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Effect of poultry production on air quality and human health in selected agricultural zones of Imo State

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ABSTRACT

The Confined Animal Feeding Operations (CAFOs) in poultry management are increasingly recognized as sources of air pollution, yet their health impacts remain underexplored. This study evaluated air pollutant levels and respiratory health among poultry workers in selected zones of the Poultry Association of Nigeria, Imo State, from December 2021 to May 2022. Air samples were collected monthly from six poultry pens across three zones. Pollutants measured included CO_2, CH_4, NO_2, NH_3, H_2S, SO_2, and $PM_{2.5}$, alongside microclimatic parameters such as temperature, humidity, and wind speed. Gaseous pollutants were assessed using Kanomax and iTX multigas analyzers, and $PM_{2.5}$ levels were measured with a pDR-1200 Monitor. A structured questionnaire and spirometry tests were used to evaluate workers' health. Results showed mean NH_3 concentrations (2.22±1.67 ppm) exceeded FEPA limits, while $PM_{2.5}$ levels (337.28±420.19 µg/m³) surpassed standards set by NESREA, WHO, and USEPA. CO_2, CH_4, NO_2, and SO_2 levels were within permissible limits. Relative humidity negatively influenced $PM_{2.5}$ and most gases ($p < 0.01$), except NH_3. Wind speed had a significant negative effect ($p < 0.10$) on $PM_{2.5}$, NO_2, NH_3, H_2S, and SO_2, while temperature negatively impacted CH_4, NO_2, and NH_3, but positively affected SO_2 and $PM_{2.5}$. Health assessments revealed high prevalence of symptoms among workers, including headache (86.8%), tiredness (86.8%), nasal irritation (71.1%), and eye irritation (47.7%). Lung function tests indicated 10% of workers had obstructive patterns (FEV_1/FVC: 86.84±18.32%), while the control group had normal values (98.82±1.52%). PEFR was significantly lower in workers (61.12±27.85%) compared to controls (88.41±21.76%), with 13.3% showing severe airway narrowing. The study concludes that poultry farm air quality is poor and significantly impacts workers' respiratory health, increasing their risk of lung function impairment and airway obstruction due to prolonged pollutant exposure.

KEY WORDS: *Poultry production*; *Air quality*; *Agriculture*; *Human health*

1. Introduction

One major source of animal protein and a significant contributor to the Nigerian economy is poultry production, which is a subsector of livestock production and accounts for 19% of the country's meat supply (SAGTAP, 2012). The Nigerian poultry business, according to Sahel (2015), is projected to worth 80 billion ($600 million) with 165 million birds in it. With over 25 million people employed directly and indirectly in the commercial poultry industry, which has

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gradually grown from small backyard farms to large confined structures with intensive management systems. The poultry industry is considered to be the most industrialized segment of the livestock sub-sector (Bello *et al.*, 2015). According to Adene and Oguntade (2006) and Abimiku (2008), the poultry industry in Nigeria is divided into small-scale (500-2,500), medium-scale (2,500-10,000) and large-scale (over 10,000 birds).

The expansion of poultry production resulting to Confined Feeding Animal Operations (CFAOs) is increasingly recognized as a source of air pollutants that have significant environmental and health impacts in and around poultry facilities (Copeland, 2014). This is mainly due to litter and manure generated during production, which pose a serious risk of air pollution arising from the emission of unpleasant odours and microorganisms. According to Akinbile (2012), harmful gas pollutants such as NH_3, CO_2, O_3, N_2O, and other gases are released and contribute between 3−8% to global warming, exacerbating the effects of climate change.

In poultry manure, 57% of the total nitrogen is lost via volatilization within 14 days of dumping (Adeoye *et al.*, 2004). Ammonia volatilization can increase greenhouse gas emissions, generate acid rain, and suffocate people (McGinn and Janzen, 2018). According to Oguntoke *et al*. (2010), indoor air pollution causes a bigger health risk on a worldwide scale than contaminated outdoor air pollution does while a source of air pollution is the unregulated dumping of waste inside and outside the poultry pens. Toxic gases (NH_3, CO_2, and H_2S), odours, dust, and microorganisms are found in poultry housing and are known to have a negative impact on poultry health.

Objectives of the Study

The overall objective was to assess the effect of poultry production on air quality and human health in selected agricultural zones of Imo State.

The specific objectives of this study were to

i. Assess the gaseous and Particulate Matter pollutants from poultry production systems.
ii. Determine the microclimatic parameters from intensive poultry production systems and their effect on air pollutants;
iii. Assess the effects of air pollutants on the health status and lung function of poultry workers.

2. Material and Methods

2.1 Study area

The research area consisted of chicken farms in a few agricultural zones in Imo State, in the southeast of Nigeria. The State was established in February 1976 with 27 Local Government Areas (LGA) and 37 Local Council Development Areas (LCDA) as at the time of writing the reports. ImoState is located between latitude 5°29'0" north and longitude 7°2'0" east. The study area is bordered by Anambra State to the north, Rivers State to the south, Delta State to the west, and Abia State to the east. 4.93 million People live in the state, which has a land area of around 5530 km^2 (NPC, 2006). The state experiences tropical weather with yearly rainfall ranging from 1600 mm to 900 mm. All year round, the area experiences warm temperatures. Temperatures in the area range from 28°C to 35°C all year round. Fig. 1 displays the map that depicts the sample at the study area of Imo state.

