available P ($mgkg^{-1}$)	2.85	2.91
Exchangeable bases ($Cmolkg^{-1}$)		
Calcium (Ca2+)	1.28	1.33
Magnesium (Mg2+)	0.85	0.82
Potassium (K+)	0.20	0.23
Sodium (Na+)	5.74	5.64
CEC (Cmolkg-1)	8.00	8.34

Table 2: Effect of phosphorus levels on plant height of cowpea in 2021 and 2022 wet season

Treatment Phosphorus KgP/ha	2021			2022		
	3 WAS	6 WAS	9 WAS	3 WAS	6 WAS	9WAS
0	15.62	25.59	33.80b	16.3	36.77	55.1
30	17.23	25.73	33.92b	22.7	36.40	46.7
50	20.02	26.35	35.56ab	22.5	34.33	50.7
70	16.69	26.20	37.34a	23.8	33.37	53.2
SE+	1.460	0.637	0.837	3.90	0.84	2.10

Means followed by the same letter(s) within column are not significantly different using SNK at 5% probability Level

Table 3: Effect of phosphorus levels on number of branches per plant of cowpea variety in 2021 and 2022 wet season

Treatment Phosphorus KgP/ha	2021			2022		
	3 WAS	6 WAS	9 WAS	3 WAS	6 WAS	9WAS
0	4.25	8.25b	16.32	4.20	12.50b	27.40
30	3.99	10.43ab	14.672	4.06	15.50b	27.40
50	4.66	10.66ab	14.745	4.06	20.70a	28.50
70	4.27	11.866a	14.425	3.93	21.90a	27.00
SE+	0.209	0.806	0.672	0.162	3.12	2.90

Means followed by the same letter(s) within treatment column are not significantly different using SNS at 5% probability Level

Table 4: Effect of phosphorus levels on number of nodules of cowpea in 2021 and 2022 wet season

Treatment Phosphorus KgP/ha	2021			2022		
	3 WAS	6 WAS	9 WAS	3 WAS	6 WAS	9 WAS
0	5.62	3.27b	6.79c	5.83	6.07c	7.3b
30	6.75	4.62b	6.12c	6.50	6.17c	7.2b
50	6.12	7.80a	8.62b	6.17	8.13b	10.5a
70	6.12	8.75a	9.50a	7.67	9.63a	12.6a
SE+	0.90	4.43	0.426	1.35	0.99	2.49

Means followed by the same letter(s) within treatment column are not significantly different using SNS at 5% probability Level

Table 5: Effect of phosphorus levels on number of podand grain yield of cowpea variety in 2021 and 2022 wet season

Treatment Phosphorus kg/ha	2021		2022	
		Grain Yield		Grain Yield
0kg	6.48	542.0c	8.87c	726.3c
30kg	6.60	1385.7b	9.40c	1495.5b
50kg	5.66	1492.2b	13.65b	1785.6a
70kg	7.57	1725.6a	17.47a	1827.4a
SE+	1.198	107.3	1.198	109.3

Means followed by the same letter(s) within treatment column are not significantly different using SNK at 5% probability Level

Conclusion

The results obtained from this trial indicated that applicationof 70 kgPha^{-1}under rain fed conditions, in well drainedsandy loam soil resulted to highest growth and yield ofSAMPEA 11 cowpea variety in Malam MadoriJigawa, Nigeria and thus recommended.

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Effects of NPK and Biofertilizer on Some Soil Properties, Growih and Yield of Fluted Pumpkin (Telferia Occidentalis) in Calabar, Cross River State, Nigeria

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ABSTRACT
Field experiment was carried at the Teaching and Research Farm of Faculty of Agriculture, University of Calabar to assess the effects of NPK and biofertilizer on the physico-chemical properties of Soil, growth and yield of Fluted Pumpkin (*Telferia occidentalis*) in Calabar, Cross River State, Nigeria. Organic wastes (Banana peels) obtained from banana sellers along University of Calabar Staff School Road and Cow dung obtained from the University of Calabar Teaching and Research Farm, were digested for biofertilizer using the process of anaerobic digestion. The weights of individual substrates were 6.5kg and combination of two gave 13 kg. Each substrate combination was mixed with water at a ratio of 1:3 (water volume was 36 liters). The treatment consisted of bio-slurry produced from Cow dung and Banana peels and rate of fertilizer application was 40kg/ha and 60kg/ha of NPK 20:10:10. The bio-fertilizer applications were applied on the field based on nitrogen content of the biofertilizer. At 40 kgN/ha the quantity of bio-fertilizer was 5,952.38 litres/ha and 60kg/N/ha was 8,928.57 litres/ha. The experiment was a 3 x 2 factorial fitted in Randomized Complete Block Design (RCBD). It was replicated three (3) times to give a total of eighteen (18) experimental units or sized plots. The result obtained showed that soil used for the experiment was sandy loam in texture and moderately acid with pH in water value of 5.7. The soil was generally low in organic carbon (0.85%), total nitrogen (0.07 %), ECEC (7.45 cmol/kg) and exchangeable bases Mg (0.8), K (0.06) and Na (0.07) cmol/Kg, except exchangeable Ca (5.2 cmol/kg) but moderate in available phosphorus content (15.2 mg/kg) and high in base saturation (82.28 %). The result of the effect of biofertilizer on soil properties indicated that there was a significant ($p<0.05$) improvement in soil pH, OC, AP, Ca, Mg, K, AI, H, ECEC and BS. Similarly, the result showed bio-fertilizer A_1B_1 to significantly increased leaf width and length while A_0B_1 significantly increased number of leaves and number of branches.
Keywords: Biofertilizer, Anaerobic, Bioslurry, Cow dung, NPK.

INTRODUCTION
The excessive use of high chemical fertilizer in Nigerian has led to serious soil degradation, depletion of soil organic matter, leaching of nutrients and compaction of soil. This has resulted to decreasing soil fertility and rapid declining production level of crops. Scientists and researchers have decided to reduce these problems by augmenting their soils with biofertilizer which is eco-friendly, odourless, accessible, and cost effective (Akpan *et al*., 2017; Akpan *et al*., 2020).

Bio-fertilizer is a substance containing living cells or latent cell of efficient strains of microorganisms that help plant to absorb nutrients by their interaction in the rhizosphere when applied through leaves or soil (Nooralvandi, 2016; Akpan *et al*., 2020). Biofertilizer not only improve soil fertility with their content but also have a stimulating effect upon plant growth and development (Raja, 2013). Biofertilizer can be produced anaerobically through the process of anaerobic digestion.

Frequent and high rate of NPK fertilizers used have been associated with soil degradation and some environmental pollution. Also these important production input has become expensive and scarce in many parts of Nigeria. It therefore becomes necessary to carry out studies on ways of reducing the dependence on NPK fertilizer. Research work on other crops revealed that best yields were obtained by appropriate combination of biofertilizer and NPK fertilizers (Han *et al*., 2016). The combination of biofertilizer and NPK can add 20-200 kg N/ha/year (Ogbonna, 2008). The soil applied with biofertilizer changed the soil pH from 4.5 to 7.8 (Akpan *et al*., 2020). Organic carbon values (≥ 1.5%) and total nitrogen (≥ 0.2%) were obtained on amended soils compared with low values on control soils (Akpan *et al*., 2020). Similarly, soil amended with the combination of water melon peels plus cow dung plus paw-paw peels and banana peels biofertilizer significantly ($p \leq 0.05$) produced maximum yield of pepper (Akpan *et al*., 2020).

Fluted pumpkin (*Telfairia occidentalis* Hook F.) is a dioecious, creeping annual vegetable shrub that spreads low across the ground and climbs by means of vines and often coiled tendrils (Udoh *et al*., 2005). *T. occidentalis* thrives well within the temperature range of 30 - 50°C and most tropical vine crop thrives well under a warm environment with sufficient sunshine and prolonged rainy season. Rainfall appears to be the major factor in its productivity with a requirement of 1000 - 2500 mm per annum.

Fluted pumpkin leaves have high iron and protein and contains about 86% moisture, 11% crude protein, 25% carbohydrate, 3% oil, 11% ash as much of 700ppm of iron (Muoneke *et al*., 2011). Its seed contains 13% oil which is used for cooking, manufacturing and cookies formulation.

This study was therefore conducted with the aim of accessing the effect of NPK and bio-fertilizer on the physico-chemical properties, growth and yield of fluted pumpkin (*Telferia occidentalis*) in Calabar, Cross River State, Nigeria.

The specific objectives were to:

1) Determine the physico-chemical properties of soil with the application of NPK rates and biofertilizer.
2) Evaluate the effect of NPK rates and biofertilizer on growth and yield performance of Fluted pumpkin (*Telferia occidentalis*).

MATERIALS AND METHODS

The experiment was conducted in University of Calabar Teaching and Research Farm (latitude 04° 48' and 04° 54' North and longitude 08° 23' and 08° 41' East). The substrates (cow dung + Banana peels) were the two main sources for the biofertilizer production. The cow dung was collected from the University of Calabar Teaching and Research Farm (Cattle Unit). The Banana peels were sourced from banana sellers along University of Calabar staff school road. The fluted pumpkin (*Telferia occidentalis*) seeds were bought from Ika-ika Qua Market (Marian Market) in Calabar. The Banana peels were ground with grinding engine and mixed with the cow dung to get a weight of 13 kg (cow dung 6.5kg+ banana peels 6.5k g). Sixty liters capacity anaerobic digester was constructed where the l3 kg of the mixture of cow dung and banana peels were mixed with water at a ratio of 1:3 (C + B was 13kg and water 39kg (w/w) which gave 36 liters. (The quantity of water at 1kg was 12 liters; therefore 3 kg gave 36 liters of water). The mixture was placed in anaerobic chamber for 45days for fermentation to take place and the bio-slurry was collected.

The treatment consisted of bio-slurry produced from cow dung (C) and banana (B) peels which contained 11,940.30 litres/ha and the rate of fertilizer application was 40 kg/ha and 60 kg/ha of

NPK 20:10:10. The hectare contained 27,778 plant/ha and 430 ml/ plant were applied by splinting into three times. The choice of the combination was based on the previous research which showed that the combination of cow dung and banana peels produced best result as reported by Akpan *et al*., 2020. The experiment was a 3 x 2 factorial fitted in randomized complete Block Design (RCBD). It was replicated three times to give a total of eighteen (18) experimental plot sizes with A_0 (no biofertilizer), A_1 (biofertilizer of C + B (430 ml/plant), B_0 (no NPK), B_1 = NPK at 40 kg/ha (7.2g/plant), B_2 = NPK at 60kg/ha (11g/plant).

The experimental area measured 21.5 m x 13 m. Blocks were separated from each by an alley of 1m. Each plot measured 3m x 3m ($9m^2$) and separated from each other by a distance of 0.5 m and plant spacing was 60 cm by 60 cm (0.6 m x 0.6 m). Data was collected from 4 plants in the 2 inners rows of the net plot (0.24 m^2). The following variables were collected at various sampling period. Leaf length, leaf width, numbers of branches and vine length at 4, 6, 8 and10 weeks after planting (WAP). Soil samples were collected before the experiment at the depth of 0-1 5cm using soil auger from a different point at the experimental site and bulk to form one composite sample. The samples were thoroughly mixed, air-dried, sieved through a 2 mm sieve and analyzed for physico-chemical properties in the laboratory following the procedures described by Udo *et al*. (2009). Data collection was subjected to statistical analysis using analysis of variance (ANOVA). Significant means was separated through Ducan's New Multiple Range Test (DNMR) at 5% probability level.

RESULTS AND DISCUSSION

Initial physical and chemical properties of the soil before planting

Results of initial physical and chemical properties of the soil before planting are shown in Table 1. The soil used for the experiment was sandy loam in texture and moderately acid with pH in water value of 5.7. The soil was generally low in organic carbon (0.85 %), total nitrogen (0.07 6), ECEC (7.4Scmol/kg) and exchangeable bases except exchangeable Ca (5.2 cmol/kg) but moderate in available phosphorus content (15.2 mg/kg) and high in base saturation (82.28 %) when compared to the critical minimum for Nigerian soils (Landon, 1991). The low organic carbon and total nitrogen contents could be attributed to continuous cropping of the soil without adequate fallow period or additional nutrient supply.

Table 1: Initial physical and chemical properties of the soil used for the experiment

Soil properties	Values
Particle size distribution	
Sand	76
Silt	16
Clay	8
Textural classification (USDA)	Sandy loam
Chemical properties	
pH(H_20)	5.7
Organic carbon (%)	0.85
Total nitrogen (%)	0.07
Available phosphorus (mg/kg)	15.2
Exch. Ca (cmol/kg	5.2
Exch. Mg (cmol/kg)	0.8
Exch. K (cmol/kg)	0.06
Exch. Na (cmol/kg	0.07
Al (cmol/kg)	0.12
H (cmol/kg)	1.20
ECEC (cmol/kg)	7.45
BS (%)	82.2

Effect of biofertilizer on soil physical and chemical properties

The influence of biofertilizer on soil physical properties as presented in Table 2 showed that there was no significant ($p>0.05$) difference in sand, silt and clay contents between treated soils and the control soil. The result also showed that there was a significant ($p<0.05$) difference in pH between treated soils compared to control soil after planting with A_1B_0 having highest pH value of 7.16 which was significantly ($p< 0.05$) different from control (A_0B_0) (5.43) and those treated with A_0B_2 (6.2). This result is in line with the report of Oviyanti *et al*. (2017), who demonstrated that biofertilizer had increased soil pH in their studies, but contrary to the studies of Berger *et al*. (2013) who reported that biofertilizers reduced soil pH.

The result showed significant ($p<0.05$) difference in available phosphorus and OC between treated soils compared to control soil after application of biofertilizers. The result further showed that the available P values obtained for the various treatments were within the high critical limits of Landon (1991). This result is in line with the report of Berger *et al.* (2013), who reported that biofertilizers increased available P in their studies. The control soil had high available phosphorus content of 37.5 mg/kg.

Table 2: Effect of bio-fertilizer on soil physical and chemical properties after the experiment

Treatments	Particle size sand	silt	clay	pH (H_2O)	OC	TN	AV.P ($mgkg^{-1}$)	Exch. Cations Ca	Mg	K	Na	Exch. Acidity Al^{+3}	H^+	ECEC	BS (%)
	⟶ % ⟵				⟶ % ⟵			⟶ $cmolkg^{-1}$ ⟵							
A_0B_0	83	6.33	10.67	5.43c	1.63f	0.17	37.5f	3.24b	1.44d	0.57b	0.08	0.093c	3.14a	8.56b	62.22e
A_1B_0	83.67	6.33	11.33	6.83a	2.36c	0.19	54.46d	1.34d	0.63e	0.33d	0.08	0.12b	1.22c	3.64d	63.61d
A_0B_1	82.67	7.0	11.33	7.16a	1.93d	0.17	48.39e	2.38c	2.24b	0.47c	0.08	0.12b	1.31c	6.60c	78.36b
A_1B_1	82.33	6.33	10.67	6.87a	2.79a	0.17	68.05b	3.17b	2.01c	0.40cd	0.07	0.087c	1.98b	8.05b	70.13c
A_0B_2	82.67	6.00	10	6.20b	2.45b	0.16	78.41a	7.60a	3.59a	0.76a	0.13	0.00d	0.44d	12.53a	95.82a
A_1B_2	83.33	7.0	10.33	6.73a	1.89e	0.16	63.20c	2.28c	2.24b	0.40cd	0.08	0.14a	1.30c	6.47c	77.60b
LSD (≤0.05)	NS	NS	NS	0.45	0.010	NS	0.874	0.113	0.016	0.086	NS	0.015	0.45	0.071	1.13

A_0B_0 = control; A1 = Biofertilizer of C + B (430 ml/plant); B1 = NPK at 40 kg/ha (7.2g/plant); B2 = NPK at 60kg/ha (11g/plant); WAP = weeks after planting; LSD = least significant difference; means with the same letter(s) are statistically not significant at p≤ 0.05 according to Fisher's LSD.

The result also showed that there was no significant ($p>0.05$) difference in total nitrogen and Na between treated soils and the control soil after biofertilizer application. Despite soil amended with A_1B_0 having highest TN, it was rated low in total nitrogen alongside with other amended Soils following critical fertility rating of Landon (1991) established for productive soils. This result is contrary to the report of Oviyanti *et al*. (2017), who demonstrated bio-fertilizer to have significantly increased soil total N. The result showed that there was a significant ($p<0.05$) difference in exchangeable Ca, exchangeable Mg, exchangeable Al^{3+} and exchangeable H^+ between control soil and those treated with biofertilizers.

Effect of bio-fertilizer on growth parameters (leaf length, leaf width, number of branches, number of leaves and vine length) of fluted pumpkin

The effects of bio-fertilizer on growth parameters of fluted pumpkin plant are shown in Table 3 and 4. Results obtained indicated that the application of biofertilizer significantly ($p <0.05$) enhanced the leaf length, leaf width, number of branches, number of leaves and vine length in fluted pumpkin at 6 weeks after planting (WAP) relative to the control. Similarly, the application of A_1B_1 produced plants with the longest leaf (0.97 cm) and heaviest leaf width which were significantly ($p<0.05$) different from those in the control soil. At 4 WAP the application of biofertilizer significantly ($p <0.05$) enhanced the leaf length, number of branches and vine length, while leaf width, number of leaves was not significantly ($p<0.05$) different from those in the control soil. However, the application of A_2B_1 produced plants with the longest leaf (0.87 cm) at 4WAP which was statistically not significant ($p > 0.05$) with soils amended with A_1B_2, A_1B_0, A_1B_1 and the control soil but was Significantly ($p < 0.05$) higher than those in soil amended with A_0B_1 and A_0B_2, respectively. At 8 and 10 WAP, the number of branches and vine length in soil amended with biofertilizer was significantly ($p<0.05$) more than those in control soil.