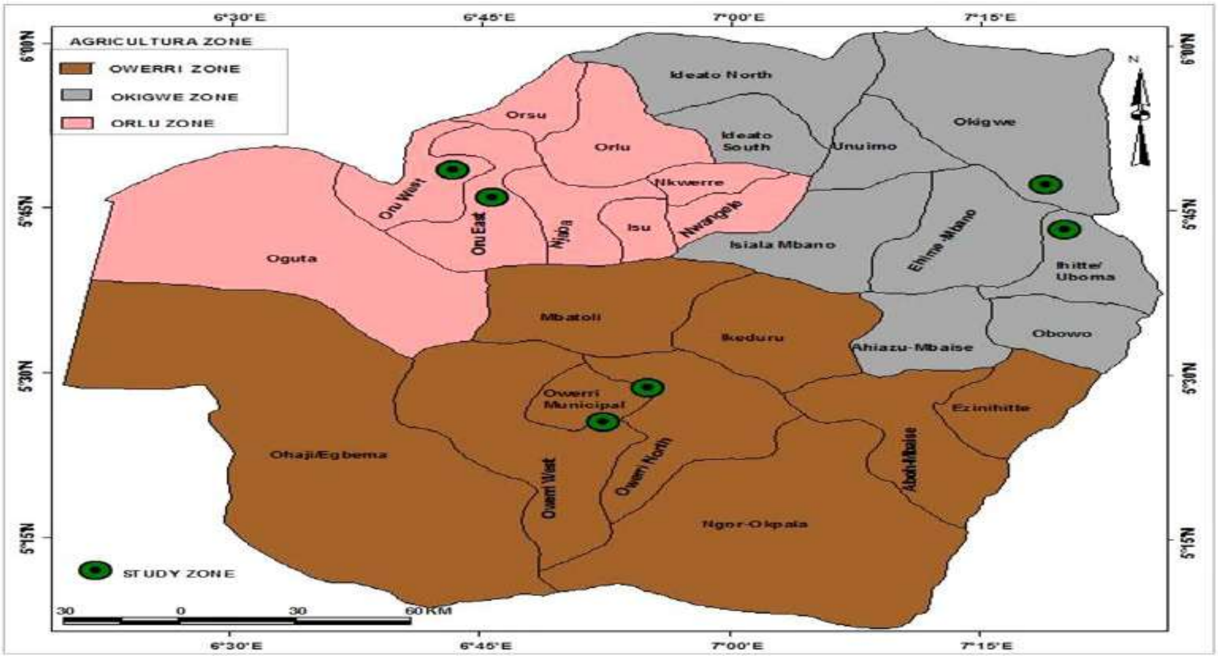

Fig. 1: Map of Imo State, Nigeria, showing the Sampled Locations in the Study Area

2.2 Sample collection and analysis

The Six poultry houses in three zones; Orlu, Okigwe, and Owerri, each marked by the letters R, K, and W as illustrated in Plates 1 - 6 were purposefully chosen from three poultry zones categorized by the Imo State-based Poultry Association of Nigeria (PANIS). Every month from December, 2021 to May, 2022, two poultry houses in each zone were sampled. These poultry houses passed both indoor and outdoor air sampling using the air sampler. In order to achieve a complete coverage of the surroundings for optimal coverage, both inside and outdoor air sampling spots were determined based on the air pollution levels in the poultry houses and population density of the poultry birds. Table 1 displays the parameters of the pens (W_1, W_2, K_1, K_2, R_1 and R_2) at the time of sampling. The sampled areas outside the pens are designated as W_3, K_3, and R_3.

Thermo PDR 1250 metric sampler was used to detect $PM_{2.5}$ while KanoMax and iTXmultigas Analysers, hand-held air quality monitoring devices, provided direct reading readings of NH_3, CH_4, N_2O, H_2S, and CO_2 over the course of an hour at 10-minute intervals. The Kanomax gas analyzer's associated probe was used to acquire meteorological data such as temperature and relative humidity, while the Benetech Model GM816 multipurpose microprocessor digital anemometer was used to monitor wind speed. Monthly sampling was done between December, 2021 and May, 2022.

2.3 Study population

Clearly defined questions to ascertain the extent/level to which air pollution from the production of poultry affects people's health. In addition to asking for information on their

Table 1: Characteristics of Pens across sampled zones in Imo State

Pen	Bird Type	Bird Age (Weeks)	Stock Size	Manure Removal / Frequency	Housing Type	Ventilation Type
W_1	Layers	45-69	7000	Flushing/ daily	3-tier battery cage	Mechanical and Natural
W_2	Layers	30-54	20,722	Belt conveyor/ 3 days	4-tier battery cage	Mechanical and Natural
K_1	Broilers	2-3	9100-10000	Use of shovels/2-3 weeks	Wood shavings litter	Natural
K_2	Broilers	4-6	5000-10000	3-tier battery cage/4 days	3-tier battery cage	Natural
R_1	Pullets	15-22	3000	Use of shovel/ 6 weeks	Wood shavings litter	Natural
R_2	Layers	52-56	1200	Designed to self-flush	3-tier battery cage	Natural

W_1 and W_2 = Sampled Poultry houses in Owerri Zone in Imo State
K_1 and K_2 = Sampled Poultry houses in Okigwe Zone in Imo State
R_1 and R_2 = Sampled Poultry houses in Orlu Zone in Imo State

personal judgment of their health. The purpose of choosing respondents, a purposive sample technique is doubtable. The whole workforce at the three poultry farms comprised the targeted respondents. The demographic distribution between the three poultry farms is shown in Table 2.

Table 2: Population distribution across the three poultry farms

Poultry Zone	Poultry Pen	Number of Workers
Owerri	1	12
	2	14
Okigwe	1	5
	2	5
Orlu	1	1
	2	1
Total		38

2.4 Impacts of air pollutants on the health status of poultry workers

Thirty-eight respondents which represented the total population of workers in the six sampled poultry pens were administered questionnaires and their responses documented.

2.5 Lung Function Assessment

A hand-held spirometer SP10 in accordance with the ATS standard, respiratory function parameters (FVC, FEV_1, FEV_1/FVC % and PEFR) were assessed (Miller *et al.*, 2020). To help each respondent act appropriately, demonstration exercises of the maneuver were explained to them. Prior to the lung function testing, they were advised to practice this maneuver. Each subject was examined while seated. Each participant's mouthpiece was discarded, and air was forced through it into the spirometer to prevent contamination. The subjects were told to inhale deeply and quickly before exhaling fiercely and thoroughly into the apparatus. The highest FVC, PEFR, and FEV measurements obtained during the first one second were recorded after three readings.

Plate 1: Poultry Pen 1 in Owerri Zone

Plate 2: Poultry Pen 2 in Owerri Zone

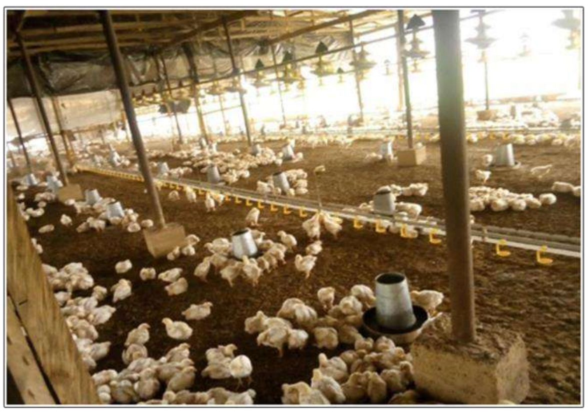

Plate 3: Poultry Pen 1 in Okigwe Zone

Plate 4: Poultry Pen 2 in Okigwe Zone

Plate 5: Poultry Pen 1 in Orlu Zone

Plate 6: Poultry Pen 2 in Orlu Zone

2.6 Anthropometric characteristics

Each person from the control group and the poultry workers was questioned about their age in years. A portable stadiometer was used to measure the workers' heights and the weights were determined using a weighing scale.

2.7 Calculation of predicted values of FVC, PEFR and FEV

The observed FVC, PEFR, and FEV values were reported as a percentage of the expected values using regression analysis and a set of prediction equations for adults (Ingle *et al.*, 2005; Reddy *et al.*, 2014; Olujimi *et al.*, 2016).

The following are the prediction equations:
Poultry workers:
FVC (L) = 0.019H-0.015A-0.70
FEV1 (L) = 0.019H-0.012A-1.07
PEFR (L/Sec) = -0.008H-0.121A+8.45

Control group:
FVC (L) = 0.037H-0.014A-3.82
FEV1 (L) = 0.037H-0.015A-3.72
PEFR (L/Sec) = -0.002H-0.006A+6.46

Where,
H is height in cm
A is age in years.
FVC is Forced Vital Capacity
FEV_1 is Forced Expiratory Volume in one second (1s)
PEFR is Peak Expiratory Flow Rate Litres per minutes (L/min)

Subjects with (FEV_1/FVC) less than 70% were categorised as having an obstructive pattern of lung function defect (Ibhafidon *et al.*, 2014; Lopez *et al.*, 2014).

(ANOVA, t-test, and regression). In order to establish the association between the pollutants and microclimatic factors, the Duncan's Multiple Range Tests and t.test were employed to separate the means of the pollutant concentration variations. Equation (1) depicts the multiple regression model used by to ascertain the association between microclimatic factors and contaminants (Obayelu and Adeniyi, 2006; Nwagwu *et al.*, 2012)

$$Y = a + x_1b_1 + + x_2b_2 + + x_3b_3 + e \text{ ----------------(1)}$$

Where,
Y = Dependent variables NH_3, CH_4, N_2O, H_2S, CO_2 and $PM_{2.5}$
x = Independent variables:
x_1 = relative humidity
x_2 = temperature
x_3 = wind speed
a = regression constant
b = regression coefficient
e = error term

2.8 Description of activities at studied poultry sites

This section indicates the concentrations of gaseous pollutants CO_2, across the sampling locations from December, 2021 to May, 2022. W_1, W_2, K_1, K_2, R_1, R_2 represent pens while W_3, K_3 and R_3 denote the sampled points outside the pen. Pen K_1 and K_2 had varying age of birds because broilers were only raised for 6 weeks and were restocked at intervals. K_1, K_2 and K_3 were not sampled in January because there were no birds. Also layers in R_2 were sold after three months of sampling and the pullets were transferred to the battery cage in February, as they had reached point of lay. About half of the birds were later sold, leaving R_1 with no birds for the rest of the sampling months.

The results BDL = Below Detection Limit
DL: Detection Limit
Control NPPW: Non-Poultry Production Workers

3. Results and Discussion

3.1 Levels of CO_2 pollutants from the studied poultry farms

Carbon dioxide (CO_2) indoor concentrations (Mean±Standard deviation) ranged between 1041.33±32.25 and 1971.25±145.96 mg/m^3 with the highest concentration W_2 in the month of March and the lowest in W_3 in January as shown in Fig. 2.

3.2 Mean concentrations of gaseous pollutants and $PM_{2.5}$

The summary of means of air pollutants are presented in the Table 3. Carbon dioxide (CO_2) concentrations (Mean±Standard deviation) had a range between 1273.52±221.71 and 1545.65±279.30 mg/m^3 with the highest at W_1 and the lowest at W_3 and were significantly higher in the pens. [3].

Methane (CH_4) concentrations ranged from 0.06±0.40 to 0.81±1.37 ppm. The CH_4 was however not detected W_3, K_1, K_3, R_1, R_2, R_3. The highest mean concentration was significantly highest in W_1 and lowest in K_2. The battery cage system operated in W_1 allows collection of manure in slurry form in the pit which provides anaerobic condition resulting in CH_4 production unlike manure in the solid form in R_2.

Nitrogen dioxide (NO_2) mean concentrations ranged between 0.032 and 0.034 ppm. The highest concentration was recorded in R_1 and the lowest in K_1. NO_2 concentration was significantly highest in R_1.