The leaf length and leaf width was not significantly ($p > 0.05$) different from those in the control soil. Similar increase in growth parameters were observed in different crops treated with biofertilizer (Abd EI-Hamid et al., 2013; Abdel-Hakim et al., 2015). At 8 WAP, soil amended with A_1B_0 gave the highest number of leaves (35.07), and longest vine length (78.90) which was significantly ($p<0.05$) higher than those observed for other amended soils and the control soil. This is in agreement with the result of Nahed *et al*. (2015) on response of sweet pepper plants to some organic and bio-fertilizers, which in their studies had significantly more leaves than those grown in natural conditions.

CONCLUSION

The trial have shown the efficacy of biofertilizer as good organic amendments in the soil for enhanced growth of fruited pumpkin (*Telfairia Occidentalis* hook. f) and improvement of soil chemical properties. The best treatment was bio-slurry obtained from combinations of A_1B_1 and A_1B_0. While A_1B_1 consistently increased leaf width, and length, A_1B_0 significantly increased number of leaves and number of branches. Hence, the application of this biofertilizer could substitute NPK fertilizer in marginal soils which characterizes coastal plain sands of humid tropical rainforest of Calabar, Nigeria.

Table 3: Effect of bio-fertilizer on leaf length and leaf width fluted pumpkin

A_0B_0 = control; A1 = Biofertilizer of C + B (430 ml/plant); B1 = NPK at 40 kg/ha

Effect of bio-fertilizer on leaf length (cm)					Effect of bio-fertilizer on leaf width (cm)			
Treatments	4WAP	6WAP	8WAP	10WAP	4WAP	6WAP	8WAP	10WAP
A_0B_0	0.83a	0.80cd	0.94	10.01	0.90	0.53c	0.93	10.05
A_1B_0	0.83a	0.86bc	0.91	10.02	0.88	0.87b	0.90	10.05
A_0B_1	0.70b	0.75d	0.97	10.03	1.30	1.01a	0.90	10.05
A_1B_1	0.86a	0.97a	0.97	10.05	0.90	1.05a	0.90	10.53
A_0B_2	0.63b	0.90ab	0.95	10.86	0.70	1.03a	0.90	10.05
A_1B_2	0.87a	0.93ab	0.95	10.04	0.90	0.99a	0.90	10.04
LSD (≤0.05)	0.127	0.079	NS	NS	NS	0.083	NS	NS

(7.2g/plant); B2 = NPK at 60kg/ha (11g/plant); WAP = weeks after planting; LSD = least significant difference; means with the same letter(s) are statistically not significant at p≤ 0.05 according to Fisher's LSD.

Table 4: Effect of bio-fertilizer on number of branches, number of leaves and vine length

Effect of bio-fertilizer on number of branches				Effect of bio-fertilizer on number of leaves			Effect of bio-fertilizer on vine length			
Treatments	6WAP	8WAP	10WAP	4WAP	6WAP	8WAP	4WAP	6WAP	8WAP	10WAP
A_0B_0	0.92b	1.33d	4.40bc	9.33	15.70c	24.13c	24.30a	55.97b	58.7c	116.3c
A_1B_0	1.75ab	3.32a	7.47a	9.97	21.57a	35.07a	23.63ab	65.07a	78.90a	140.3b
A_0B_1	2.25a	2.65ab	6.17ab	10.90	18.80abc	23.90c	24.87a	49.80c	63.30bc	122.2c
A_1B_1	0.92b	2.33bc	4.13c	10.37	17.67bc	31.13b	17.23c	57.47b	65.23b	186a
A_0B_2	2.50a	1.80cd	4.47bc	10.57	19.67ab	29.22b	20.57bc	58.0b	67.83b	139.3b
A_1B_2	0.92b	2.50bc	5.13bc	9.20	18.83ab	31.57b	18.57c	59.80ab	69.0b	170.8a
LSD (≤0.05)	0.87	0.73	1.84	NS	3.12	3.19	3.55	5.47	5.79	16.5

A_0B_0 = control; A1 = Biofertilizer of C + B (430 ml/plant); B1 = NPK at 40 kg/ha (7.2g/plant); B2 = NPK at 60kg/ha (11g/plant); WAP = weeks after planting; LSD = least significant difference; means with the same letter(s) are statistically not significant at p≤ 0.05 according to Fisher's LSD.

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Correlation Between Soil Electrical Conductivity and Extracellular Enzyme Activities in Hierarchical Aggregates as Affected by Biochar and NPK Fertilizers in an Ultisol

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ABSTRACT

Soil electrical conductivity (EC) relates to soil physiochemical propertieswhose interaction with soil microbes characterizes soil nutrient cycling, soil fertility, and soil productivity potential. A hierarchical aggregate model was used to assess soil EC and the activities of eight extracellular enzymes involved in the C, N, P, and S cycles. Soil EC was measured in a 1:5 soil water suspension, while enzyme activity was analyzed by a modified fluorescence multiplate assay after a 20-day incubation experiment on five hierarchical fractions (large, medium and small macroaggregates, microaggregates, and bulk soil) of four treated soils (reapplication of biochar and/or NPK fertilizers, including the control) from a 4-year field trial. Soil EC increased approximately 2-fold with NPK and NPK+biochar treatments and approximately 1.2-fold with biochar treatment. Both the aggregate-associated EC and the activities of all investigated enzymes were significantly higher in microaggregates than in macroaggregates and bulk soil, indicating specific microbe-particle associations and the significance of explicit hierarchical computation. The larger surface area of silt and clay fractions is central to higher soil conductivity and microbial colonization in microaggregates. Percent enzyme activity showed the lowest level of P-cycling among the treatments; and higher C-cycle enzyme activity in the control (50 %) and biochar (46 %) treated soils than in the NPK (21 %) and NPK+biochar (11 %) treated soils. However, the percentage of C and N-, N-, and S- cyclic enzymatic activities in the latter two soils was about 1.5 to 2.0 times higher than in the biochar treated soil. A positive significant correlation coefficient (*r*) was obtained between soil EC and N-Acetyl-β-glucosaminidase, tyrosine-aminopeptidase, arginine-aminopeptidase and sulfatase, highlighting the importance of C, N and S availability for microbe-mediated mineralization in an Ultisol.

Key words: Ultisol, electric conductivity, soil enzymes, biochar reapplication, NPK fertilizer

Introduction

The application of BSR as a soil amendment increased the retention of soil organic carbon (SOC), total N and exchangeable K, but restricts the cycling of some important nutrients due to suppressed microbial metabolism, particularly, sulfatase (sulf), α-glucosidase (α-glu), β-xylosidase (β-xyl), and β-cellobiosidase (β-cello) enzymes (Okebalama et al., 2000). These purported inhibitory properties necessitated the conversion of BSR into bambara groundnut seed biochar (BSB) on the assumption that the technique would facilitate the bioavailability of its nutrients.

After repeated application of BSB over a two-year field trial (Okebalama et al., 2022), progressively more nutrients (C, N, P, K and Mg) were preserved. However, little is known about the processes involved in microbial nutrient cycling and retention in BSB-amended soil. Using the hierarchical aggregate model can provide insights that would contribute to our understanding of the mechanisms of microbial mediated C degradation processes and responses to BSB reapplication.

The decomposition of soil organic matter (SOM) by soil microbes often leads to the release of soil nutrients. More importantly, the gluing and bonding substances produced during SOM decomposition process affects soil aggregation (Liu et al., 2013; Costa et al., 2018) and play a role in SOC preservation and turnover. The fractionation of soil aggregates, which separates free SOM and occluded SOM into secondary organo-mineral complexes of different size fractions makes it possible to distinguish between young (free SOM; active), old (SOM occluded by macro- and micro-aggregates; intermediate) and older (SOM in clay microstructures; passive) SOM pools (von Lützow et al., 2007). As noted in Puget et al. (2008), the influence of turnover times on soil aggregate formation is important for C storage and stabilization. Monreal et al. (1997) showed evidence of increasing turnover times of SOM with decreasing aggregate size.

Soil microbes play an important role in soil nutrient cycling and preservation. Soil microbial responses to initial and repeated application of biochar have shown differential effects on soil enzyme activities, microbial diversity and community composition (Nguyen et al., 2018; Song et al., 2019; 2020). Mineralization is a well-known enzymatic process facilitated by extracellular hydrolytic enzymeswhose usual inhabitants is the soil (Sahu et al., 2017). The initial addition of biochar resulted in decreased basal respiration and activities of C-cycling enzymes but increased microbial biomass C, including N-cycling enzyme activities (Asirifi et al., 2021). In contrast, Elzobair et al. (2016) found no effect of initial biochar addition on soil microbial biomass, and soil C, N and P cycle enzyme activities. Though there have been numerous reports on the effects of a single application of biochar, very little information has been presented on the effects of biochar reapplication on microbial nutrient cycling and activities. The effects of biochar on some soil properties are more pronounced with repeated application rather than single application (Horák et al., 2021). However, the interactive effect of repeated co-application of biochar and inorganic fertilizers on microbial nutrient cycling under tropical conditions; particularly in a vegetable-based continuous monoculture system is still unclear.

Soil electrical conductivity (EC) relates to soil physiochemical properties whose interaction with soil microbes characterizes soil nutrient cycling, and soil fertility (Ehtaiwesh, 2022). Soil EC is a useful indicator of soil health that largely influences microbial processes, including respiration, decomposition and N cycling (Grisso et al., 2005). Soil EC, a measure of soil salt concentration, indicates changes in nutrient availability, with some microbial mediated processes being affected by shifts in EC (Smith and Doran, 1997). Soil enzymes continuously play an important role in the catalysis of many vital reactions required for the maintenance of soil microbial processes, organic matter (OM) decomposition, nutrient cycling and stabilization of soil structure (Nannipieri et al., 2012; Sahu et al., 2017). Due to the different concentrations of enzymes in soil systems and the complexity of soil aggregates, which maintain different concentrations of OM and support different biological activities with different intensities, soil microbes are thought to produce different responses in soil aggregates.

The use of the hierarchical aggregate model can therefore provide insights that contribute to our understanding of the mechanisms of biochar-C mineralisation and nutrient cycling responses to biochar reapplication. Studyingthe relationship between EC and microbial nutrient cycling in different soil aggregate fractions, especially with repeated biochar and inorganic fertilizerapplications, may be important for maintaining soil health and regulating soil-plant ecosystems.The aim of the study was to investigate the effects of repeated application of biochar and/or NPK fertilizer on (i) soil EC in different aggregate fractions after a twenty-day incubation experiment; and (iii) the relationship between aggregate-associated soil EC and extracellular enzyme activities after four years of continuous cucumber cultivation on an Ultisol in eastern Nigeria.

Materials and methods

Study site

The field trials was conducted at the Teaching and Research Farm of the Department of Soil Science, University of Nigeria, Nsukka, Nigeria, which lies between latitude 06^o 52´´N and longitude 07^o 24´´E. The study site falls within the Derived Savannah agro-ecological zone and is characterized by a humid tropical climate. An average annual rainfall of 1719 mm and average temperature of 26 ^{o}C (Climate-data, 2021) prevails in the study area. The soil texture is sandy loam, belonging to the Ultisols order and originated from weathered sandstone that is deep, permeable and well drained (Nwadialo 1989).

Description of treatments

Okebalama et al. (2022) document a detailed description of the pyrolysis of the Bambara feedstock. Some chemical properties of the biochar and the soil (before the commencement of the experiment in 2015) are presented in Table 1.

Experimental setup and treatment application

The establishment of theexperimental field in 2015 involved a 224 m^2 field area with twelve beds, each measuring 1.50 m x 3.75 m with spacing of 1 m between blocks and beds. In 2017 and 2018, the biochar was spread evenly over the whole plot 2 and 4 weeks before planting, respectively, and worked 0 - 20 cm deepinto the soil with a hand hoe. The subsequent application of $N_{20}P_{10}K_{10}$ was by ring method and in divided doses of one-third and two-third at 2 and 4 weeks after planting, respectively. The application of each treatment was on a whole plot basis.

The field experimental setupwas a randomized complete block design (RCBD) with three replicates of four treatments (0, 10, 20, and 30 t ha$^{–1}$ Bambara seed residue) applied repeatedly in 2015 and 2016. In 2017 however, the 10, 20 and 30 t ha^{-1} bambara seed residue plots were overlaid with 5t ha^{-1} BSB + 350 kg ha^{-1} $N_{20}P_{10}K_{10}$, 10t ha^{-1} BSB + 350 kg ha^{-1} $N_{20}P_{10}K_{10}$, and 15 t ha^{-1} BSB + 350 kg ha^{-1} $N_{20}P_{10}K_{10}$ treatments, respectively, while 300 kg ha^{-1} $N_{20}P_{10}K_{10}$, 20 t ha^{-1} BSB, and their combination (NPK+BSB) were superimposed, respectively, in 2018. The control plot was maintained during the four-year cucumber field trials. After the cucumber fruits harvest in 2018, the effects of the treatments (control, NPK, BSB, and NPK+BSB) were evaluated.

Table 1: Some chemical properties of the field soil and biochar treatment

	pH KCl	SOC	Total N	C/N	Avail. P	Na^+	K^+	Ca^{2+}	Mg^{2+}
Sample		…... % ……..			mg kg^{-1}	……… $cmol_c$ kg^{-1} ………			
Soil (2015)	4.0	1.26	0.07	18.00	10.26	0.04	0.05	3.00	0.40
Soil (2017)	4.4	0.97	0.11	8.82	13.99	0.01	0.07	0.12	0.06
Biochar	9.3	89.78	9.67	9.28	0.26	0.33	1.34	1.20	0.40

(Okebalama et al., 2022).

Soil sampling and preparations

From each treatment plot, undisturbed soil samples were taken with a spade along a Z-plane. The soil samples were air-dried and a part of the soil samples was sieved with 2 mm mesh (bulk soil), while the other part was sieved with 4.75 mm mesh size. The samples were stored and analyzed in the laboratory of the Department of Soil Science/Soil Ecology at the Ruhr University Bochum, Germany.

Laboratory analysis

Soil physiochemical analysis

Aggregate size separation intofour dry-stable aggregates (mm) of 4.75-2.00 (large aggregates; Lma), 1.00-2.00 (medium aggregates; Mma), 0.25-1.00 (small aggregates; Sma), and < 0.25 (micro-aggregates including silt and clay; Mia)was performed by dry-sieving method as described in (Okebalama et al., 2022). The proportion of aggregate samples retained on each size sieve were obtained, weighed and expressed as a percentage to the initial sample weight (equation 1).

$$\text{DSA } (\%) = \frac{W_i}{\text{Weight of soil}} \text{ x } 100 \quad (1)$$

The EC of the soil was determined in a soil suspension in water at a ratio of 1:5 w/v using an EC meter (EC 730, WTW series).

Soil biochemical analysis

A soil basal respiration experiment as described in Okebalama and Marschner (2024) preceded the determination of soil enzyme activities. The soil samples were rewetted to a water holding capacity of 60 % and incubated for 20 days in the dark at 20 ^oC in a temperature-controlled respirometer (prw electronics, Berlin, Germany). After the incubation study, the incubated soils were analyzed for microbial enzyme activities. Eight soil enzyme activities involved in the C-cycle(β-xylosidase (β-xyl)), β-glucosidase (β-glu)), and β-cellobiosidase (β-cello)); N-cycle(tyrosine-aminopeptidase (tyr)) and (arginine-aminopeptidase (arg));C- and N- cycle enzymes (N-Acetyl-β-glucosaminidase (N-acet)); P-cycle(acid phosphatase (pho))and S-cycle enzyme as sulfatase (sulf)were analyzed using the modified fluorescence multiplate assay (Marx et al., 2001). One gram of soil from each treatment sample was frozen at -18 ^oC and the determination of the eight soil enzymes was according to the procedure described in Heitkötter et al. (2017).

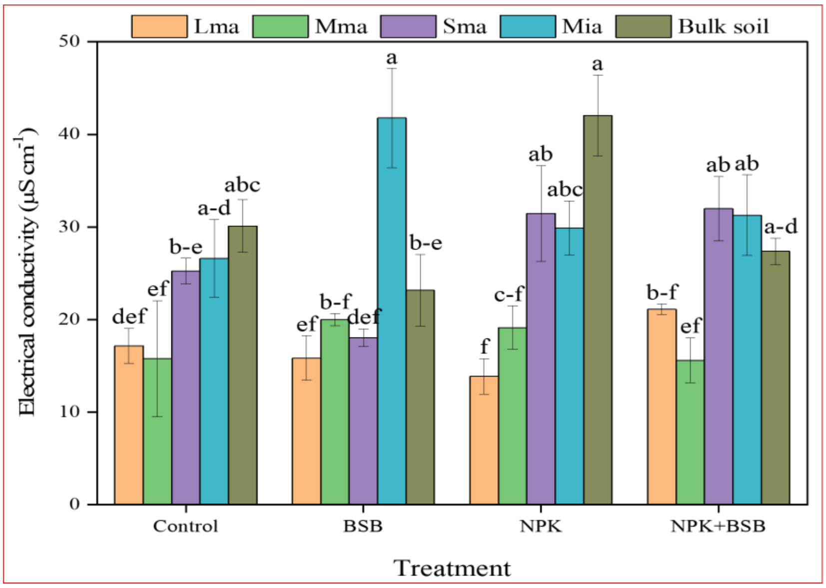
Statistical analysis

A two-way analysis of variance (in randomized blocks) using R software (version 4.0.5). was performed on the data collected. Accordingly, the individual effects of factors A (treatment) and B (aggregate), and their interaction were determined. Mean separation was performed using the least significant differences (LSD) of means at 5 % probability level. Pearson's correlation analysis was performed using the 16th edition of SPSS statistical software to determine the degree of relationship between soil electrical conductivity and the various extracellular enzymes.

Results

Treatment effects on the electrical conductivity in different soil hierarchies

Figure 1 shows significant differences in EC among the treatments and the soil aggregates fractions. The EC was lowest in the control soil but increased significantly with the BSB, NPK, NPK+BSB treatments. The aggregate associated EC was significantly ($p \leq 0.05$) higher in the micro-aggregates than in the macro-aggregates and the bulk soil.