Ammonia (NH_3) concentration ranged between 0.23±0.43 and 3.04±1.64 ppm. It was BDL in W_3,

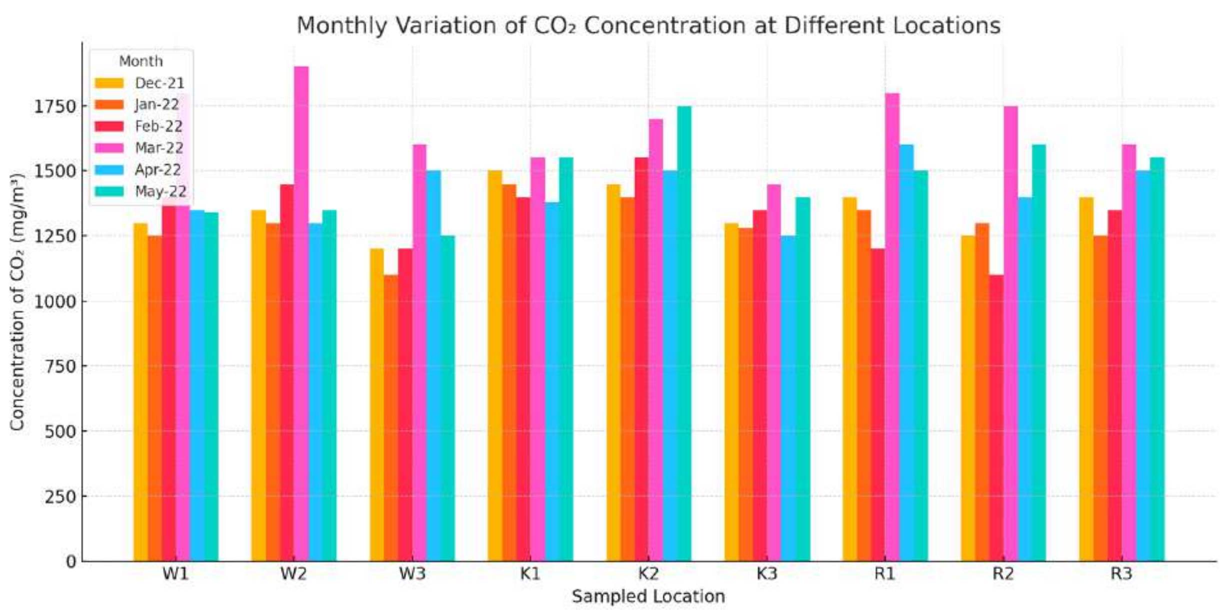

Fig. 2: Monthly variation of CO_2 concentration at different locations

lowest in K_3 and significantly highest in R_2. This may be attributed to the manure management practices. Manure is held back in $R_2$for two weeks while the wastes from other battery cage pens are disposed within 2-3 days.

Hydrogen Sulphide (H_2S) concentration ranged from 0.02±0.03 to 0.4±0.88 ppm. H_2S was below detection limit in R_1 and R_3, lowest at R_2 and significantly highest in K_2.

Sulphur Oxide (SO_2) concentration had a range of 0.01±0.01 and 0.44±0.90 ppm. It was BDL in R_1, lowest in K_1 and was significantly higher in zone K_2 and K_3 compared to others. This can be attributed to outdoor source of the emissions from the generator set of the farm which were in operation at the time of sampling.

Particulate Matter ($PM_{2.5}$) concentrations ranged from 97.90±50.54 to 1469.70±423.44 µg/m^3. It was lowest at W_3 but was statistically highest in R_2. This can be attributed to the poultry

Table 3: Mean concentrations of gaseous pollutants and $PM_{2.5}$

Location	CO_2 (mg/m^3)	CH_4 (ppm)	NO_2 (ppm)	NH_3(ppm)	H_2S(ppm)	SO_2 (ppm)	PM2.5 (µg/m3)
W1	1545.65±279.30^a	0.81±1.37^a	0.033±0.001^b	2.73±1.86^{ab}	0.04±0.05^c	0.03±0.78^b	222.94±228.46^c
W2	1466.82±295.91^a	0.06±0.40^b	0.033±0.001^b	2.00±1.5^c	0.34±0.83^b	0.33±0.06^b	222.77±259.26^c
W3	1273.52±221.7^b	BDL	0.033±0.001^b	BDL	0.02±0.02 ^{c}	0.04±0.05^b	97.90±50.54^d
K1	1493.94±206.81^a	BDL	0.032±0.001^c	2.38±1.36^b	0.02±0.03 ^{c}	0.01±0.01^b	434.39±399.05^b
K2	1476.04±262.18^a	0.18±0.45^b	0.033±0.001^b	2.20±1.48^c	0.4±0.88^a	0.38±0.83^a	269.92±.241.61^b
K3	1303.97±128.82^b	BDL	0.033±0.001 ^{b}	0.23±0.43^e	0.33±0.67^b	0.44±0.90^a	125.61±91.63^d
R1	1353.22±225.0^b	BDL	0.034±0.002^a	1.36±1.12 ^{d}	BDL	BDL	1469.70±423.44^a
R2	1475.17±264.85^a	BDL	0.033±0.001^b	3.04±1.64^a	0.02±0.03^c	0.04±0.9^b	321.88±.278.52^b
R3	1353.19±226.03^b	BDL	0.033±0.001^b	0.25±0.44^e	BDL	0.01±0.03^b	179.07±212.98^d
Mean	1476.04	0.20	0.033	2.22	0.10	0.10	337.28
SD	262.18	0.72	0.001	1.67	0.42	0.42	420.19
Range	1273.52-1545.65	0.06-0.81	0.032-0.034	0.23-3.04	0.02-0.4	0.01-0.44	97.90-1469.70
NESREA	NA	NA	0.04-0.06	0.3	0.10	0.10	250
WHO(2005)	900	0.06	0.11		0.19	0.06	25
USEPA(2001)					0.5		35

Values are Mean±SD. Values with similar superscripts along the same column are not significantly ($p > 0.05$) different according to Duncan Multiple Range Test, BDL- Below Detection limit of 0.01ppm/mg/m^3, NA- Not Available, SD- Standard deviation management systems. Pullets of 6 months were raised on litter (wood shavings and dust). This promotes behavioural expression of birds such as scratching and dust bathing. On the other hand, W_1 and W_2 had the lowest $PM_{2.5}$ concentrations across the pens because both combined mechanical and natural ventilation while other pens have only natural ventilation. Hence, increase in air velocity helps to disperse pollutants, and reduce their concentrations as observed in W_1 and W_2.

3.3 Mean values of the microclimatic parameters

Table 4 shows the summary of the mean values of microclimatic parameters of all the poultry sites.

The relative humidity (Mean±SD) ranged from 32.75±8.53 to 59.57±11.44%. The highest and the lowest RH were obtained in W_2 and R_1 respectively. W_1 and W_2 had significantly higher relative humidity than others.

Temperature (Mean±SD) values ranged between 30.74±3.50and 34.08±2.71 ˚C. The highest temperature was recorded at K_3 and the lowest at W_2. R_1 and R_2 had significantly higher temperatures than pens.

Wind speed (Mean±SD) ranges from the poultry sites were between 0.05±0.22 and 1.8±0.9 m/s. The highest wind speed was obtained at R_3 while the lowest was at K_2. This may be linked to low/still air movement since temperature was mostly high during sampling period. Pens W_1 and W_2 had significantly higher wind speed which can be attributed to the combination of both mechanical and natural ventilation system adopted compared to other pens.

4. Discussion

The results of the values obtained in the pens are similar to that which was obtained in confined poultry houses in studies conducted by Oriola *et al.* (2013) in Ibadan, Oyo State and Zhao *et al.*

Table 4: Mean values of microclimatic parameters in poultry sites

Sampled Sites	Relative Humidity (%)	Temperature (˚C)	Wind Speed (m/s)
W1	58.34±9.12[a]	31.73±2.79b[cd]	1.20±0.76[b]
W2	59.57±11.44 [a]	30.74±3.50 [d]	0.83±0.61[b]
W3	56.58±13.79 [ab]	33.06±2.99[ab]	0.22±0.50[cd]
K1	56.88±12.42 [ab]	31.13±5.26[cd]	0.06±0.20[d]
K2	50.88±15.44 [b]	33.53±2.36 [ab]	0.05±0.22 [d]
K3	52.39±7.17 [b]	34.25±24.29[a]	0.70±0.57[bc]
R1	32.75±8.53[d]	34.08±2.71[a]	0.48±0.48[cd]
R2	41.57±14.74 [c]	32.38±4.36[bc]	0.15±0.29 [d]
R3	41.89±13.61[c]	33.94±56[a]	1.81±0.9[a]
Mean	51.39	31.59	0.54
SD	15.29	4.00	1.54
Range	32.75-58.34	30.74-34.25	0.04-1.8

Note: Values are Mean±SD
Values with similar superscripts along the same column are not significantly ($p > 0.05$) different according to Duncan Multiple Range Test
SD-Standard deviation

(2015). However, NH_3 levels recorded in most pens exceeded the limit of 0.3 ppm NESREA tolerance limit. H_2S was however BDL in all poultry sites in December. These H_2S concentrations were below that which was recorded by Nwagwu *et al.* (2011) in the poultry pens in Port Harcourt, Nigeria during the dry season. The H_2S concentrations were however above the NESREA (2011) tolerant limits of 0.10 ppm in few pens (W_1, W_2 and K_2), and also exceeded the WHO limits of indoor H_2S (0.06 ppm). Sulphur dioxide (SO_2) concentrations were BDL in the months of December and January in the sampled poultry site. Mean concentrations were however above NESREA (2011), WHO (2015) and USEPA (2011) air quality standard of 0.10 ppm, 0.19 ppm and 0.5 ppm respectively in pens K_2, K_2 and R_2. High concentrations as clearly observed at K_2 and K_3 was also reported by Iyogun *et al.* (2018) who attributed the high concentration to combined outdoor and indoor sources of SO_2. This can be linked to the emissions from the generator set of the farm which was in operation at the time of sampling. Concentrations of $PM_{2.5}$ in most pens were above the recommended WHO (2015), USEPA (2011) and NESREA (2011) limits of 25 µg/m^3, 35 µg/m^3 and 250 µg/m^3.

The high concentration in January can be associated with combination of dust generated in the poultry houses and harmattan dust. During the sampling in January, 2021, harmattan was quite severe; hence the prevalence of harmattan dust must have had its cumulative effect on the recorded $PM_{2.5}$ concentrations. This supports the studies conducted on PM pollution in Nigeria during the harmattan period (Efe, 2008; Obioh *et al.*, 2008).

5. Conclusion

The research confirms that poultry production has a significant negative effect on air quality and human health in selected agricultural zones of Imo State, Nigeria. Addressing this issue requires the cooperation and commitment of all stakeholders involved to implement sustainable practices and regulations that prioritize environmental conservation and human well-being.

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Impact of mango cultivation on soil nutrient dynamics at institute for agricultural research farm, Samaru, Kaduna State, Nigeria

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ABSTRACT

This study assesses the effects of more than 35 years of continuous mango cultivation on soil properties at the Institute for Agricultural Research Farm, Samaru, Nigeria, by comparing current soil conditions to legacy data from 1984 using T Student's independent T-test. Results revealed notable changes in soil properties over time. The results revealed that mango cultivation has led to an increase in soil organic carbon (T=2.21, P=0.075, MD= 4.11 g kg^{-1}), total nitrogen (T=3.78, P=0.009 MD= 2.05 g kg^{-1}) attributed to the decomposition of mango leaves, twigs, and flowers, which contribute to humus formation and improve soil fertility. However, the study also identified a decline in essential nutrients such as calcium, magnesium, and potassium, indicating nutrient depletion likely due to tree uptake and leaching. Soil pH decreased significantly, suggesting acidification, while available phosphorus showed slight improvement over time. Despite these challenges, the overall soil degradation index showed a slight improvement, indicating that mango cultivation, when managed sustainably, can enhance soil quality. To sustain mango cultivation and enhance soil health, integrated nutrient management strategies combining organic and inorganic inputs are recommended. Practices like mulching with mango leaves to boost phosphorus recycling, erosion control measures (cover cropping and contour planting), and the adoption of agroforestry systems to enhance nutrient cycling and diversify income are also proposed.

KEY WORDS: *Mango*; *Soil properties*; *Soil degradation*; *Sustainable farming*; *Soil nutrient dynamics*

1. Introduction

Mango (*Mangifera indica*) is one of the most popular, nutritionally rich, and economically important fruits globally. Nigeria ranks among the top ten mango-producing countries (Jekayinfa *et al.*, 2013), with major production occurring in states such as Benue, Jigawa, Plateau, Yobe, Kebbi, Niger, Kaduna, Kano, Bauchi, Sokoto, Adamawa, and Taraba (Yusuf and Salau, 2007). The cultivation of mango can help mitigate environmental degradation by reducing soil erosion and improving soil fertility. Mango trees provide shade, which minimizes wind erosion, and their fallen leaves and fruits contribute organic matter to the soil. However, mango productivity is

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often hindered by decreasing soil nutrient levels and the imbalanced use of chemical fertilizers and pesticides (Balakrishna *et al*., 2021).