Lma; Large macroaggregates

Mma; Medium macroaggregates

Sma; Small macroaggregates

Mia; Microaggregates, silt and clay

Control; No amendment

BSB; Bambara seed biochar

NPK; $N_{20}P_{10}K_{10}$ fertilizer

Fig. 1: Soil electrical conductivity in aggregates hierarchies of the amended soils

Treatment effects on percentage composition of extracellular enzyme activity in different soil hierarchies

The percentage enzyme composition of the different nutrient cycles is presented in Figure 2. The P-cycle enzyme activity was the lowest (about 1 %), while the S-cycle enzymegave the highest percentage enzyme compositionin the soils treated with NPK (56 %) and NPK+BSB (64 %).

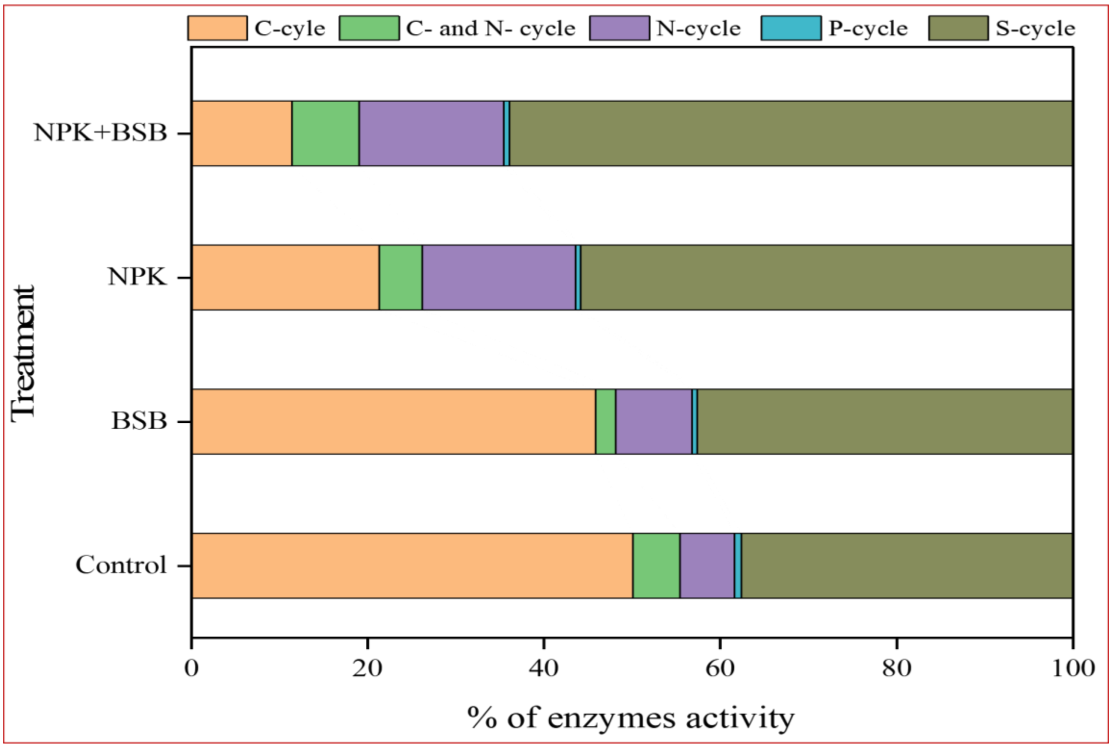


Fig. 2: Effect of treatments on extracellular enzyme activity composition after 30 days incubation of amended soils

Relationship between various soil extracellular enzyme activities and electrical conductivity

The correlation coefficients (*r*) of the soil enzyme activities and soil EC showed that the activities of N-acet, sulf, arg and tyr enyzmes maintained a positive significant correlation with the soil EC (Table 2). With the exception of β-glu, a similar relationship was observed for the other enzymes, although it was not significant.

Table 2: Correlation coefficients (r) of soil electrical conductivity and extracellular enzyme activity

Dependent variable	Enzyme activity							
	ß-glu	ß-cello	ß-xyl	N-acet	Sulf	Phos	Arg	Tyr
Soil EC	-0.37	0.33	0.42	0.70**	0.81**	0.32	0.78**	0.95**

ß-glu, β- glucosidase; ß-cello, β-cellobiosidase; ß-xyl, β-xylosidase; N-acet, N-Acetyl-β-glucosaminidase; Arg, arginine-aminopeptidase; Tyr, tyrosine-aminopeptidase; Phos, acid phosphatase; Sulf, sulfatase; **, significant at the ≤ 0.01 probability level.

Discussion

Treatment effects on the electrical conductivity of different soil hierarchies

The positive effect of BSB treatment on soil EC corroborates Xu et al. (2016) who showed an increase in EC with biochar input. In comparison, the soil EC increased approximately 2-fold with NPK and NPK+BSB treatments and approximately 1.2-fold with the BSB treatment. The maximum soil EC obtained with the NPK and NPK+BSB treatments could be related to an increased concentration of dissolved cations (salts) from the NPK input (Othaman et al., 2020). On the other hand, the increase in soil EC due to BSB treatment could be related to improved electrochemical properties of biochar, which enable the formation of biochar-mineral complexes (Chacón et al., 2017; Wang et al., 2017). Yang et al. (2018) showed a reduction in biochar reactivity and a loss of biodegradable C due to biochar-kaolinite soil interaction. The relative increase in soil EC in the micro-aggregates (32.53 µS cm^{-1}) compared to the macro-aggregates (24.98 to 19.81 µS cm^{-1}) and the bulk soil (22.77 µS cm^{-1}) could be related to the higher conductivity of silt and clay sized particles due to their ability to retain a greater amount of moisture and cations (Grisso et al., 2005).

Treatment effects on percentage composition of extracellular enzyme activity in different soil hierarchies

The results and discussion of the effect of the treatments on the eight extracellular enzyme activities in the various soil hierarchies is documented in Okebalama and Marschner (2024). The highest percentage composition of C-cycle enzymes in the control and BSB treated soils could be associated with the strong increase in β-glu activity, which was approximately twice as high as that of β-cello enzyme. Okebalama et al. (2020) found that in all soils treated with bamboo seed residues, the N-cycle enzymes dominated (about 75 to 81 %), while the activity of S-cycle enzymes was the lowest (about ≤ 0.5 %). The substantial N- and S-cycle enzyme activities in the NPK and NPK+BSB treated soil compared to BSB treated soils indicate the contribution of NPK fertilizer to the microbial mineralization of organic/inorganic N and organic S. Due to the lack of S data from the control and BSB soils, further scientific explanation on the effects of the treatments on the S-cycle enzyme in terms of C:S and N:S ratios could not be given.

Relationship between various soil extracellular enzyme activities and soil electrical conductivity

Pearson correlation between soil EC and the activities of eight enzymes showed that a shift in the soil EC would affect the activities of the various soil microbes responsible for the production of N-acet, arg, tyr and sulf enzymes, which represent theC, N, and S nutrient cycles. This result confirms the reported strong effects of salinity on the N cycle (Grisso et al., 2005). The importance of substrate availability in regulating soil enzyme activities by influencing microbial growth and enzyme production has been elucidated (Tiemann et al., 2015; Trivedi et al., 2017). Aon and Colaneri (2001) stated that the factors affecting soil microbial activity would certainly control the production of soil enzymes. Recall that N-acet activities decreased in the BSB treated soil, whereas N-acet, arg, tyr and sulf either increased or remained unchanged in the NPK and NPK+BSB treated soils.Therefore, the repeated application of NPK+BSB treatment, which resulted in a relatively higher composition of these enzymes activities compared to addition of NPK alone, is considered a better soil management practice to maintain soil fertility and promote ecosystem sustainability.These findings provide a strong framework for determining the short-term effects of reapplication of BSB and/or NPK on microbial nutrient cycling at the soil microenvironment level.

Conclusions

The repeated application of the biochar and the NPK+BSB improved the soil electrical conductivity level. However, the biochar reduced percentage N-cycle enzyme composition, indicating microbial N mining. The increased percent composition of C-, N-, and S- cycle enzymes due to the reapplication of NPK+BSB promoted more active microbial activity that maintains soil quality. The correlation between soil EC and enzyme activities linked soil health to the availability of C, N, and S nutrients, mediated by the activities of the N-Acetyl-β-glucosaminidase, arginine-aminopeptidase, tyrosine-aminopeptidase and sulfatase enzymes. The reapplication of NPK and NPK+BSB rather than the biochar alone optimizes soil biochemical responses in micro-aggregates, but the NPK+BSB treatment results in a more superior soil microbial nutrient cycling process in an Ultisol.

Funding

This work was supported the Alexander von Humboldt Foundation through the Humboldt Research Fellowship for Postdoctoral Researchers to CBO [Ref 3.4 - NGA - 1196552 - HFST-P].

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Nitrogen Mineralization During Manure Incubation and Yield of Maize in Northern Guinea Savanna Soil

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ABSTRACT

Availability of nutrients during manure decomposition has been a concern for many workers. Manure varies in composition; nutrients release patterns and efficiency due to variation in source, diets and management. Chemical fertilizers could influence manure decomposition. A study was set up at the Institute for Agricultural Research to investigate N mineralization under incubation and effect on maize yield in a Northern Guinea Savanna Alfisol of Nigeria. The experiment consisted of a factorial combination of 3 rates of N (0, 60 and 120 kg N ha $^{-1}$), S (0, 15 and 30 kg S ha $^{-1}$) and 0, 5, 10 t ha $^{-1}$ manure (cowdung), which resulted to 27 treatments laid in Completely Randomized Design, while the field trial was set up in Randomized Complete Block Design with three replicates. Ammonium-N and nitrate-N were measured after six weeks of incubation and grain yield during the field trial. Ammonium-N increased significantly from the control (0.42 g kg $^{-1}$) to 0.70 g kg $^{-1}$ at120 kg N ha $^{-1}$ representing about 40 % difference. Also, nitrate-N was highest with 10 t ha $^{-1}$ CD (0.25 g kg $^{-1}$) compared to the control (0.02 g kg $^{-1}$) or 86 % difference. Grain yield increased significantly ($P < 0.01$) among N, S and CD rates with 120 kg N ha $^{-1}$ having 1401.5 kg ha^{-1} compared to 697 kg ha^{-1} from the control. Nitrogen fertilizer increased manure decomposition compared to sulphur while the interaction of 120 kg N ha^{-1} x 30 kg S ha^{-1} x 10 t ha^{-1} CD increased grain yield over other treatments. The study indicated that mineral N fertilizer is essential for manure decomposition and application of N, S and manure is required for maize production in a savanna soil.

Keywords: Decomposition, manure, savanna and sulphur

INTRODUCTION

The current thrust in enhancing a sustainable crop production for the teeming population coupled with the adverse effect of climate change on soil fertility is the need to integrate mineral fertilizers and manure in farming systems. But variation in source of manure and varied chemical composition affect the quality of manure, ease of decomposition and its use efficiency, therefore developing alternatives strategies which would have a positive impact on manure decomposition to enhance nutrients release for crop utilization becomes imperative. Chemical fertilizers especially N fertilizers have been reported to influence manure decomposition. Some studies (Muhlbachova *et al*., 2021; Han *et al*., 2018; Mujuru *et al*., 2015 and Veres *et al*., 2015) have reported the benefits of mineral nitrogen fertilizers on manure decomposition especially by providing the immediate substrate and energy for the decomposer organisms. It has been reported that the inorganic nutrient element abundantly required by microbes is nitrogen (Mujuru *et al*., 2015, Xia, *et al*., 2017), thereby being the element that often becomes the first and most limiting nutrient to microbial activity in soil.

Organic manure is a good contributor of N in soils, though the amount of N contained in manure varies with source, quality of the substrate, age and management, therefore its co-application with readily soluble inorganic N and S becomes necessary and offers a realistic approach towards sustainable soil productivity, while at the same time improving the soil physical conditions for nutrient retention and uptake by plants.

Fertilizer regime for cereal crops in the savanna of Nigeria emphasises on the continuous application of high rates of N, fairly high rate of P and K, with no attention given to sulphur and micronutrients (Afolabi, 2019; Chude *et al*., 2012). In view of this, crop exploitation of soil available nutrients often leads to the deficiency of S, thereby resulting in poor crop yields. Incidental inclusion of sulphur in fertilizers has been effective in masking soil depletions in the past, such that deficiency symptoms were not of any serious concern. But increased cropping intensity, higher crop yields per hectare of cultivated lands, use of high analysis fertilizers such as urea and triple super phosphate (TSP) with no sulphur content, coupled with a low soil organic matter (SOM) content, has contributed to the greater incidence of S deficiency observed in the soils.

Studies on maize response to sulphur fertilizer application in the Northern Guinea Savanna of Nigeria revealed that yield was reduced by about 20% due to sulphur deficiency (IITA, 2005) even when the full recommended rates of N-P-K were applied. It is therefore expected that application of S in combination with N and manure will enhance availability and efficient use of these essential nutrients and equally increase yield of maize. Although organic matter provides a retention base for plant major and micronutrients (Syers and Craswell, 1995), the slow rate of mineralization often hinders its short- term efficiency relative to long term benefits. Still, many workers have recorded increased and significant yield of crops from organic and inorganic fertilizer application (Adeleye and Ayeni, 2010). There is therefore the need to incorporate organic residues to boost plant nutrient base while pegging down on excessive mineral fertilizer application in view of its deleterious effect on soil properties.

Studies have shown that nitrogen and sulphur play a vital role in plant nutrition, being components of proteins, nucleic acid, auxins and chlorophyll and promoting a healthy crop performance. Sulphur is also an important element involved in plant biochemistry; being a major constituent of amino acids and in the formation of enzymes and vitamins (Havlin *et al.* 2006; Ceccotti, 1996). Efficient crop response to N fertilization in the savanna of Nigeria especially on cereals is available in literature (Chude *et al*., 2012, Ukem, 2011), but information on the performance of maize to N and S combination amended with manure and their effect on soil properties is scarce. Therefore, farmers and other workers need adequate information regarding N availability from organic residues as a guide towards the determination of the optimum inorganic N fertilizer application rate for improved maize yield especially in combination with sulphur in the savanna.

MATERIALS AND METHODS

Study Area

The study was conducted from 2009 to 2011 at the Experimental Station of Institute for Agricultural Research (IAR), Faculty of Agriculture, Ahmadu Bello University, Samaru, Zaria. Samaru is located in Latitude 11^0 11^1 N and Longitude 7 ^{0} 38^1 E, 685 m above sea level in Northern Guinea Savanna agro-ecological zone of Nigeria. Annual rainfall regime in the area presents a unimodal pattern, falling from May to October which usually peaks between July and August with a mean of about 1000 mm and average daily temperature of about 27 ^{0} C (Oluwasemire and Alabi, 2004). Soils of the area are classified as Alfisols (typic Haplustalf) by the USDA Soil Taxonomy and as Orthic Acrisol by the

FAO/UNESCO Legend (Valette and Ibanga, 1984).

Soil and manure sampling and preparation

Composite soil samples were collected from the Experimental Farms of the Institute for Agricultural Research, Ahmadu Bello University Zaria, Nigeria. The soil was initially sieved in 1 cm mesh screen to remove coarse rocks and plant residues. A representative sample was later collected, air-dried, crushed and sieved through a 2 mm mesh screen for physical and chemical analyses. Manure (cowdung or CD) was obtained from the Animal Production Unit of the National Animal Production and Research Institute (NAPRI) Experimental Station, Shika, Zaria, Nigeria. It was mixed and placed on a concrete floor for 4 weeks in order to homogenize it and for aeration. Representative samples were taken for chemical analysis. Both soil and manure were stored in polyethene bags until the experiment commenced.

Fertilizer and manure treatments

Manure, urea and gypsum (sulphur fertilizer material) were applied to 100 g portions of moist soil and mixed thoroughly to form the microcosms. Manure was applied at the rate of 0, 5 and 10 t ha $^{-1}$, N was applied at the rate of 0, 60 and 120 kg N ha $^{-1}$, while sulphur was applied at 0, 15 and 30 kg S ha $^{-1}$. The 27 treatments (3 x 3 x 3) factorial combinations were conducted using Completely Randomized Design (CRD) with three replicates.

Experimental Procedure

The microcosms were collected in clean cylindrical plastic jars measuring 12 cm depth. The amendments (N, S and CD) were mixed thoroughly with the soil at the rates presented above. The mixtures were moistened to about 70% water holding capacity (Olayinka and Ailenubhi, 2001). The jars were corked tightly to provide a closed system thereby reducing gaseous escape and were arranged in triplicates and incubated at 25^0 C in an incubation chamber for 6 weeks. Moisture loss from the microcosms was minimized by adding 2 ml of water to jars at weekly interval to maintain saturated humidity in the headspace (Calderon *et al*., 2004).

Nitrogen mineralization was determined when 5 g portion of the incubated soil mixture was extracted with 2 M KCl by shaking for one hour$^-$ and the extracts analysed for NH_4^+ and NO_3^- concentrations by employing the Kjeldahl analytical method (Bremner and Mulvaney, 1982). The amounts of N (NH_4^+ and NO_3^-) mineralized during the incubation were calculated from the following equations (Haney *et al*., 2004).

$$NH_4 - N = TA_2 - TA_1$$

$$NO_3 - N = TN_2 - TN_1$$

Where, TA_1, TA_2, TN_1 and TN_2, represent total concentration of ammonium and nitrate before and after incubation respectively. In this case, the amount of NH_4^+ - N mineralized at the end of the incubation was obtained by the difference between the concentration obtained before and after incubation (Shen *et al*., 1984). A similar procedure was carried out for NO_3^- - N.

Field Study

Field trial was established on 2598 m^2 or 0.26 ha at IAR Experimental Farms at Samaru. The site was ploughed, harrowed and divided into 3 replicates each consisting of 27 plots and each plot measured 22.5 m^2. They were 6 rows in a plot, each measuring 5 m long with a ridge - spacing of 0.75 m. Manure was incorporated at the rate of 0, 5 and 10 t ha^{-1} by splitting the ridge and mixing with the soil and then allowed to equilibrate for 2 weeks before planting. Nitrogen and S were applied at the same rates as in the incubation study. Nitrogen was applied in two equal splits (60 and 120 kg ha^{-1} at 2 and 6 WAP), each at half of the recommended rate, while all of S treatments were applied once at 2 WAP by band application. There was also a basal application of P (SSP) and K (MOP) fertilizers at 2WAP at 60 kg ha^{-1} as recommended for maize in the area (Chude *et al*., 2012). The P and K fertilizers were applied by banding as described already for N and S.