The nutrition of mango trees depends on the soil's inherent ability to supply essential nutrients, which are absorbed by the trees. The availability of these nutrients is vital for effective orchard management (Balakrishna *et al*., 2021). Nutrient content and availability play a significant role in a plant's ability to produce fruits and complete its life cycle. Over time, long-term mango cultivation may cause variations in soil nutrients due to clearing native vegetation, applying inorganic chemicals such as fertilizers and pesticides, and routine farm operations (da Silva *et al*., 2014). These changes can either improve soil properties or accelerate degradation, depending on soil type, management practices, and the duration of cultivation. According to Aminu and Ladan (2021), soil nutrient levels often decline over time following crop harvesting, as nutrients are not replenished. As a result, large quantities of fertilizers are applied, but only a small proportion is absorbed by plants, with the remainder leaching away. This necessitates continuous fertilizer application (Aminu and Ladan, 2021). The extensive use of chemical fertilizers, however, deteriorates soil properties, leading to long-term fertility loss (Aminu and Ladan, 2021).

Despite the significance of mango cultivation, limited research has been conducted on its influence on soil properties in this region. Understanding the changes in soil properties caused by management practices could inform sustainable approaches to mango production while minimizing environmental degradation. Additionally, knowledge of soil nutrient status aids in diagnosing nutritional issues and estimating fertilizer requirements for fruit trees.

2. Material and Methods

2.1 Study area

The Institute for Agricultural Research (IAR) is located in Samaru, Sabon Gari Local Government Area, Northwest Nigeria, between latitudes 11°10′30″N and 11°11′40″N and longitudes 7°36′30″E and 7°38′6″E, covering approximately 227.8 hectares. The precise date of the mango orchard's establishment is not documented; however, available records indicate its existence as far back as 1984. The region has a tropical climate, with annual precipitation ranging from 300 mm to 1000 mm. Rainfall intensity peaks in July and August (Aliyu, 2023). Temperatures vary between 22.18°C and 30.38°C, with the highest values occurring in April, as in other parts of Northern Nigeria. The lowest temperatures, ranging from 22.9°C to 23.1°C, are experienced in December or January (Aliyu, 2023). The mean atmospheric relative humidity ranges between 70–90% during the rainy season and 25–30% during the dry season. High relative humidity is caused by southwest trade winds carrying moisture-laden air from the Atlantic Ocean. In contrast, the low relative humidity between October and March results from the dry, dusty, and cold northeast trade winds originating from the Sahara Desert (Balarabe *et al*., 2015).

2.2 Methodology

Soil samples were collected from a depth of 0–30 cm within the projection area of the canopy in a mango orchard located at the IAR Samaru Farm, Zaria, Nigeria. The samples were air-dried, crushed, and sieved through a 2 mm sieve. Particle size distribution was determined using the Bouyoucos hydrometer method as described by Gee and Or (2002). Soil texture was classified using the USDA textural diagram (Soil Survey Staff, 2017). Bulk density was determined using the core sampling method (Blake and Hartge, 1986).

Soil pH was measured in a 1:2 soil-to-water suspension using a pH meter with a glass electrode, following the method outlined by Jackson (1973). Organic carbon content was estimated using the Walkley and Black (1934) wet oxidation method (Jackson, 1973). Organic matter content was calculated by multiplying the organic carbon content by a factor of 1.724. Exchangeable Bases and Cation Exchange Capacity (CEC) were determined using the 1N neutral ammonium acetate extraction method, following the percolation tube procedure (Van Reeuwijk, 1993). Sodium (Na) and potassium (K) concentrations were measured using an atomic absorption spectrophotometer (AAS), while calcium (Ca) and magnesium (Mg) were measured using a flame photometer. Results were expressed in cmol(+) kg^{-1} of soil. Total Nitrogen was determined by extracting the soil with 1N KCl and using the micro-Kjeldahl distillation method (Agbenin, 1995). Results were expressed in g kg^{-1} of soil. Available Phosphorus was extracted using 0.5M $NaHCO_3$ and determined colorimetricaly (Olsen *et al*., 1954). Results were expressed in mg kg^{-1} of soil. Base saturation was calculated as the ratio of the total exchangeable bases (Ca, Mg, K, and Na) to the CEC (obtained using NH_4OAc) and expressed as a percentage. The procedure is as follows;

$$\text{Base saturation} = \frac{\text{Total exchangeable bases}}{\text{CEC}} \times 100$$

2.3 Land degradation assessment

The level of soil degradation within the mango orchard, as well as data obtained from the legacy soil survey report of the site (Valette and Ibanga, 1984), was assessed using standard indicators and criteria for land degradation evaluation provided by the Global Assessment of Land Degradation (GLASOD, 1998), as outlined in Table 1. Table 2 provides an interpretation guide for evaluating the overall soil degradation level (FAO, 2004).

The degradation class was determined by

Table 1: Indicators and criteria for Land Degradation Assessment

Indicator degree of degradation	1	2	3	4
Physical degradation				
Soil bulk density (Mg m^{-3})	<1.5	1.5-2.0	2.0-2.5	>2.5
Chemical degradation				
Content of N (%)	>0.13	0.10-0.13	0.08-0.10	<0.08
Content of Phosphorus (mg kg^{1})	>8	8-7	7-6	<6
Content of Potassium (cmol (+) kg^{1})	>0.16	0.14-0.16	0.12-0.14	<0.12
Content of ESP	<10	10-25	25-50	>50
Base saturation	<2.5	2.5-5	05-10	>10
Excess salt (Salinization)	<2	2-3	3-5	<5
Biological degradation				
Content of humus in soil (%)	>2.5	2.5-2.0	2.0-1.0	>1.0

Source: GLASOD (1998)

matching the results of soil properties with the corresponding land degradation indicators. The degree of degradation was estimated mathematically using physical, chemical, and biological parameters, as shown in the equation below;

$$\text{Degree of Degradation} = \frac{\sum_i^n \text{degree of degradation of each quality} \times 100}{\text{Max. degree of degradation} \times \text{number of qualities}}$$

Table 2: Key to interpreting overall degradation class

Class of degradation	Overall, Degree of degradation (%)	Description
1	0-25	Non to slightly degraded soil
2	26 – 50	Moderately degraded soil
3	51 -75	Highly degraded soil
4	76 – 100	Very highly degraded soil

Adapted from: GLASOD, (1998)

2.4 Statistical analysis

Impact of mango cultivation on soil properties was assessed using Student's independent T-Test.

3. Results and Discussion

3.1 Impact of mango farming on soil properties

The results of the T-test reveal temporal changes in soil properties between the current study and the 1984 soil survey report (Table 3).

Soil Texture

There was increase in the sand fraction (T-value = 1.47, P-value = 0.190, mean difference (MD) = 80.00 g kg^{-1}). However, this increase was not statistically significant ($P > 0.05$). The observed increase in sand fraction could be attributed to the wide canopy of mango trees which reduces the impact of raindrops on the soil, minimizing erosion. The litter layer acts as a protective cover, reducing soil compaction and improving infiltration. Silt and clay fractions exhibited a non-significant decrease (T-value = -1.48 and -0.34, MD = -53.00 gkg^{-1} and -31.00 gkg^{-1}, respectively). Negative T-values and mean differences indicate a decrease in these fractions, possibly due to the erosion of fine particles. This suggests that mango farming has minimal impact on the textural composition of the soil, which is largely determined by parent material and weathering processes.

Table 3: Impact of mango farming on some soil properties at IAR farm, Samaru

Variable	T val	p	MD
Sand	1.47	0.190	80.00
Silt	-1.48	0.184	-53.00
Clay	-0.34	0.746	-31.00
pH	-6.94	0.000	-1.39
OC	2.21	0.075	4.11
Ca+Mg	-2.63	0.074	-7.00
K	-3.01	0.057	-0.42
Na	-4.72	0.018	-0.68
CEC	-0.57	0.591	-1.63
CEC clay	6.3	0.003	43.61
BS	-6.3	0.003	-55.70
TN	3.78	0.009	2.05
AvP.	1.2	0.272	1.57

Note: T val. = T value, p = Probability, MD = Mean Difference

Soil pH

The significant decrease in soil pH ($T = -6.94$, $p < 0.001$, MD = -1.39) indicates decreased soil acidity under mango farming. This could result from organic matter decomposition, root exudates, or leaching of base cations. Sadia *et al*. (2023) and Aliyu *et al*. (2023) attributed higher pH in mango orchards to reduced leaching of basic cations, while Mosweu *et al*. (2013) suggested that canopy cover reduces evaporation rates, promoting conditions conducive to pH stabilization.

Organic Carbon

Soil organic carbon showed anincrease after 34 years of mango farming (T-value = 2.21, P-value = 0.075, MD = 4.11). This increase aligns with findings by Santos and Ribeiro (2002) in the São Francisco River Valley. Mango trees shed a significant amount of leaves, twigs, and flowers throughout the year. The decomposition of this organic material adds humus to the soil, which improves soil structure, nutrient availability, and water retention capacity.

Exchangeable Bases and CEC

The decline in Ca+Mg levels ($T = -2.63$, $p = 0.074$, MD = -7.00) is not significant, indicating possible nutrient leaching or uptake by mango trees. Mango plants require adequate supply of calcium and Magnesium for higher fruit production (Khan and Ahmed, 2020). The reduction in K ($T = -3.01$, $p = 0.057$, MD = -0.42) was significance, suggesting depletion due to high uptake or leaching, particularly in acidic soils. The significant decrease in Na ($T = -4.72$, $p = 0.018$, MD = -0.68) highlights potential effects of leaching or exchangeable sodium depletion. Aliyu (2023) attributed low exchangeable bases in soil to the absorption. Research shows that mango leaf litter contains appreciable amounts of magnesium, potassium and calcium, essential for plant growth (Kumar *et al*., 2021). There was a decline in CEC ($T = -0.57$, $p = 0.591$), although this decline was not significance suggesting stability in the soil's nutrient-holding capacity. The decline in CEC might be attributed with the decline in exchangeable bases above.

Total Nitrogen

A significant increase in TN ($T = 3.78$, $p = 0.009$, MD = 2.05) points to nitrogen enrichment, likely from organic inputs like leaf litter and application of nitrogenous fertiliser. The decomposition of mango leaves releases essential nutrients such as nitrogen replenishing soil fertility. The increase in nitrogen (N) concentration during the decomposition of mango litter and other organic materials has been noted by several researchers (Berg and McClaugherty, 2008; Prescott, 2005; Wei *et al*., 2023). This phenomenon often occurs as carbon (C) is lost more rapidly than nitrogen, leading to an increased N concentration in the remaining material. He *et al*. (2016) reported that nitrogen addition significantly increased soil dissolved organic N and inorganic N content.

Available Phosphorus

Available phosphorus increased (T-value = 1.20, p-value = 0.272, MD = 1.57 mg kg^{-1}) over the 35 years of mango cultivation. The increase in AvP is not significant, suggesting limited changes in phosphorus availability. Mango trees shed significant amounts of leaf litter, which decomposes and releases nutrients, including phosphorus, into the soil. Wei *et al*. (2023) reported that organic phosphorus in the litter is mineralized by soil microbes, making it available for plant uptake.

3.2 Impact of mango cultivation on soil degradation

Physical degradation

The degradation score for bulk density remained constant at 1.00 from 1984 to 2018, indicating no measurable physical degradation. This stability suggests that mango farming does not significantly compact the soil, likely due to reduced soil disturbance and organic matter contributions from the orchard.