Treatment composition for field studies followed the same pattern as presented already for the incubation study. The treatments were laid in Randomized Complete Block Design (RCBD) and replicated 3 times. Quality Protein Maize variety (Samaz-14) was planted at 3 seeds per hill at 25 cm spacing and thinned to 1 plant per stand at 2 WAP. The net plot consisted of four inner rows. Grain yield was measured after the cobs were harvested from the net plot by cutting the stover at the soil level. The cobs were removed and threshed, bagged and weighed for each net plot.

Analytical methods for manure and soil characterization

Physical and chemical properties of the soil and chemical composition of manure were determined as follows: Organic carbon was determined by the Walkley-Black Wet Oxidation method (Nelson and Sommers, 1982), pH was determined potentiometrically in 1:2.5 soil/solution ratio in water and in 0.01M $CaCl_2$ with a glass electrode pH metre. Total N was determined by the micro Kjeldahl method (Bremner and Mulvaney, 1982). Available P was determined using Bray-1 extraction method as described by Bray and Kurtz (1945), and the concentration of phosphorus in extract was then determined colorimetrically (molybdo-phosphoric blue colour) using a spectrophotometer, as described by Murphy and Riley (1962). Exchangeable Ca, Mg, Na, and K were determined by extraction with 1N ammonium acetate (NH_4OAc) saturation method at a pH of 7.0. The amounts of K and Na were determined using the flame photometer, while Ca and Mg were determined by the Perkin Elmer Model 403 Atomic Absorption Spectrophotometer (AAS) (Anderson and Ingram, 1993). Exchangeable acidity was determined by shaking the soil with 1 N KCl and titrated with 0.1 N sodium hydroxide (NaOH) (Juo, 1979). Effective Cation Exchange Capacity (ECEC) was determined by summation of total exchangeable bases and exchangeable acidity (Anderson and Ingram, 1993). Sulphur content was determined by using potassium dihydrogen phosphate (KH_2PO_4) extractant. Suphur was determined in extract as SO_4^{2-} sulphur by the turbidimetric method using Cecil-2000 spectrophotometer as described by Udoh and Ogunwale (1986). Particle size distribution was carried out using the standard hydrometer method. The results obtained were fitted into the USDA textural triangle in order to determine its correct textural class. The results obtained for physical and chemical analyses of soil are presented in Table 1.

Statistical Analysis

All data collected during the study were subjected to statistical analysis of variance (ANOVA) at 0.05 level of probability using the General Linear Model GLM) Procedure of SAS. Least Square Means (LSM) was used to compute treatments (SAS, 2010).

RESULTS AND DISCUSSION

Physical and chemical characterization of soil

The results (Table 1) showed that soil texture was dominated mainly by the sand fraction which constituted about 66% of the separates, followed by silt (22%) and clay (12%). The textural class was generally sandy loam (USDA Soil Survey Staff, 1999). The soil was moderately acidic in reaction with a pH ($CaCl_2$) of 5.8. Organic carbon content was low indicating low organic matter content of the northern Guinea savanna soils. Results obtained for total N, organic carbon and S were low and based on soil fertility rating for soils in the area (Esu, 1991; Chude *et al*., 2012), the nutrients were deficient. But the concentration of available phosphorus in the soil was medium (10-20 mg kg^{-1}).

Exchangeable bases were above the critical limits (Esu, 1991) of their concentration in the soil (3.40; 1.37; 0.22 and 0.16 cmol kg^{-1} for Ca, Mg, K and Na respectively, indicating that the soil had low to medium levels of exchangeable bases. However, the concentration of Ca in the soil surpassed the concentration of Mg by about 60%, indicating that calcium generally dominates the exchangeable bases in the savanna soils. Value for effective cation exchange capacity (ECEC) was 5.75 cmol kg^{-1} which was low. The result is consistent with findings of Abdu *et al*. (2008); Maniyunda and Malgwi (2011); Abu and Malgwi. (2012).

Table 1: Physical and chemical characteristics of soil (0-20cm) of the trial site

Properties	Values
Particle size distribution	
Sand (%)	66
Silt (%)	22
Clay (%)	12
Textural class	Sandy loam
pH (1:2.5 w/v H_2O)	6.30
pH (1:2.5 w/v 0.01M $CaCl_2$	5.80
Total Nitrogen (g kg^{-1}))	0.53
Organic carbon (g kg^{-1}))	5.3
C: N (g kg^{-1})	10.0
Sulphur – SO_4^{2-} (mg kg^{-1})	4.83
Available P (Bray-1 mg kg^{-1})	19.25
Exchangeable cations	
Calcium (cmol kg^{-1})	3.40
Magnesium (cmol kg^{-1})	1.37
Potassium (cmol kg^{-1})	0.22
Sodium (cmol kg^{-1})	0.16
Exchangeable acidity (cmol kg^{-1})	0.60
ECEC (cmol kg^{-1})	5.75

Chemical composition of manure

The chemical properties of cowdung used for the trial are presented in Table 2. The pH in water was above 8.0. It was moderately high in total N, organic carbon (OC), S and P contents. Also, the contents of basic cations: Ca, Mg, K and Na were low indicating that the material would have low liming effects judging from the values of Ca and Mg. However, the content of OC indicated that CD had the potential of improving soil fertility especially that of tropical savanna soils widely reported for their acute N and P deficiency (Vanlaue *et al*., 2000; Abdu *et al*., 2008; Chude *et al*., 2012). Therefore, mineralization of the organic material was expected to increase soil fertility by releasing nutrients for crop use and equally buffering the soil against change in soil pH. The low C: N ratio (11.0 g kg^{-1}) indicated that the organic manure possessed the characteristic of quick mineralization to release nutrients to the soil.

Table 2: Chemical composition of the manure

Chemical composition	Values
pH (1:2.5 w/v H_2O)	8.50
pH (1:2.5 w/v 0.01M $CaCl_2$	8.20
Total nitrogen (g kg^{-1})	22.0
Organic carbon (g kg^{-1})	242.6
C: N (g kg^{-1})	11.00
Total phosphorus (g kg^{-1})	7.70
Sulphur- SO_4^{2-} (mg kg^{-1})	8.21
Calcium (mg kg^{-1})	0.20
Magnesium (mg kg^{-1})	0.88
Potassium (mg kg^{-1})	1.75

Main effect of treatments on NH_4^+ - N concentration

Treatments effect on N mineralization (NH_4^+) is shown in Fig. 1, 2 and 3 for N, S and CD respectively. Ammonium concentration increased from 0.42 g kg^{-1} in the control to 0.70 g kg^{-1} at 120 N level which represented a difference of about 40% increase. Similarly, S and CD levels followed the same trend as observed with N rates, though, the difference between the control and 5 t ha^{-1} CD was not significant ($P > 0.05$). The result show that NH_4^+ concentration increased with increasing levels of N, S and CD application which peaked at 0.70 g kg^{-1} for NH_4^+ – N at 120 kg/ha urea N application.

The combination of 120 kg N ha^{-1} with 30 kg S ha^{-1} and 10 t CD ha^{-1} had the highest interaction effect while the least effect was obtained from 60 kg N ha^{-1} x 0 kg S ha^{-1} x 0 t CD ha^{-1} (Table 3). Their corresponding means were 0.09 g kg^{-1} and 0.04 g kg^{-1}. The difference in the means was significant ($P < 0.01$). Comparably, the least content of ammonium ion within the microcosm of the control further demonstrated the deficiency of biodegradable organic matter in the soil. It was observed therefore, that mineral fertilizer application along with manure amendment positively influenced mineralization characteristics of organic matter in the soil resulting in higher levels of NH_4^+ - N compared to the control. Their differences were highly significant ($P < 0.01$).

The difference in treatment means at the highest levels of N, S and CD was highest with N followed by S while CD was least, suggesting that mineral nitrogen fertilizer contributed relatively more inorganic forms of N as ammonium during mineralization than with either S or CD at the time of sampling. Organic carbon fraction within the substrate may have been immobilized by microorganisms, which led to the comparable lower concentration of NH_4^+ in manure. In a study conducted by Ayeni (2012) in south western Nigeria to determine effect of single and combined application of cattle dung and urea fertilizer on nitrogen mineralization, it was reported that urea – N released the highest amount of NH_4^+ - N than with cattle dung after 60 days of incubation. This was attributed to minimum fixation of urea – N by soil microbes, denitrification or volatilization. This finding was therefore consistent with the result of the present study.

Effect of treatments on NO_3^- - N concentration

Nitrate concentration in incubated soil also increased from the control for each of N, S and CD rates with the highest concentration of 0.23 g kg^{-1} obtained from 10 t ha^{-1} CD, representing 86.96% amount of nitrate mineralized compared to the control (0.02 gkg^{-1}) (Fig. 3). The result revealed that amount of NO_3^- mineralized during incubation was significant ($P < 0.01$) and greater with CD than with mineral N fertilizer application. This comparison shows that the applied fertilizer N and S were already in their soluble forms, thus readily utilized by soil microbes. Also, the interaction of 60 kg N ha^{-1} with 30 kg S ha^{-1} and 10 t ha^{-1} had the highest effect on amount of nitrate while the least was the control (Table 3).

The greater potential of manure mineralization to release NO_3^- relative to fertilizer N or S was indicative that the activities of nitrifying bacteria were not hindered within the soil, perhaps, due to optimum conditions such as air and temperature during the incubation and considering the favourable C/N ratio of the organic compound. Beauchamp and Paul (1989) suggested that manures with C/N ratios below 15 were likely to result in positive N mineralization after application to soil. These observed factors may have led to a greater effect of manure than with mineral N or S fertilizer application on NO_3^- content of the incubated soil. A comparison of means obtained for NH_4^+ - N and NO_3^- - N revealed that the concentration of NH_4^+ - N was higher than that of NO_3^- - N though the two were subjected to the same conditions during sampling for analysis. This may be due to the presence of a positive electrical charge in ammonium ions to enable its retention on the soil colloid, usually having a net negative charge (Brady and Weil, 2005). Biologically, NH_4^+ - N in the soil may have been fixed by soil micro biota than was the case for NO_3^-. It has been reported that soil microbes have a preference for NH_4^+ rather than NO_3^- as a mineral nitrogen source (Rice and Tiedje, 1989). Furthermore, Calderon *et al*. (2004) reported that nitrifying bacteria were important sinks for NH_4^+ in soil.

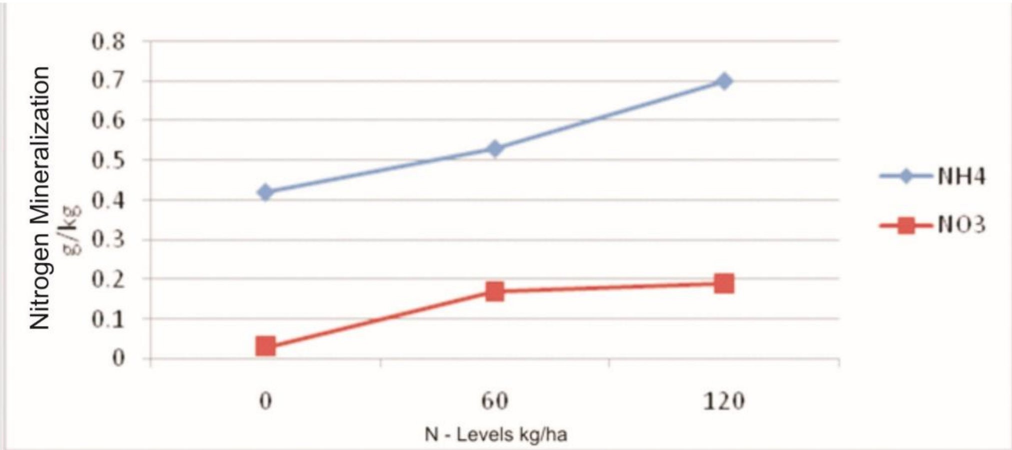

Fig 1: Main effect of rates of N on nitrogen mineralization

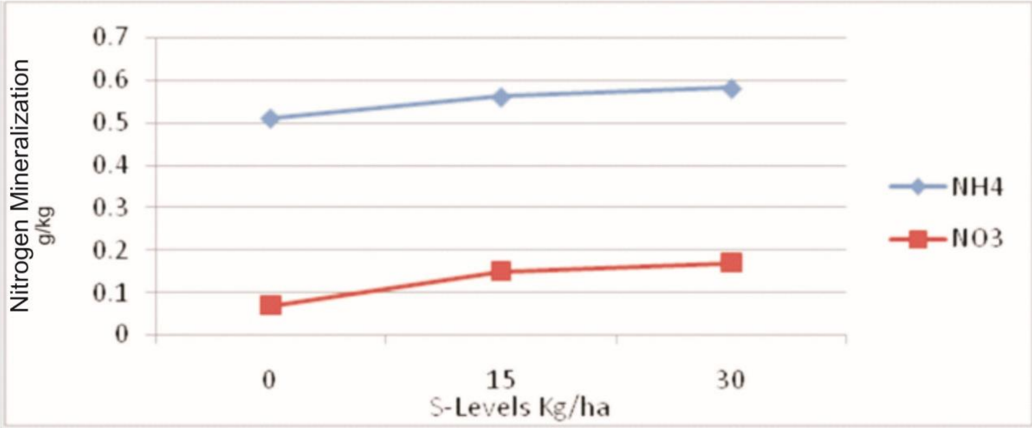

Fig 2: Main effect of rates of S on nitrogen mineralization

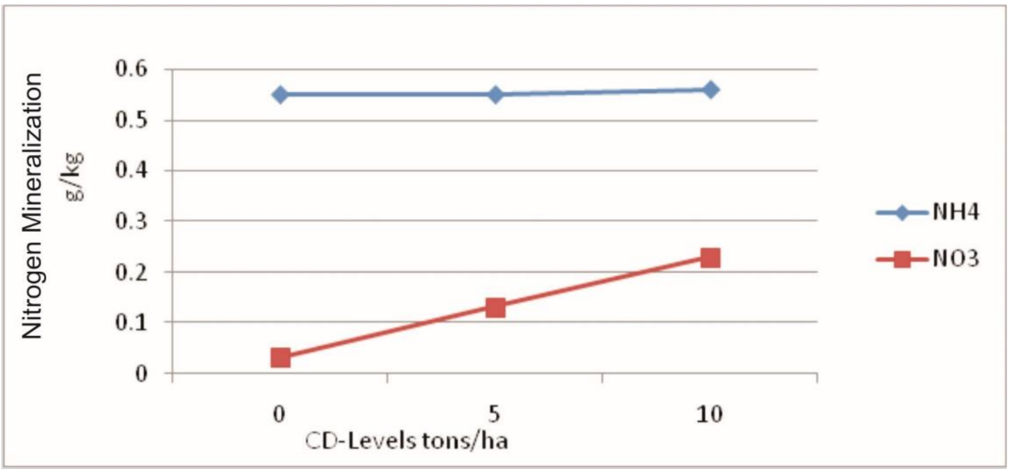

Fig 3: Main effect of rates of CD on nitrogen mineralization

For NH_4^+: Mean = 0.55; CV = 7.54; R-Square = 0.96; LSD (0.05) = 0.01; ** = *Significant at 0.01,*
For NO_3^- : Mean = 0.13; CV = 6.97; R-Square = 0.88; LSD (0.05) = 0.02; ** = *Significant at 0.01.*

Table 3: Interaction effect of N, S and CD on nitrogen mineralization during incubation (g kg^{-1})

Treatment Number	N	S	CD	NH_4^+	NO_3^-
1	0	0	0	0.037 ^{jk}	0.002 ^{c}
2	0	0	5	0.046 ^{hij}	0.004 ^{c}
3	0	0	10	0.042 $^{h-k}$	0.003 ^{c}
4	0	15	0	0.041 ^{ijk}	0.005 ^{c}
5	0	15	5	0.040 ^{ijk}	0.003 ^{c}
6	0	15	10	0.044 $^{h-k}$	0.003 ^{c}
7	0	30	0	0.043 $^{h-k}$	0.002 ^{c}
8	0	30	5	0.042 $^{h-k}$	0.004 ^{c}

9	0	30	10	0.047 ghi	0.005 c
10	60	0	0	0.035 k	0.002 c
11	60	0	5	0.056 fg	0.013 c
12	60	0	10	0.051 gh	0.011 c
13	60	15	0	0.066 cde	0.004 c
14	60	15	5	0.065 def	0.017 c
15	60	15	10	0.048 ghi	0.037 ab
16	60	30	0	0.062 def	0.003 c
17	60	30	5	0.049 ghi	0.019 c
18	60	30	10	0.046 hij	0.048 a
19	120	0	0	0.061 ef	0.003 c
20	120	0	5	0.065 def	0.019 c
21	120	0	10	0.067 b-e	0.015 c
22	120	15	0	0.075 bc	0.003 c
23	120	15	5	0.061 ef	0.021 bc
24	120	15	10	0.068 b-e	0.045 a
25	120	30	0	0.076 b	0.07 c
26	120	30	5	0.071 bcd	0.019 c
27	120	30	10	0.089 a	0.046 a
	Mean			0.055	0.014
	R-Square			0.96	0.88
	CV			7.54	6.97
	LSD			0.01	0.02
	NxSxCD			**	**

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Main effect of N, S and CD on grain yield

The response of maize grain yield to N, S and CD in 2009 was significant ($P < 0.01$). Nitrogen at 120 kg ha^{-1} had the highest grain yield of 1,132 kg ha^{-1} while the lowest effect was obtained in the control for either N, S or CD (Table 4). Similarly, S at 30 kg ha^{-1} and CD at 10 t ha^{-1} were significant ($P \leq 0.01$) and more effective than S at 15 kg ha^{-1} and CD at 5 t ha^{-1} respectively. The results revealed that grain yield increased with an increase in nitrogen application from 0, 60 to 120 kg ha^{-1} (24.5%, 26.4% and 49.1% respectively). Also, sulphur produced 30.5%, 32.5% and 37% respectively from 0, 15 and 30 kg S ha^{-1}. Manure at 0, 5 and 10 t ha^{-1} recorded a corresponding increase in grain yield as 20.8%, 33.6% and 45.7% respectively. Differences in their treatment means were significant ($P \leq 0.01$). However, there was no significant ($P > 0.05$) difference in grain yield in the highest rates of N, S and CD (Table 4). The result show that there was a good response obtained from the highest rates of the amendment due to the initial low soil fertility. The application of N, S and manure at their highest rates was more effective in increasing grain yield compared to their median rates and the control. Grain yield obtained in 2011 at highest N rate was 2,011.30 kg ha^{-1} compared to 1,519.20 kg ha^{-1} and 827.90 kg ha^{-1} obtained from half N rate and control respectively. Significant responses of maize to N fertilizers have been reported in the savanna soil (Uyovbisere and Lombin, 1991). Similarly, grain yield at 30 kg S ha^{-1} rate was 1,519.20 kg ha^{-1} compared to 1,453.40 kg ha^{-1} and 1,385.90 kg ha^{-1} respectively, obtained from control and 15 kg S ha^{-1}. Grain yield with CD rates were 1,145.60 kg ha^{-1}, 1,412.20 kg ha^{-1} and 1,800.70 kg ha^{-1} at 0, 5 and 10 t ha^{-1} respectively. There was no significant difference (P > 0.05) between 60 and 120 kg N ha^{-1}, mean effects of S rates were not significant and a similar pattern of response was obtained in CD rates. Differences in yield were only marginal especially with S and CD rates.

Table 4: Main effect of rates of N, S and CD on grain yield

N rates (kg ha^{-1})	2009	2011
0	566.20	827.90
60	608.90	1,519.20
120	1,132.40	2,011.30
S Rates (kg ha^{-1})		
0	702.80	1,453.40
15	750.50	1,385.90
30	854.20	1,519.20
CD Rates (t ha^{-1})		
0	478.90	1,145.60
5	775.20	1,412.20
10	1,053.40	1,800.70
Mean	769.20	1,452.80
R-Square	0.74	0.71
LSD (0.05)	539.80**	823.90**

*** = Significant at 0.01*

Interaction effect of rates of N, S and CD on grain yield

Interactive combinations of levels of N, S and CD on grain yield showed that 120 kg N ha^{-1} x 30 kg S ha^{-1} 1 x 0 t ha^{-1} CD had the highest interaction with mean grain yield of 1822.03 kg ha^{-1} which was higher than the yield obtained from 120 kg N ha^{-1} x 15 kg S ha^{-1} x 10 t ha^{-1} CD (1703.57 kg ha^{-1}) by 7%, while the least effect was obtained from the control with mean grain yield of 207.43 kg ha^{-1} or 87 % less than the performance of full rate of N, S and CD (Table 5). The difference among the treatment means was significant (P < 0.05). The result differed slightly with the performance in 2011, where the best performing combination was 120 kg N ha^{-1} x 0 kg S ha^{-1} x 10 t ha^{-1} CD (2533.10 kg ha^{-1}), while 0 kg N ha^{-1} x 30 kg S ha^{-1} x 0 t CD ha $^{-1}$ had the least effect (222.20 kg ha^{-1}). The result indicated that grain yield increased with combinations having either half or full application rates of N, S and CD, but interactive combinations without any of N, S or CD was significantly lower. In view of this, the application of N and S fertilizers in addition to manure improved soil fertility which was good for the growth and yield of maize. Also, the combination of N and S in particular provided nutritional benefits to the crop (Bharathai and Poongothai, 2008), while manure in combination added more nutrients to the soil through mineralization (Makinde and Ayeni, 2013). Therefore, availability of the required plant nutrients and in their correct proportion was essential for a good crop performance.

The result further showed that interactions of N and S at their full application rates with CD at 10 t ha^{-1} were significantly (*P* < 0.05) higher than those with 5 t ha^{-1} CD and least with 0 t ha^{-1} CD (Table 5). Therefore, there is still need for manure application to complement and enhance use efficiency of the applied mineral fertilizers, by boosting nutrients retention and also contributing plant food to the soil during mineralization. Studies have shown that integrating mineral fertilizers with organic residues improves soil fertility and ultimately increases crop productivity (Adeleye and Ayeni, 2010; Nyongesa *et al.*, 2010). But a reversal of this trend in 2011 where 120 kg N ha^{-1} x 0 kg S ha^{-1} x 10 t ha^{-1} CD had the highest interaction rather than with 15 or 30 kg S ha^{-1}, suggested that addition of S from CD and the residual effect of previous sulphur application was able to meet crop requirements, therefore, further application did not increase maize grain yield. This observation should be taken into consideration when making recommendations for maize sulphur requirements in the Nigerian savanna.

Table 5: Interaction effect of rates of N, S and CD on grain yield

				2009		2011		Mean	
	N	S	CD	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
1	0	0	0	207.43	f	355.53	kl	385.19	k
2	0	0	5	325.90	f	636.97	i-l	644.50	h-j
3	0	0	10	1,170.27	bcd	1,466.53	c-i	1903.50	c-h
4	0	15	0	281.47	f	444.43	j-l	503.69	jk
5	0	15	5	562.93	def	814.73	g-l	970.29	f-k
6	0	15	10	429.57	ef	1,214.73	e-k	1036.94	e-k
7	0	30	0	666.63	gef	222.20	l	777.73	ijk
8	0	30	5	281.47	f	1,259.17	d-j	910.97	e-k
9	0	30	10	1,170.23	bcd	1,036.93	f-l	1688.50	d-k
10	60	0	0	251.83	f	711.03	h-l	607.35	g-k
11	60	0	5	1,169.93	bcd	1,747.97	a-f	2043.92	a-e
12	60	0	10	459.20	ef	1,555.40	b-h	1236.70	c-h
13	60	15	0	577.73	def	1,199.90	e-k	1177.68	e-k
14	60	15	5	785.13	cdef	1,822.03	a-f	1696.00	b-f
15	60	15	10	399.97	ef	1,496.17	c-i	1695.98	c-j
16	60	30	0	429.60	ef	1,436.90	d-i	1148.05	e-k
17	60	30	5	399.97	ef	1,288.77	d-j	1044.36	d-k
18	60	30	10	1,007.33	cde	2,414.57	ab	2214.51	abc
19	120	0	0	429.57	ef	2,088.67	a-e	1474.50	c-i
20	120	0	5	992.47	cde	1,985.00	a-e	1985.50	abcd
21	120	0	10	1,318.37	abc	2,533.10	a	2584.51	ab
22	120	15	0	859.20	c-f	1,807.23	a-f	1762.50	c-g
23	120	15	5	1,155.47	bcd	1,525.80	c-h	1919.05	b-f
24	120	15	10	1,703.57	ab	2,147.93	a-d	2778.23	ab
25	120	30	0	607.33	def	2,044.23	a-e	1629.01	bcde

26	120	30	5	1,303.60	abc	1,629.47	b-g	2119.10	abcd
27	120	30	10	1,822.03	a	2,340.53	a-c	2992.50	a
	Mean			769.19		1,452.81		1495.50	
	R-Square			0.74		0.71		0.73	
	LSD			629.90		823.90		659.1	
	N x S x CD			**		**		**	

*** = Significant at 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

CONCLUSION

We investigated the effect of mineral N and S fertilizers on manure decomposition, nitrogen mineralization and grain yield of maize in an Alfisol of northern Nigeria. The concentration of ammonium increased significantly with rates of N fertilizer application whereas the concentration of nitrate increased significantly with rates of manure application where 10 t ha^{-1} CD was most effective. The application of mineral N fertilizer enhanced soil microbial activity much more than with S fertilizer. Therefore, mineralization of manure and the ultimate improvement in soil fertility from organic matter input will benefit from mineral N fertilizer application. Since the yield of maize was optimum with N, S and CD at their highest application rates, it indicated that the initial low soil fertility was addressed through their application. In view of this, the use of N and S fertilizers with manure amendment will be required for sustainable maize production in the savanna soil.

ACKNOWLEDGEMENTS

The authors profoundly thank Professors E. O. Uyovbisere, B. D. Tarfa and Dr. W. B. Malgwi as well as the Farming Systems of the Institute for Agricultural Research (IAR) of Ahmadu Bello University, Zaria for their technical and material assistance.

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Effect of Different Fertilizer Sources (Poultry Manure, Sheep and Goats Manure, N.P.K 15:15:15 and Cowdung) on the Growth and Yield of Irish Potato

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ABSTRACT
This study was carried out at Federal College of Land Resources Technology precisely on Soil Science Technology Research farm. The research work was conducted to determine the effects of different fertilizer sources on the growth and yield of Irish potato. There were five (5) treatments for the research work, which were control, poultry, manure, sheep and goat manure, cowdung manure and NPK 15:15:15 on the growth and yield of Irish potato. The treatments were replicated (4) four times. The parameters used for assessment were plant height. Number of stem, number of tubers and tuber yield. The experimental design used was Randomized Complete Block Design (RCBD). The variables were assessed by taking readings forth nightly for plant height and stem count from the second week of planting while the main yield was obtained at harvest. From the result, the fifth treatment which is NPK 15:15:15 was observed to be the highest in al variables. The overall result of the research work shows that there were significant difference at (P<0.05) among the treatment of the yield of Irish potato. However, treatment five (5) which is NPK 15:15:15 (T_5) gave the highest yield of 12733.75kg/ha and the least yield recorded was in T1 which is the control at 4137.50kg/h. yield obtained from the treatments are as follows: (T_3) NPK 15:15:15 which gave 12733.75kg/ha, follow by poultry manure and (T_2) 98.3236kg/ha sheep and goat gave 9311.57kg, cow dung manure (T_4) gave 7974.61kg/ha. The least obtained was in the control (T_1) which produced 4137.50kg/ha.

INTRODUCTION
Irish Potato (*solanum tuberosium*) are grown on a worldwide basis and is the fourth most important food crop in the world. In Nigeria, it is also rated fourth after cassava, yam and cocoyam (Nyambo, B (2013)). The establishment of the Potato Research Centre, Kuru-Plateau State by the National Root Crops Research Institute (NRCR) in 1976 marked the beginning of rapid expansion of Irish Potato production in Nigeria. A lot of effort has been made to develop and transfer new technologies to improve Irish Potato Production in Plateau State including seeds multiplication, training of farmers, Irish potato research breeding and selection of new improve varieties (Zemba et al., 2013).

The focus of researchers and policy makers on Irish Potato production in recent time has mainly been on efficiency and adoption of new technologies in farm operations in order to boost output and increase income. Although growth in output is not only determined by introducing new technology alone, but by efficiency with which existing technology and inputs are used (Kiptoo et al., 2016; Jwanya et al., 2014). It has also been discovered that several Irish Potato farmers are losing in output due to inefficiency in resources used; and attaining high technical efficiency remains a major problem amongst many small holder Irish Potato farmers (Kiptoo et al., 2016). Some of the major constraints mitigating against its development include adequate supply of good quality seed, type of fertilizer used, poor storage facilities, poor disease and pest management and high cost of production inputs (Ugonna, 2013). It is in this regards that the researcher seeks to find out the effect of different fertilizer sources on the growth and yield of Irish Potato.

Several studies have shown that inorganic fertilizer are not only scare and expensive, the are also reported to pollute water and ponds located near crop farms where inorganic fertilizer are used for crop production (Negesse, et a., (2014). Modern farming is moving toward organic fertilizer because it is environmentally friendly. Inorganic fertilizers are scarce and expensive and are also discovered to pollute ground water and ponds located near crop farms. Organic fertilizers on the other hand are easy and cheaper to get and have no negative effect on both crops and the environment are more preferable to use and gives optimum yield. It is on this basic that the research will be carried out.

Due to increase in population and the need to become self-sufficiency toward food production in the country and also due to scarcity and expensive nature of inorganic fertility there is need to move toward the used of organic fertilizer especially poultry manure which is cheap and available.

Objective of the Study

- To determine the effect of different fertilizer sources (poultry manure, sheep /goat manure, cow dung manure and N.P.K 15:15:15) on the growth and yield of Irish potato.

MATERIALS AND METHODS

Experimental site and soil characteristics

The project site was located within the compound of Federal College of Land Resources Technology Kuru, Jos Plateau State precisely on the Soil Science Practical Farm, after the overhead tank. The school is located precisely 24 km to south east of Jos, Plateau State, along Bukuru Vom Road opposite National Root Crop Research Institute (NRCRI) Vom and it is exactly 6.6 km from Bukuru Vom Road Junction (Anguldi) in Jos South Local Government Area of Plateau State.

Climate Condition of the Study Area

Temperature

The study area Kuru was one of the coldest part of Jos Plateau State as a reduction in temperature is brought about by high altitude. Record from the Meteorological station at National Root Crop Research Institute (NRCRI) Vom showed that the mean monthly temperature ranges from 12°C to 18.4°C. The highest temperature occurs between March and April while the lowest temperature occurs between November and February.

Rainfall

The onset period of the rainy season in Jos Plateau State is between March and April while cessation period is between 1st and 31st of October. The onset of rainfall by March is recorded about 34.1 mm, and rainfall continues through September and stops by October when 28.9 mm of rainfall is recorded. The highest rainfall of about 269.25 mm is recorded in July which has a mean of 20 rainy days as a whole, the Mean Annual Rainfall in Kuru area, of Jos Plateau State is l 176.78mm

Relative humidity

Mean relative humidity is significantly high in the rainy season which rises from 48.33% in April to 74.14% in August. In the dry season the relative humidity decreases from south to north due to high altitude.

Sunshine hours

The maximum sunshine hours in Jos Plateau State occurs between January/February and November/December. While the minimum sunshine now occurs in the mid year that is July/August. It is during this period that Jos Plateau State has the lowest radiation.

Table 1: Showing the Metrological Data of the Study Area

Month	Rainfall (mm)	Temperature O^C		R/H (5)
		Max	Min	
Jan	0	26	11	18
Feb	10.05	25	15	20
March	36.0	26	19	22
April	28.0	26	18	56
May	218.5	25	19	64
June	156.4	22	17	73
July	283.2	24	18	80
Aug	384.8	24	18	80
Sept	208.6	26	17	80
October	79.4	27	15	78
November	0	29	12	54
December	0	-	-	-

Source: NRCRI Met. Station, Kuru, 2021

Variety of Crop

The variety of crop that was used is called Nicolar which was known easily because the crop (seed) were bought at National Root Crop Research Institute (NRCRI). The variety, usually spend 90 days (3 months) before maturing for harvesting.

Treatment and Replicate

There was five (5) treatment which was replicated four (4) times

The treatments are:-

Control (0kg/ha) T_1

Poultry manure (3T/ha) T_2

Sheep/goat manure (800kg/ha - T_3

Cow dung manure (800kg/ha) T_4

N.P.K 15:15:15 (300kg/ha) T_5

These four types of fertilizer sources shall be used because of the experimental objective to know the most effective fertilizer on growth and yield of Irish Potato.

Agronomic Practices

One of Irish potato (Nicolar) will be planted per hole and about 4 cm to 5 cm deep with spacing of 30 cm x 30 cm given 10 seed per ridge and 40 seed, per plot to a total of 600 seeds on the experimental field.

Weeding

Weeding was done 3 to 4 weeks after planting and was done manually.

Earthening

Earthening up in potatoes is a common and an important agronomic practice. It involved drawing mounds of soil up around the plant to prevent new tuber from growing and turning green and poisonous. It also helps to prevent greening tuber moth and blight infection

Fertilizer Application

The application of fertilizer to the crop is at early stage of growth and development to crop because the early application of fertilizer is the highest uptake time. Late application sometimes aerbuesless because older root of crop do not absorb nutrient.

Pest and Disease Control

Use of seed variety that is free of disease agents is the best way to control tuber — borne viruses, control insects. Early weeding is also good to control disease.

Data Collection

Data was collected on each of the parameters, at 2 week, '4 weeks, 6 weeks, and 8 weeks, after planting for number of stem, plant height and at the harvest for crop yield. Infected plant was also observed.

Number of stem

Number of stem was taking by /counting the germinated seed i.e counting the plant in each plot, with an interval of 2 weeks.

Plant height

When taking the height of the plant, a total of six (6) plant was taken from each plot with at least two plant from each ridge also taken randomly in each plot, when taking the measurement of the height of a plant, the first plant which is the tallest, second the medium and third the least were measured in each plot. The height of the randomly sample plant was measured from the ground surface of the highest leaf using a meter ruler at 2,4,6,8 and 10 week after planting (i.e in two week interval).

Tuber Yield

The plant yield was accessed after harvesting and the yield from each plot by measuring and weighing the yield, weighing balance or scale and also the one that give more yield was accessed.

Method of Data Analysis

The data collected was subjected to the analysis of variance (ANOVA).

Table 2: Physio-chemical Properties of the Soil of Project Site

Sample	Particle size			Textural class	pH	pH	EC
	% silt	% clay	% sand	Clay loam	(H_20)	($CaCl_2$)	
1.	19.56	40.94	39.50		5.04	4.09	20.50

Continuation

OM (%) (mgamol/kg)	K (ppm)	N Phosphorus (ppm)	Mg (meg/100g)	Ca (meg/100g%)	Phosphorus	Sulphur (ppm)
1.5	47.50	15.93	0.85	2.45	0.19	1.42

EC- Exchangeable Cations

The soil texture from the result above is said to be clay loam which is okay for the growth of the Irish Potato. The pH values is also favourable, meanwhile other properties need to be improved by adding source of fertilizer to improve the fertility status of the soil of the study area.

RESULTS AND DISCUSSION

The results of the experiment is presented in Table 3 - 5

Plant Height

Table 3 revealed the effect of the different fertilizer sources on the height of Irish potato plants at 2, 4, 6 and 8 weeks after planting (WAP). At 2WAP, the heights of the plants obtained were 4.90, 4.78, 4.60, 4.62 and 4.68 for T_1, T_2, T_3, T_4 and T_5, respectively. This shows that T_1 (control) has the tallest plant, followed by T_2 and lastly T_4. The results of the ANOVA showed that there is no significant difference at ($P<0.05$) between the various treatments. This is due to the fact that at this stage and age, the plants are still utilizing the stored nutrients in their seed tubers and not much nutrients have been absorbed from the soil Tisdale and Nelson,

1975. There is no significant difference in height of Irish Potato plant at 2 weeks after planting.

At 4WAP, the result obtained shows that T_1, T_2, T_3, T_4 and T_5 have the following 16.83, 21.73, 19.33, 18.90 and 19.52, respectively. This shows that T_2 had the average tallest plant while T_1 had the shortest plant. The ANOVA showed that significant different from the other treatments while there was no significant difference at (p<0.05) exist amongst the treatments revealing that T_2 is significantly different from the other treatment while there was no significant different between T_3, T_4 and T_5 while Ti is significantly different from the others

At 6WAP the result shows that T_1, T_2, T_3, T_4 and T_5 had the highest 20.52, 28.12, 26.25 cm, respectively. This shows that poultry has the highest value in terms of plants height while the control is the lowest amongst the treatment. The ANOVA showed that there was significant difference and the pair wise comparison showed that T_2 is significantly different from the other treatments while there was no significant difference between, T_3, T_4 and T_5. On the other hand, T_1 is significantly different from the others.

Table 3 also displays the height of the Irish Potatoes plants at MAP. It shows that T_1, T_2, T_3, and T_4 and obtained 22.80, 34.48, 31.95, 29.93 and 30.80 the result shows that 12 has the highest plant and the lowest is control treatment. The ANOVA revealed that T_2 is higher and significantly different from T. In furtherance to the results shown by Table 1, the heights of the Irish potato plants increased across the treatment with every passing week recorded (i.e. from weeks 2 to 4 to 6 and to 8).

Table 3: Shows the Effect of Treatments on the Height of Irish Potato (cm), T Treatment

Treatment	2WAP	4WAP	6WAP	8WAP
T_1(Control)	4.90^{ns}	16.83^{d}	20.52^{d}	22.80^{d}
T_2 (Poultry)	4.78^{ns}	21.73^{a}	28.12^{a}	34.48^{a}
T_3 (Sheep/Goat)	4.68^{ns}	19.33^{bc}	26.25^{bc}	31.95^{c}
T_4 (Cowdung)	4.62^{ns}	18.90^{c}	24.52^{c}	29.93^{c}
T_5 (NPK 15:15:15)	4.68^{ns}	19.52^{b}	25.60^{b}	$30.80b^{c}$
LSD (P<0.05)				

WAP = weeks after planting, LSD = Least Significance difference, abed mean's followed by different letters differ significantly at P<0.05

Number of Stem

The results of the number of stems on the Irish potato plants from week 2 to 8 is presented in Table 4. It shows that the average number of Stems for the T_1, T_2, T_3, T_4 and T_5 increased from weeks 2 to weeks 8. For T_1, it increased from 1 to 9. For T_2, T_3, T_4 and T_5it increased from 1 to 9, 1 to 10, 1 to 10, 1 to 9 and 1 to 9, respectively. The ANOVA for the treatments showed that there is no significant difference at (P<0.05) for the number of stems at 2Wap, 4WAP, 6WAP and 8WAP. The results obtained in this study does not agree with those reported by Rumhungwe *et al*., (2016) who reported that significant difference at (P<0.05) existed between different treatments. In their study, they used higher dosage of different organic and inorganic fertilizers.

Table 4: Shows the Effect of Treatments on the Number of Stems of Irish Potato, T - Treatment

Treatment	2WAP	4WAP	6WAP	8WAP
T_1(Control)	1.00^{ns}	4.00^{ns}	7.25^{ns}	8.50^{ns}
T_2 (Poultry)	1.60^{ns}	4.00^{ns}	6.75^{ns}	9.50^{ns}
T_3 (Sheep/Goat)	1.20^{ns}	4.50^{ns}	8.75^{ns}	10.25^{ns}
T_4 (Cowdung)	1.10^{ns}	4.50^{ns}	7.50^{ns}	8.75^{ns}
T_5 (NPK 15:15:15)	1.15^{ns}	4.50^{ns}	7.75^{ns}	8.50^{ns}
p-value	0.220	0.873	0.423	0.433
LSD (P<0.05)		1.507	2.201	2.285

WAP = weeks after planting, LSD = Least significant difference, ^{abcd} Means followed by different letters differ significantly at P<0.0

Number of Tuber and Tuber Yield

Table 5 shows the effect of different fertilizer sources on the number of tubers and the average weight of the tubers for the different treatments. The results shows that the average numbers of tubers produced by T_1, T_2, T_3, T_4 and T_5 were 8, 9, 9, 8, and 8 tubers respectively. The analysis of variance shows that there is no significant difference at (P<0.05) amongst the treatments from plant height, number of stem and number of tuber. However, the results of the weight of tubers obtained showed that 4137.50, 9832.36, 9311.57, 7974.62 and 12733.75 kg/ha were produced by T_1, T_2, T_3, T_4 and T_5, respectively. T_5 produced the highest weight of tubers while the control had the least in terms of weight. The ANOVA revealed that T_5 is significantly different at (P<0.05) from each other. This results shows that the inclusion of the fertilizers significantly increase the weight of tubers produced. This result obtained in this study are consistent with the results obtained by Rumhungwe *et al*., (2016).

The findings indicates that poultry manure and sheep/goat manure attributed for plant height and the number of stem due to its high content of nutrient than other organic manure sources weeks after planting.

However the significance difference which was observed shows that Irish Potato plant can tolerate concentrated fertilizer of NPK 15:15:15 on the number of stem tubers and yield of the plant.

Table 5: Shows the Effect of Treatments on the Number of Tubers and Yield of Irish Potato, T Treatment

Treatment	Number of tubers	Weight of tubers (kg/h)
T_1(Control)	8	4137.50^{d}
T_2 (Poultry)	9	9832.36^{b}
T_3 (Sheep/Goat)	9	9311.59^{bc}
T_4 (Cowdung)	8	7974.61^{c}
T_5 (NPK 15:15:15)	8	12733.75
p-value	0.581	<0.005
LSD (P<0.05)	2.529	3064.73

WAP = weeks after planting LSD = Least significance difference, ^{abcd} means followed by different letters differ significantly at p<0.05

CONCLUSION

The overall result of the research work shows that there were no significance difference at (P<0.05) among the treatment, from the plant height, number of stem and number of stem and number of tubers, there was significance difference at (P<0.05) among the treatments of the yield of Irish potasto. However, treatment five (5) (T5) which is NPK 15:15:15 gave the highest yield of 12733.75kg/ha and the least yield recorded was in T4 which is the control at 4137.50kg/ha

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APPENDIX

Observation **Plant Height**

		Sum of squares	Df	Mean square	F	Significant
Height at 2 weeks	Between groups Within groups Total	192 590 782	4 15 19	048 039	1.220	343
Height at 4 weeks	Between groups Within groups Total	48.838 18.970 67.808	4 15 19	12.210 1.265	9.654	000
Height at 6 weeks	Between groups Within groups Total	127.757 12.733 140.490	4 15 19	31.939 849	37.627	000
Height at 8 weeks	Between groups Within groups Total	305.253 15.525 15.525	4 15 19	76.313 1.035	73.733	000

Observation **Number of Stem**

		Sum of squares	df	Mean square	F	Significant
Number of stems at 2weeks	Between groups Within groups Total	000 000 000	4 15 19	000 000		
Number of stems at 4weeks	Between groups Within groups Total	1.200 15.000 16.200	4 15 19	300 1.000	300	873
Number of stems at 6weeks	Between groups Within groups Total	8.800 32.000 40.800	4 15 19	2.200 2.133	1.031	423
Number of stems at 8weeks	Between groups Within groups Total	9.300 34.500 43.800	4 15 19	2.325 2.300	1.011	433

Observation **Number of tuber and weight of tubers**

		Sum of squares	df	Mean square	F	Significant
Number of tubers	Between groups Within groups Total	8.300 42.250 50.550	4 15 19	2.075 2.817	737	581
Weight of tubers (kg/ha)	Between groups Within groups Total	156.679 620.511 218.189	4 15 19	392.170 413.701	9.486	000

Effects of Aquatic Weeds on The Level of Dissolved Oxygen (Do) In the Polluted Fish Pond

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ABSTRACT

Green house experiment was conducted to determine the effect of waterweeds on oxygenation of polluted fish pond. Eighteen pieces of 40 litres basins were filled with 30 litres of polluted fish water which were divided into six treatments replicated three times and arranged in completely randomized design. Treatment one contained 10 water hyacinth plants (Eicchornia grassipes), treatment two contained 10 water lettuce (Pistiastratiotes), treatment three contained 20 water hyacinth plants, treatment four contained 20 water lettuce plants, treatment five contained the combination of 10 water hyacinth and 10 water lettuce plants in the same basin and finally treatment six was the control which contained no water weeds. The study was conducted for 36 days and the levels of dissolved oxygen (DO) were determined at four days intervals.Dissolved oxygen increased from 0 mg l^{-1} O_2 in the polluted water at the rate of 0.4 mg $l^{-1}O_2$ day^{-1} with water hyacinth and water lettuce plants at the first four days. At 16^{th} day, DO in water hyacinth treatments reached the peak of 3.83 mg l^{-1} O_2. Whereas the peak of 2.30 mg l^{-1} O_2 was attained at 36^{th} day with water lettuce treatments.Water hyacinth plants oxygenated polluted water faster than water lettuce plants. The oxygenation level reached 3.83 mg l^{-1} O_2 and 4.07 mg l^{-1} O_2 in 6^{th} and 36^{th} days respectively with water hyacinth and water lettuce plants. Thus, polluted fish water can be oxygenated and made fit for fish with water weeds and farmers can adopt this system to reduce the need for changing polluted water.

Keywords : Dissolved oxygen, aquatic weeds, polluted fish pond

1.0 Introduction

Water is dynamic, complex and naturally occurring liquids (Miller, 1962) and vital to living and abiotic nature and also to life itself (Malenkov, 2006). Conservation of natural resources like water implies utilization without waste, so as to make possible a continuous high level of production while improving environmental quality. Maintaining a stable water quality condition is a very important factor and its lack may represent one of the main causes for the high fish mortality rates (Waichman*et al*., 2001). However, the global supply of fresh water available for use is fixed while human demand is ever growing. It is clear that disparities in the availability and supply of fresh water are truly a matter of life and death, and constitute one of the greatest governance imperatives of our time. Hence, agriculture consumed about 83 % of the total use from all sources of water including precipitation (Soil Conservation, 1981; Hoekstra *et al*., 2012).

Aquaculture is the only alternative to continue the depletion of natural fisheries and the problem of aquaculture is the availability of water. The abundance and pond able nature of several fish species in the Nigerian waters also make commercial fish culture a sound and profitable option for prospective investors in Nigeria (Olubanjo*et al*., 2002).

In the pond, the water is the solvent and the oxygen is the solute. None of the oxygen fish absorb through their gills comes from the tightly bound oxygen in the water molecules, therefore the oxygen that fish use is derived only from the dissolved oxygen (DO) free in the water (Elliot, 2002). According to Trach (2003), he stated that fish need an average DO concentration of about 4 to 6 ppm to stay alive. Thus, the concentration of DO is an important gauge of water quality and the ability to support a well-balanced aquatic animal and plant population.

During photosynthesis, living plants release oxygen and fish depend on this oxygen for respiration. However, apart from DO, other gases that dissolved in the water which is detrimental to the fish when present in high quantities include CO_2, N_2, CH_2 and NH_2. Numerous scientific studies suggested that 4 – 5 mg l^{-1} O_2 of DO will support a large, diverse fish population of any species. According to Trach 2003, fish need an average DO concentration of about 4 – 6 parts per million to stay alive. Though, some fish species can still survive in water below 1 mg l^{-1} O_2 as stated by Chapman and Liem (1995) that *Barbusneumayeri* can survive in waters with DO concentration between 0.34 and 1.24 mg l^{-1} O_2.

Aquatic plants growing in ponds are beneficial for fish (Helfrich *et al*., 2000). Aquatic weeds help in water purification, nutrient recycling and also serve as physical link between water and air for many aquatic animals. Introduction of aquatic plants into the polluted fish ponds has beneficial effect (Helfrich *et al*., 2000), but the rate and time at which different species of these aquatic weeds will oxygenate the polluted pond is still open to research. This probed the research to: (1) determine the rate and dynamics of dissolved oxygen and build up in the presence of waterweeds. (2) determine the quantity of the waterweeds that will bring about optimal increase in the dissolved oxygen. (3) evaluate the role of different waterweeds introducing the dissolved oxygen in polluted fish pond.

2.0 Materials and methods

2.1 Location of the study area

The experiment was conducted in the green house at Olabisi Onabanjo University, Ayetoro Campus, Ogun State, Nigeria, located between latitude 7° 12′ North and longitude 3° 0′East.Ayetoro lies on the latitude 70 12’N and longitude 30 3’ E in a deciduous- derived savannah zone of Ogun State. The climate is sub-humid tropical with a longtime average annual rainfall of 1,909.30mm. Ayetoro is about 35 km northwest of Abeokuta, a town in south-west part of Nigeria and the capital of Ogun State. The town is the administrative seat/headquarters of Yewa (formally known as Egbado) North Local Government Area.Ayetoro lies between 90 and 120 metres above the sea level. The entire area is made up of undulating surface, which is drained majorly by River Rori and River Ayinbo (Senjobi*et al*., 2012). These two rivers meet at a point to the West side of the town and finally empty into River Yewa after SaalaOrile.

2.2 Experimental design

The experiment was 3 × 5 factorial design and entailed planting of two species of water hyacinth (*Eicchorniagrassipes*) and water lettuce (*Pistiastratiotes*) in 40 litres basins. Different quantities of waterweeds were placed in 30 litres of polluted fish pond water in each basin. The experiment contained five treatments with three replicates. The aquatic weeds were counted into each basin in the order: 10 plants of water hyacinth, 10 plants of water lettuce, 20 plants of water hyacinth, 20 plants of water lettuce, 10 plants of water hyacinth and water lettuce combined in each basin, and the control with no waterweeds.

2.3 Laboratory analysis

The level of DO in the polluted fish pond water was tested with the use of Hanna DO test kit (HI 3810). During the analysis, manganous ions reacted with O_2 in the presence of potassium hydroxide (KOH) to form manganese oxide precipitate. Azide reagent was added to the manganoussulphate solution in the bottle to prevent any nitrite (NO_2) ions from interfering with the test. On addition of the sulphuric acid, manganese oxide hydroxide oxidizes the iodide to iodine. The amount of iodine generated was equivalent to the O_2 in the sample, because the concentration of iodine was calculated by titration of thiosulfate ions.

STEP 1

$2Mn^{2+} + O_2 + 4OH^- \longrightarrow 2MnO(OH)_2$ (Yellow)

STEP 2

$MnO(OH)_2 + 2I^- + 4H^+ \longrightarrow Mn_2+ + I_2 + 3H_2O$ (Blue)

STEP 3

$I_2 + 2S_2O_3^{2-} \longrightarrow 2I^- + S_4O_6^{2-}$ (Colourless)

3.0 Results and Discussion

3.1Effects of waterweeds on the dissolved oxygen (DO) (mg l^{-1} O_2)

At the first day of the experiment, the level of DO was 0 mg l^{-1} O_2day^{-1} while at 4thday, it increased to 1.53 mg l^{-1} O_2day^{-1} with introduction of 10 *Eicchorniagrassipes* and *Pistiastratiotes* respectively. This could support the survival of some fish species. This is in accordance with Chapman and Liem (1995), they stated that *Barbusneumayeri* fish species can

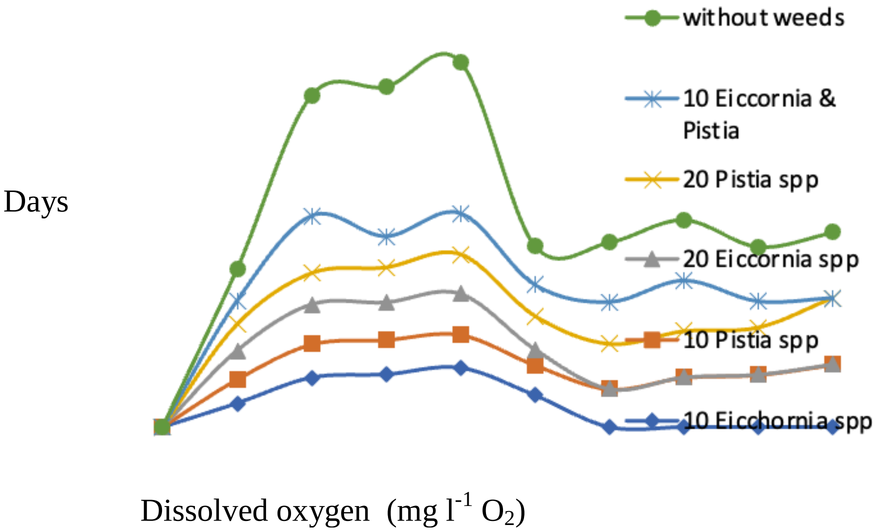

Figure 1: Relationship between the *Eicchorniagrassipes*, *Pistiastratiotes* and control

survive in waters with DO concentration between 0.34 and 1.24 mg l^{-1} O_2. More so, Saint-Paul (1988) recorded that *Colossomamacropomum* fish species can initiates aquatic surface respiration when DO level of water falls below 0.5 mg l^{-1} O_2. This fish species was known to be able to increase its haemoglobin content and erythrocyte counts associated with seasonal hypoxia. Highest DO of 1.87 mg l^{-1} O_2day^{-1} was obtained in polluted water with 20 *Eicchorniagrassipes*treatment. Although, control with no aquatic plants had DO of 2.07 mg l^{-1} O_2day^{-1} but the water was darkish in colour with more concentrated pungent smell than first day (Figure 1).

At 8th day, combination of 10 *Eicchorniagrassipes* and *Pistiastratiotes*treatmentgave the highest DO value of 3.73 mg l^{-1} O_2day^{-1} followed by 10 *Eicchorniagrassipes*treatment with the value of 3.20 mg l^{-1} O_2day^{-1}. These DO values will support a large, diverse fish population of any species. According to Trach (2003), fish need an average DO concentration of about 4 to 6 part per million to stay alive. At this point, presence of the remains of feed given to the fish disappeared. More so, the polluted water became odourless and colourless. Meanwhile, control with the DO value of 7.87 mg l^{-1} O_2day^{-1} was noticed to produce more darkish green colour compared to 4th day.

However, at 12th day, 10 *Eicchornia grassipes*treatment gave the highest DO value of 3.40 mg l^{-1} O_2day^{-1} while the combination of 10 *Eicchorniagrassipes* and *Pistiastratiotes*treatment had the lowest value of 2.03 mg l^{-1} O_2day^{-1}. Hence, the growth of phytoplankton was observed at the base of control water with DO value of 9.77 mg l^{-1} $O_2day^{-1}$and the water still smelled with dark greenish colour.

Furthermore, at 16th day, the highest DO still obtained from 10 *Eicchornia grassipes*treatment with the value of 3.83 mg l^{-1} O_2day^{-1}while *Pistiastratiotes*treatment had the least DO value of 2.20 mg l^{-1} O_2day^{-1}.

By 20th day, 20 *Pistiastratiotes*treatmenthad the highest DO value of 2.17 mg l^{-1} O_2day^{-1}followed by 10 *Eicchornia grassipes*treatment but 20 *Eicchornia grassipes*treatment gave the lowest value of 1.0 mg l^{-1} O_2day^{-1}. These were the last data collected from 10 and 20 *Eicchornia grassipes*treatment as the water was totally consumed by the aquatic plants. Thus, there was a reduction of DO in control water with DO value of 2.57 mg l^{-1} O_2day^{-1}. At this stage, the water was colourless and odourless. The phytoplankton plants floated on the water and base of the container was clear enough to be viewed.

At 24th day, 20*Pistiastratiotes*treatment gave highest value of 2.93 mg l^{-1} O_2day^{-1}whereas at 28th and 32nd day, 10 *Pistiastratiotes*treatment had the highest DO values of 3.23 and 3.40 mg l^{-1} O_2day^{-1}respectively. While 20 *Pistiastratiotes*treatment had the highest DO at 36th day of the research.

4.0 Conclusion and recommendation

A lot of water is needed for fish production because of daily need to change polluted water. This requires pumping and related costs, which increase costs of production of fish. The introduction of cleaning and oxygenation processes by waterweeds would add impetus to fish production and reduce cost of production.

Therefore, from this research, 10 waterweeds of *Eicchorniagrassipes* and *Pistiastratiotes*treatment support the increament in the level of the DO better than other quantities. But 10 *Eicchornia grassipes*treatment performed better than *Pistiastratiotes*treatment. The reason being that the *Eicchornia grassipes*treatment increased the DO level faster in the polluted water during this experiment than others.Thus, since each basin contains 10 plants/ 0.21 m^2, for standard pond with 5 m × 3 m (15 m^2) with the depth of about 1.2 m, about 70 plants will be sufficient to increase the oxygen level in the pond.

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The Effects of Three Animal Manures on Soil Available Phosphorus of a Sandy Clay Loam in Southwestern Nigeria

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ABSTRACT

The effect of animal- manures on soil phosphorus at high rates had received little research attention. This study evaluated the effects of animal-manures on soil phosphorus dynamics. The experiment was a randomized complete block design with three replications. Cured cattle, goat and poultry manures were applied (0, 5, 10, 20, 40, 60, 80, 120 and 150 tha^{-1}) once at the onset of the experiment and $N_{15}P_{15}K_{15}$ at 0.4 tha^{-1} at every six weeks. Initial soil and manures samples were analyzed for electrical conductivity, pH, ammonium-nitrogen, nitrate-nitrogen and available phosphorus using standard procedures while the soils collected fortnightly were analyzed for available phosphorus. Across weeks after manures incorporation, soil phosphorus increasedby 141, 157, 201; 257, 181, 258 and 442, 154, 395% above control for cattle, goat and poultry manures, respectively. It was concluded that, addition of cattle, goat and poultry manures increased the soil phosphorus as the rates increased.

Keywords: Animal manures, soil phosphorus, sandy clay loam, Southwestern Nigeria.

1.0 INTRODUCTION

Animal manures include the cattle, goat, poultry, sheep, rabbit and pig dungs (Joeleebass, 2012). As a result of apparent decline in soil fertility, deliberate efforts are required to promote utilization of animal manures for crop production (Maerere*et al*., 2001). Animal manures offer an affordable and readily available solution to many soil fertility problems (Spore, 2006) and are important source of Ca^{2+}, Mg^{2+}, S and micronutrients (Gomez-Brandon *et al*., 2013); they contain low and highly variable amounts of N, P and K. Aside from being source of plant nutrients, organic wastes such as those of poultry (Agbede and Ojeniyi, 2009) increase the population of soil micro - organisms which have some influence in protecting plants against pathogens like nematodes and soil borne insects and also provide plant growth hormones like auxins. The physical properties of soil are also improved (Akanni and Ojeniyi, 2008). The nutrient composition of manures vary with the age of the animal, the feed and feeding patterns, feed conversion efficiency, water intake, management system and sex (MAFF, 1994; Azeez*et al*., 2009). This can lead to large variability in manure qualities between manures from the same animal species (Chadwick *et al.*, 2000).

Phosphorus (P) is an important element required by plants for proper growth and yields. However, phosphorus has been identified as one of the most limiting nutrient elements in tropical soils (Akinola, 2005). It has low mobility in the soil. Its availability decreases in wet soils. Available phosphorus (available P) is the portion of soil P pool that its variations reflected in the corresponding change in yield of crops (Azeez*et al*., 2013). The function of P in soil is to increase the growth of the root, seed formation and development of flower (Mosaic company, 2013). Plant available P could be defined as a fraction of total P that present in the soil, which could be absorbed by plants (Mengel and Kirkby, 1987; Azeez*et al*., 2013).

Phosphorus exists in organic and inorganic forms in soils (Mosaic company, 2013). They can be found both as solid or liquid, while in some cases they are in the interface between solid and liquid. The general distribution of these forms can be used to estimate the level or degree of weathering of the soil and its availability in the soil. Soils generally have been found to vary in their total P content. Akinola (2005) reported that soil in the temperate region vary in their total P (200 mg kg^{-1} to 3,000 mg kg^{-1}) while in the tropical soil, it ranges from 70 mg kg^{-1} to 2,646 mg kg^{-1}. It was also stated by Akinola (2005), that the total P content of soils depends greatly on their parent vegetation zones and agricultural practices. Phosphorus nutrition of crop plant is more of soil problem and a higher dose of P is necessary for soils having high P fixing capacity. Akinola (2005) also established that the higher the clay content, the lower the phosphate available in the soil solution.

Organic P in Nigeria was found to range from 20 - 70 %. The amount of organic P in soils varies and greatly depends on vegetation cover of such soil. Inorganic P can be found in over 100 varieties of mineral forms. They are present in living and dead organic matter and are originally derived from rocks containing apatite during weathering processes. As a result of different human activities most importantly farming, forms and distribution of P in soil changes with land use, soil fertility and management practices. Inorganic P that is available to plants in the soil is present in the soil solution as two phosphate ions; $H_2PO_4^-$ and HPO_4^{2-} ions. However, the levels of inorganic P in soil solution, where it becomes available for uptake by plants in the form of phosphate anions ($H_2PO_4^-$ and HPO_4^{2-}) tend to be quite low compared to other macro - nutrients and may be as low as 0.001 mg kg^{-1} in low fertility soils (Brady and Weil, 1999). Therefore, the aim of this study was to investigate the potential of animal manures on soil available phosphorus in a sandy clay loam at different periods in Southwestern, Nigeria.

2.0 MATERIALS AND METHODS

2.1 Site description

The research was carried out at the Teaching and Research Farm of the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria, located between latitude 7° 12' N and longitude 3° 20' E (FUNAAB, 2013). The university is located in the transition zone between tropical humid and savannah climate, characterized by distinct wet and dry seasons. The mean annual rainfall is 1200 mm with bimodal distribution and the mean annual temperature of about 27°C.The soilsare classified as Alfisols.

2.2 Experimental design

The experiment was a randomized complete block design (RCBD) and replicated three times. Cattle, goat and poultry manures were applied at the rates of 0, 5, 10, 20, 40, 60, 80, 120 and 150 t ha^{-1} separately at the onset of the experiment. These rates were applied in order to evaluate the optimal application rates of manures for cropproduction and also for improve chemical status of the soil. NPK 15-15-15 fertilizer was used as check for each manure treatment and applied at the rate of 400 kg ha^{-1}at every six weeks. This was carried out in order to compare the NPK fertilizer treatment in relation to the animal manures. The experiment was three cycles; first cycle (A), second cycle (B) and third cycle (C).

2.3 Collection of manures and soil samples for laboratory analysis

Pretreatment soil samplestaken at a depth of 0 - 30 cm using soil auger prior to manures incorporation and representative samples of manures were bulked, air-dried, crushed using pestle and mortal, passed through 2 mm sieve and packaged for soil routine physical and chemical analysis in the laboratory. The soils and manures were analyzed for EC, pH, total N, NH_4^+- N, NO_3^-- N, available P and OC. At two weeks after addition of manures but a day after application of NPK fertilizer, soil samples were collected from the net portion of each bed at a depth of 0 - 15 cm using garden trowel and analyzed for available P. The collections of soil samples continued bi-weekly with the exception of six weeks after addition of manures due to logistic problems (climatic factors) and were analyzed for available P. Separate chemical analyses were carried out to quantify the nutrients status of both the manures and soil.

2.4 Laboratory analysis

Manures were extracted with nitric per chloric acid.Soil EC was extracted with 1: 2 soil: water ratio (Richards, 1954), Soil pH was determined potentiometrically by 1: 2 soils: water medium (Van Reeuwijk, 1993), NH_4^+- N and NO_3^-- N were extracted in 2 Molar K_2SO_4 and determined colorimetrically using the method of Okalebo*et al.*, (1993), available P was extracted by Bray P-1extraction (Bray and Kurtz 1965) and determined using colorimetric method of Murphy and Riley (1962) and organic carbon content was determined using Walkley Black method (Nelson and Sommers, 1990).Particle size analysis was determined using the hydrometer method (Bouyoucos, 1965).

2.5 Statistical analysis

The data obtained were subjected to Analysis of Variance (ANOVA) using SAS (1999). Duncan Multiple Range Test at 5 % level of probability was used to determine differences in the treatment rates means and also to show the significance effects on parameters measured in relation to the control.

3. RESULTS

3.1 Some nutrients composition of the soil used for the research

The result (Table 1) revealed that the soil used for the research had EC of very slightly saline with the value of 0.69 dS m^{-1}, with slightly alkaline pH of 7.6 while total nitrogen was low and the value was 0.8 g kg^{-1}. Ammonium – nitrogen was 0.13 mg kg^{-1} while NO_3^-- N was 0.14 mg

3.2 Soil available phosphorus (available P)

3.2.1 Influence of cattle manure rates and NPK fertilizer (t ha^{-1}) on soil available P (mg kg^{-1}) at various week intervals of first cycle.

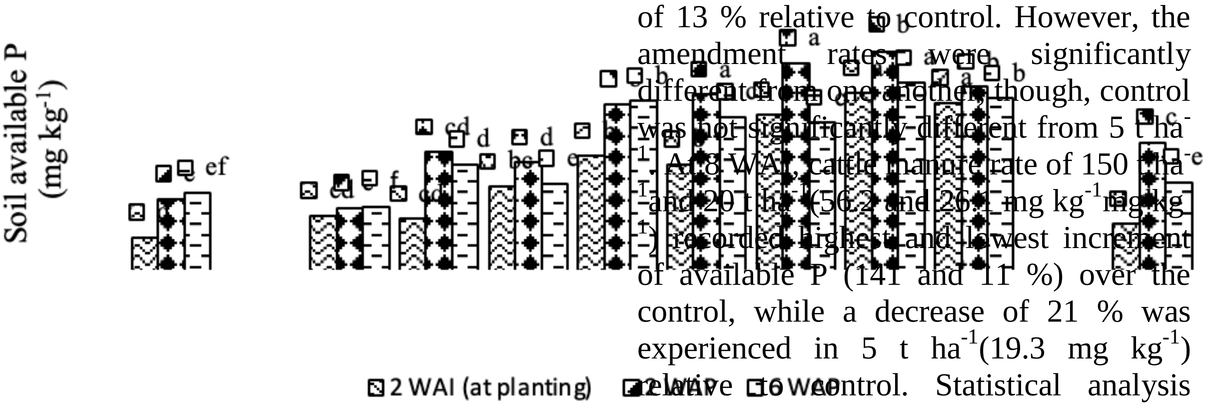
At 2 WAI (two weeks after incorporation of manures but a day after application of NPK fertilizer), cattle amendment rate of 120 t $ha^{-1}$and NPK recorded the available phosphorus valuesof 53 and 14 mg kg^{-1}(437 and 42 %, respectively) more than the control, Figure1 (A). Statistics showed that the amendment rates were significantly different from one another. Though, 80, 120 and 150 t ha^{-1} were not significantly different. At 4 WAI, cattle manure at the rate of 120 and 20 t ha^{-1} resulted to available P values of 65.3 and 32.3 mg $kg^{-1}$with highest and lowest of (204 and 50 %, respectively) over the control, Figure 1(A). But the rate of 5 t ha^{-1} which had the available

Table 1: Some nutrients composition of the soil used for the research

Physical and chemical properties	Values
pH Soil: H_2O (1: 2)	7.60
Electrical conductivity (dS m^{-1})	0.69
Total nitrogen (g kg^{-1})	1.20
Ammonium- nitrogen (mg kg^{-1})	0.13
Nitrate- nitrogen (mg kg^{-1})	0.14
Available phosphorus (mg kg^{-1})	7.50
Sand (g kg^{-1})	770.00
Silt (g kg^{-1})	68.00
Clay (g kg^{-1})	162.00
Textural class	Sandy clay loam

kg^{-1}. The value of available P was 7.5 mg kg^{-1}. Organic carbon obtained was moderate (14.2 g kg^{-1}). The properties of the cattle, goat and poultry manures applied during this study followed the report (Saka*et al*., 2017).

A



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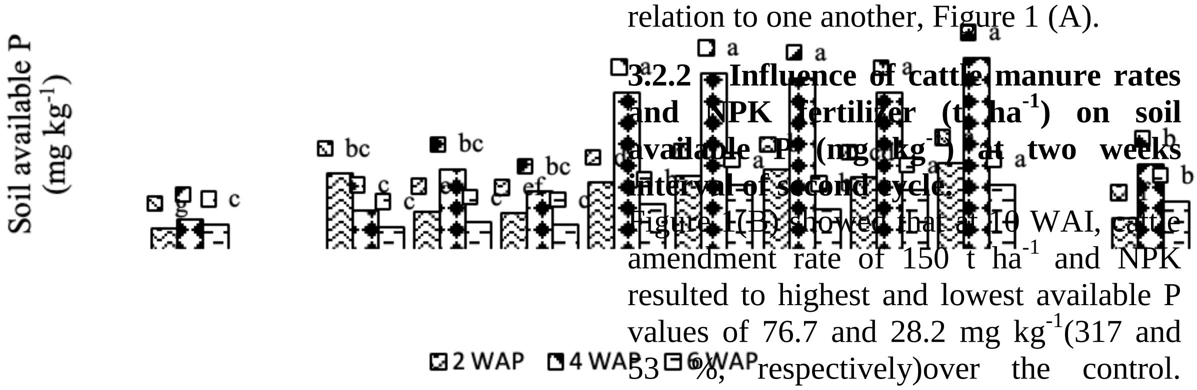

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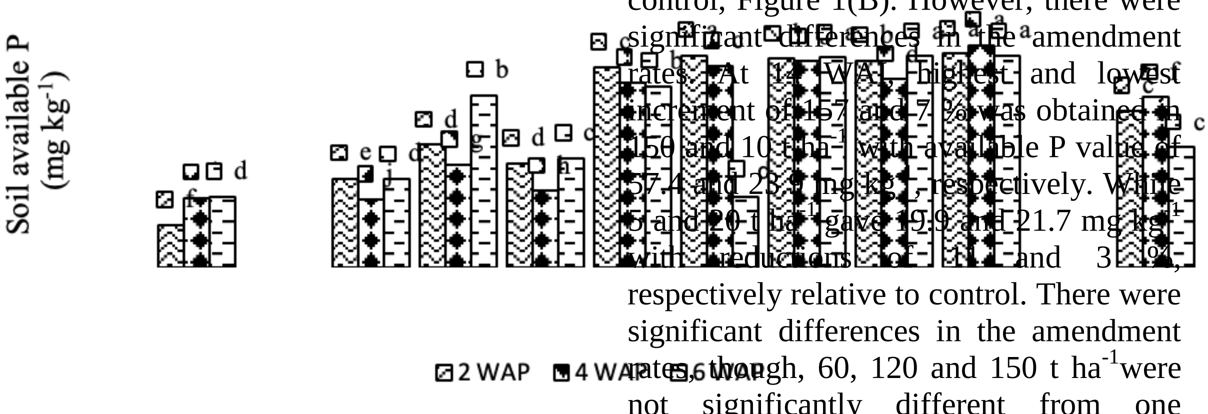

Figure 1: Influence of cattle manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at two weeks interval under first (A), second (B) and third (C) cycles of planting

WAI = weeks after incorporation of manures.

WAP = weeks after planting.

P value of 18.7 mg kg^{-1} gave a reduction of 13 % relative to control. However, the amendment rates were significantly different from one another though, control was not significantly different from 5 t ha^{-1}. At 8 WAI, cattle manure rate of 150 t ha^{-1} and 20 t ha^{-1} (56.2 and 26.1 mg kg^{-1} mg kg^{-1}) recorded highest and lowest increment of available P (141 and 11 %) over the control, while a decrease of 21 % was experienced in 5 t ha^{-1}(19.3 mg kg^{-1}) relative to control. Statistical analysis revealed that virtually every amendment rates were significantly different in relation to one another, Figure 1 (A).

3.2.2 Influence of cattle manure rates and NPK fertilizer (t ha^{-1}) on soil available P (mg kg^{-1}) at two weeks interval of second cycle

Figure 1(B) showed that at 10 WAI, cattle amendment rate of 150 t ha^{-1} and NPK resulted to highest and lowest available P values of 76.7 and 28.2 mg kg^{-1}(317 and 53 %, respectively)over the control. Statistically, the amendment rates were significantly different compared with one another. At 12 WAI, cattle manure rate of 150 and 5 t ha^{-1} had the highest and lowest available P values of 169.9 and 35.0 mg kg^{-1}(544 and 33 %, respectively) over the control, Figure 1(B). However, there were significant differences in the amendment rates. At 14 WAI, highest and lowest increment of 157 and 7 % was obtained in 150 and 10 t ha^{-1} with available P value of 57.4 and 23.9 mg kg^{-1}, respectively. While 5 and 20 t ha^{-1} gave 19.9 and 21.7 mg kg^{-1} with reductions of 11 and 3 %, respectively relative to control. There were significant differences in the amendment rates, though, 60, 120 and 150 t ha^{-1}were not significantly different from one another, Figure 1(B).

3.2.3 Influence of cattle manure rates and NPK fertilizer (t ha^{-1}) on soil available P (mg kg^{-1}) at two weeks interval of third cycle.

Figure 1(C) showed that at 2 WAP (18 WAI), cattle amendment rate of 150 and 5 t ha^{-1} with the soil available P value of 62.2 and 25.7 mg kg^{-1} recorded the highest and lowest increase of 402 and 107 %, respectively over the control. Statistically, amendment rates were significantly different compared with one another. At 4 WAP (20 WAI), cattle manure at the rate of 150 and 20 t ha^{-1} stimulated available P value of 64.8 and 22.2 mg kg^{-1} and gave the highest and lowest increase of 219 and 10 %, respectively over the control. A reduction of 3 % was recorded in 5 t ha^{-1} that had the value of 19.8 mg kg^{-1} relative to 20.3 mg kg^{-1} value of control. However, the amendment rates were significantly different from one another. The soil available P values were not consistent according to the amendment rates Figure 1(C). Cattle manure rates of 120 and 150 t ha^{-1} had the same available P value of 61.6 mg kg^{-1} and not significantly different from 80 t ha^{-1} with the value of 61.2 mg kg^{-1} at 6 WAP (22 WAI), while 5 t ha^{-1} recorded the available P value of 25.7 mg kg^{-1} and gave the lowest increment of 25 % relative to 20.5 mg kg^{-1} of control, Figure 1(C).

3.2.4 Influence of goat manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at various week intervals of first cycle.

At 2 WAI (a day after application of NPK fertilizer), goat amendment rate of 120 and 5 t ha^{-1} stimulated the available P values of 61.7 and 16.4 mg kg^{-1} and gave the highest and lowest increment of 536 and 69 %, respectively more than the control, Figure 2 (A). Statistically, amendment rates were significantly different from one another. At 2 WAP (4 WAI), goat manure rate of 40 t ha^{-1}and NPK with the available P values of 65.8 and 28.3 mg kg^{-1} recorded the highest and lowestincrease of 377 and 105 % over the control, Figure 2(A). However, the amendment rates were significantly different from one another. At 6 WAP (8 WAI), goat manure rate of 120 t ha^{-1}and NPK stimulated available P value of 63.9 and 21.9 mg kg^{-1} and recorded

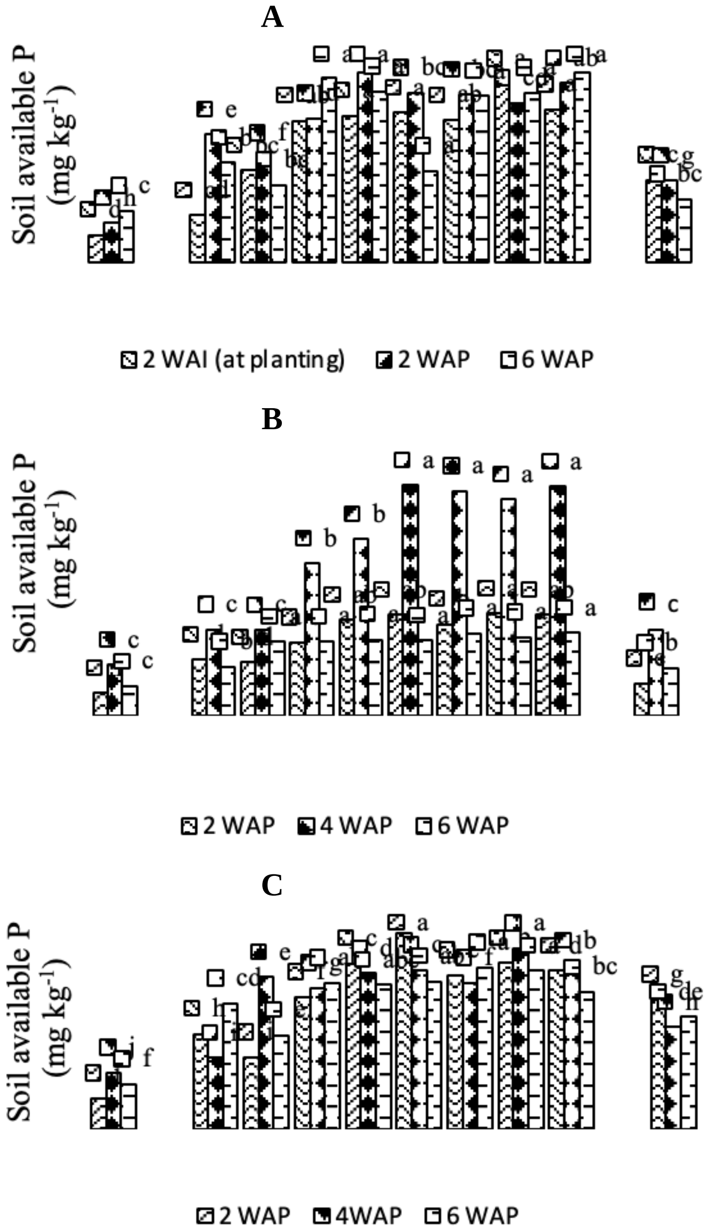

Figure 2: Influence of goat manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at two weeks interval under first (A), second (B) and third (C) cycles of planting
WAI = weeks after incorporation of manures.
WAP = weeks after planting.

the highest and lowest increment of 257 and 22 %, respectively relative to control, Figure 2 (A). There were significant differences in the amendment rates, though, 20, 40, 80, 120 and 150 t ha^{-1} were not significantly different.

3.2.5 Influence of goat manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at two weeks interval of second cycle.

Figure 2 (B) showed that at 2 WAP (10 WAI), goat amendment rate of 120 t ha^{-1} and NPK resulted to 74.2 and 23.5 mg kg^{-1} and recorded the highest and lowest increase of 350 and 42 % in soil available P compared with the control. Statistically, amendment rates were significantly different compared with one another, though, control was not significantly different from 5 t ha^{-1}. At 4 WAP (12 WAI), goat manure rate of 150 t $ha^{-1}$and NPK gave the available P values of 166.2 and 62.2 mg kg^{-1} and recorded the highest and lowest increase of 350 and 69 %, respectively, Figure 2 (B). There were significant differences in the amendment rates, though, 60, 80, 120 and 150 t ha^{-1} were not significantly different from one another. At 6 WAP (14 WAI), highest and lowest increment of 181 and 62 % was obtained in goat manure rate of 150 t $ha^{-1}$and NPK with the values of 60.2 and 34.7 mg kg^{-1},respectively over the control.

3.2.6 Influence of goat manure rates and NPK fertilizer (t ha^{-1}) on mean soil available p (mg kg^{-1}) at two weeks interval of third cycle.

Figure 2 (C) revealed that goat amendment rate of 60 and 10 t ha^{-1} with the values of 75.4 and 27.8 mg kg^{-1} recorded the highest and lowest increase of 539 and 136 %, respectively in soil available P more than the controlat 2 WAP (18 WAI). Statistics showed that the amendment rates were significantly different compared with one another. At 4 WAP (20 WAI), goat manure rate of 120 and 5 t ha^{-1} stimulated the available P values of 69.8 and 27.4 mg kg^{-1}. This recorded the highest and lowest increase of 222 and 26 %, respectively over the control, Figure 2 (C). However, the amendment rates were significantly different from one another. At 6 WAP (22 WAI), goat manure at the rate of 80 and 10 t ha^{-1} stimulated available P values of 62.3 and 36.2 mg kg^{-1} and had the highest and lowest increment of 258 and 108 %, respectively more than the control. There were significant differences in the amendment rates, Figure 2 (C).

3.2.7 Influence of poultry manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at various week intervals of first cycle.

Figure 3 (A) showed that at 2 WAI (a day after application of NPK fertilizer), poultry amendment rate of 120 t $ha^{-1}$and NPK resulted to available P values of 56.9 and 27.1 mg kg^{-1} and this gave the highest and lowest increase of 442 and 158 %, respectively over the control with the value of 10.5 mg kg^{-1}. Statistics revealed that the amendment rates were significantly different from one another.At 2 WAP (4 WAI), poultry manure rate of 150 t $ha^{-1}$and NPK with the values of 63.8 and 32.1 mg kg^{-1} recorded the highest and lowest increase of 465 and 184 %, respectively over the control, Figure 3 (A). However, the amendment rates were significantly different from one another. At 6 WAP (8 WAI), highest and lowest increment of 442 and 92 % over the control were obtained in 10 t $ha^{-1}$and NPK with the values of 71.6 and 25.3 mg kg^{-1}, respectively. There were significant differences in the amendment rates.

3.2.8 Influence of poultry manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at two weeks interval of second cycle.

Figure 3 (B) showed that at 2 WAP (10 WAI), poultry amendment rate of 60 t ha^{-1} and NPK stimulated available P values of 76.0 and 23.9 mg kg^{-1} and there was a percentage most and least increases of 477 and 45 %, respectively relative to the control. The amendment rates were significantly different compared with one another. At 4 WAP (12 WAI), poultry manure rate of 60 t $ha^{-1}$and NPK recorded available P values of 172.4 and 54.3 mg kg^{-1} and this gave the

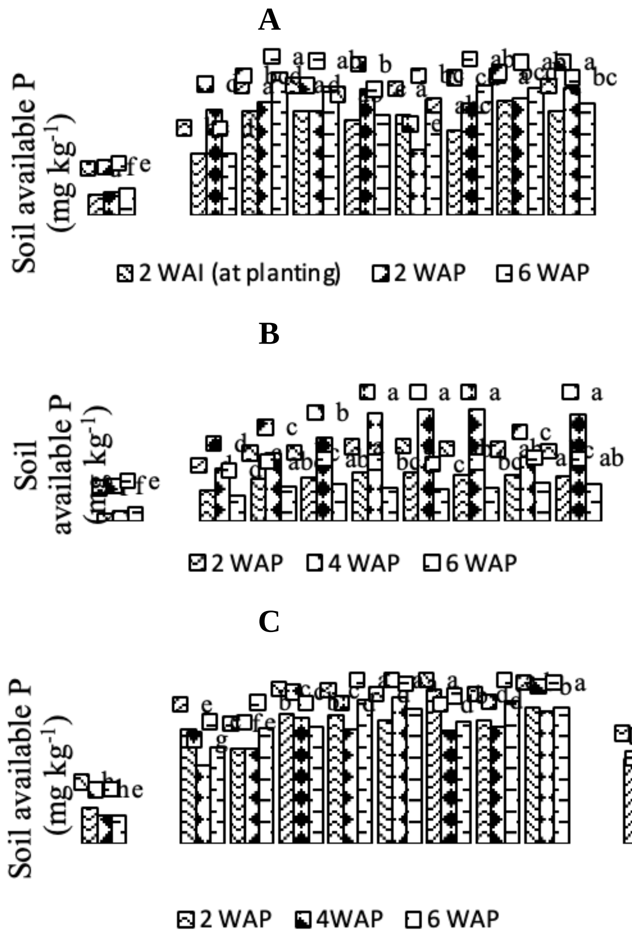

Figure 3: Influence of poultry manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at two weeks interval under first (A), second (B) and third (C) cycles of planting.
WAI = weeks after incorporation of manures.
WAP = weeks after planting.

highestand lowest increase of 984 and 242 %, respectively in relation to control. There were significant differences in the amendment rates, though, 40, 60 and 80 t $ha^{-1}$was not significantly different from one another. At 6 WAP (14 WAI), highest and lowest increments of 154 and 71 % were obtained in poultry manure rates of 120 and 5 t ha^{-1} with the available P values of 58.9 and 39.7 mg kg^{-1}, respectively over 23.2 mg kg^{-1} of control, Figure 3 (B). There were significant differences in the amendment rates, though; control was not significantly different from NPK

3.2.9 Influence of poultry manure rates and NPK fertilizer (t ha^{-1}) on mean soil available P (mg kg^{-1}) at two weeks interval of third cycle.

Figure 3 (C) showed that poultry amendment rate of 80 t ha^{-1} and NPK resulted to soil available P values of 75.2 and 41.5 mg kg^{-1} and recorded the highest and lowest increases of 323 and 133 %, respectively over the control, at 2 WAP (18 WAI). Statistics showed that the amendment rates were significantly different compared with one another. At 4 WAP (20 WAI), poultry manure rate of 60 and 5 t ha^{-1} resulted to soil available P values of 71.4 and 38.4 mg kg^{-1}. This recorded the highest and lowest increases of 410 and 174 %, respectively over the control. The amendment rates were significantly different from one another. At 6 WAP (22 WAI), 40 t $ha^{-1}$and NPK recorded available P values of 70.3 and 27.8 mg kg^{-1} and had the highestand lowest increment of 395 and 96 %, respectively. The poultry manure at the rate of 40 t ha^{-1} was not significantly different from 60, 120 and 150 t ha^{-1} with the available P values of 65.5, 69.9and 66.2 mg kg^{-1}, respectively. There were significant differences in the amendment rates compared with one another.

4.0 DISCUSSION

The soil used for this study could be classified as very slightly saline with the EC of 0.69 dS m^{-1} described by LAS (2014), slightly alkaline with pH 7.6 stated by Pam and Brian (2007), deficient in total nitrogen 0.8 g kg^{-1} (USDA-SCS, 1974), high in NH_4^+- N content of 0.13 g kg^{-1}, this could be attributed to low immobilization as a result of the normal C: N ratio of the soil, High NO_3^-- N content of 0.14 g kg^{-1} of the soil could be as a result of low rainfall during this period, the Available P content of 7.5 mg kg^{-1} was low (Mallarino, 2000).The soil was sandy clay loam with particle size classification values of 770, 68 and 162 g kg^{-1} for sand, silt and clay, respectively (USDA, 2010). This would allow more salts to be deposited at the plant roots as reported by (Virginia, 2009) that, a given amount of salt in sandy soils will be more concentrated in its effect on plant roots than an equivalent amount in clay soils.

However, the nutrients composition of cattle, goat and poultry manures applied during this research were similar to the report of Saka*et al*. 2017.The cattle, goat and poultry manures incorporated onto the soil increased the concentration of available P in the soil according to the rates and this support the studies of some researchers (Babatola*et al.,* 2002; Eghball, 2002; Adeniyan and Ojeniyi, 2005; Duncan, 2005; Agbede*et al*., 2008), their studies reported that application of manure can result in increased soil concentration of nutrients and organic matter. Mineralization of available P occurred in the soil during second cycle of planting with the maximum values at 12 WAP for cattle, goat and poultry manures and supports the work of Azeez and Van Averbeke (2010) that mineralization of manure phosphorus increased with time. The mineralization process could also be attributed to microbial activities as suggested by Vintene*t al*. (2002); during this period and high rainfall at this period compared with first and third cycles of planting during the research. This was contrary to (Ayeni, 2011; Ayeni and Adeleye, 2011), that release of poultry manure nutrients proportion is between one to two months of incubation. The slow release of available P during this research could be attributed to low rainfall during the first 2 months of the manures incorporation.

Despite the advantage of the manures to increase soil nutrients, high quantity of application could also be contributed to the poor performance of plantsduring research this at first cycle of planting. This support the studies of Gupta *et al*. (2004) that high N and P inputs due to manure applications may pose environmental risks.

During second cycle of planting which was equivalent to the period of 2 and $3^1/2$ months, application of cattle, goat and poultry manures had increased influence on the plants more than first and third cycles of planting. This positive response could be attributed to the availability of available P, NH_4^+- N and NO_3^-- N in the soil taken up by plants during this period. This confirmed (Egharevlon and Ogbe, 2002; Ibeawuchi*et al*., 2006; Mbonu and Afrifalo, 2006) that organic manure can sustain yield under continuous cropping through the high potential of gradual nutrient release to the soil. However, the decrease at third cycle of planting could be attributed to uptake of available P by plant roots, leaching and fixing of P at the exchange sites in the soil.

5. CONCLUSION

Generally, the addition of cattle, goat and poultry manures on the soil improved the soil available P compared with control. Highest available P was observed in poultry manure prior to application compared with cattle and goat manures. Application of NPK 15-15-15 fertilizer increased the soil available P but recorded lowest values relative to control. The available P contents of the soil at the first cycle of planting increased with the application of cattle, goat and poultry manures. However, mineralization of available Poccurred between 2 – $3^1/2$ months of incorporation of cattle, goat and poultry manures.Finally, the effect of cattle, goat and poultry manures on available P decreased between 4 – $5^1/2$ months of manures application considered third cycle of planting.

6.0 RECOMMENDATIONS

To increase soil available Pfor optimum production yield, application of cattle, goat and poultry manures is recommended. It is recommended that application rate of 20 t ha^{-1} of cattle manure, 40 t ha^{-1} of goat manure and poultry manure at the rate of 10 t ha^{-1} would provide optimum and increase the level of nutrients in the soil which will be retained in the soil for longer period.

Acknowledgements
We appreciate the editor, reviewers and those who contributed to the success of this study while the views, expressions and conclusions are for the authors.

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