Chemical degradation

Degradation score of total nitrogen stayed at 1.00 over the years, suggesting no degradation in total nitrogen levels. This aligns with the observed increase in TN in Table 3, likely due to organic inputs like leaf litter and nitrogen cycling under mango trees. The Degradation score of Available Phosphorus improved slightly from "very highly degraded" (4.00) in 1984 to "highly degraded" in 2018, reflecting reduced degradation. This could be due to better nutrient management, reduced erosion, or improved phosphorus availability from organic matter decomposition over time. A consistent score of 1.00 indicates no significant degradation of Exchangeable potassium levels, suggesting mango farming does not adversely affect potassium availability in this context. The score of Exchangeable Sodium Percentage (ESP) remained at 1.00, highlighting no degradation related to sodium accumulation. This aligns with Table 3, where sodium levels were reduced, suggesting effective leaching and absence of salinization. The Base Saturation of score remained at 4.00, indicating sustained chemical degradation related to base saturation levels. This is consistent with the significant decline in base saturation noted in Table 3, likely due to acidification and leaching of base cations.

Biological degradation

The content of humus in the soil is stable score of 1.00 suggests no biological degradation and implies that humus levels remain adequate under mango farming. This reflects the positive contribution of organic matter inputs from leaf litter and root biomass.

Table 4: Degradation scores for mango orchard at IAR farm, Samaru

Indicator Degree of Degradation	1984	2018
Physical Degradation		
Soil bulk density	1.00	1.00
Chemical Degradation		
Content of total nitrogen	1.00	1.00
Content of available phosphorus	4.00	3.00
Content of available Potassium	1.00	1.00
Content of ESP	1.00	1.00
Base saturation	4.00	4.00
Biological Degradation		
Content of humus in soil	1.00	1.00
Overall Degradation Index	46.43	42.86

Overall degradation index

The overall degradation rate decreased slightly, from 46.43% in 1984 to 42.86% in the present study (Table 4), indicating slight improvement in soil properties over time. This is mainly attributed to improvements in the chemical properties like available phosphorus and stability in other indicators like humus content and nitrogen levels. This supports findings by da Silva *et al*. (2014)

and Feng *et al*. (2020), which suggest that mango cultivation does not significantly deplete soil properties. The slight improvement in the overall degradation index suggests that mango farming, when managed properly, can sustain soil quality over time.

4. Conclusion

The impact of mango cultivation on soil nutrient dynamics at the Institute for Agricultural Research (IAR) Farm in Samaru, Nigeria, reveals both beneficial and challenging aspects. Over the long-term, mango farming has contributed to the enhancement of soil organic carbon and total nitrogen levels, largely due to the significant input of organic material such as leaves and twigs. These organic materials decompose, enriching the soil with essential nutrients and improving soil structure, water retention, and microbial activity. However, there are notable declines in certain exchangeable bases, such as calcium, magnesium, and potassium, which may be attributed to both uptake by the trees and leaching. Although the cation exchange capacity (CEC) remained stable, phosphorus availability showed slight improvement over time due to microbial mineralization. Mango farming has also positively impacted the soil by reducing erosion and compaction through the canopy cover and organic litter. The degradation assessment showed that soil degradation in the mango orchard decreased slightly from 1984 (4.00) to 2018 (3.00), indicating that mango cultivation has not caused severe depletion of soil properties. The stability of key soil indicators, such as bulk density, base saturation, and humus content, further suggests that mango farming can be sustained with minimal impact on soil health when appropriate management practices are adopted. To improve the productivity of mango orchards while safeguarding soil resources and minimizing long-term degradation, the following recommendations are proposed to improve soil health and sustain mango cultivation at the Institute for Agricultural Research Farm, Samaru: Implement an integrated nutrient management strategies which combine organic and inorganic inputs to enhance nutrient availability while minimizing environmental impacts, mulching with mango leaves and other organic residues to enhance phosphorus recycling through litter decomposition should be encourage. Adopt soil conservation practices, such as cover cropping, mulching, and contour planting, to minimize water and wind erosion that contributes to sand loss. Lastly, encourage intercropping or agroforestry systems to diversify income sources and enhance soil fertility through complementary nutrient cycling.

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Growth and yield response of Tomato (*Lycopersicon esculentum* Mill.) as influence by organic manure and different mulching materials in Njala Lowland

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ABSTRACT

The study examined the impact of poultry manure and different mulching materials on tomato growth and yield in the School of Agriculture and Food Sciences. However, experiment was laid out in a Randomized Complete Block Design (RCBD) in a split plot arrangement, replicated three times with a gross plot size was 187m^2 (17 m × 11 m) the bed size of (5 m × 3 m) 15 m^2. Five different levels of poultry manure (0 t ha^{-1}, 5 t ha^{-1}, 10 t ha^{-1}, and 15 t ha^{-1}, and 20 t ha^{-1}) and four different mulching materials (Elephant grass, Plastics mulch, and Rice straw) were used for the experiment. However, the physical and chemical properties show that the soil is a sandy loam as it contains more than 50% of sand with essential nutrients, which are N, P, K as well as organic matter, are all very low which indicate that the soil was in a poor state especially when the pH is low (acidic soil pH 4.45). The positive correlation between the soil factors and characteristics and some quality characters of tomato indicates that for the crop to effectively produce a high yield, the soil factors that significantly influence yield must be taken into consideration during the production process. Similarly, result shows statistically significant ($P<0.05$) variation due to the effects of treatments and mulching materials the vegetative growth and yield of tomato. In the study, 20 t ha^{-1} significantly outperformed in terms of plant height, leaf number, vine branches, leaf area which resulted in the production of higher number of flower, fruit number, fruit weight and total yield of fruit. In conclusion, the findings shows that poultry manure at 20 t ha^{-1} should be applied using rice straw materials as mulch for smallholder and commercialized farmers in order to achieve rapid growth and yield of tomato in Sierra Leone.

KEY WORDS: *Poultry manure*; *Cattle manure*; *Mulching*; *Tomatoes*

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely grown vegetable crops in the world. The tomato began its history in the coastal highlands of Western parts of South America (Khetarpal and Sehgal, 2004). Today, tomatoes are grown commercially in 159 countries. It's well-known that a healthy diet is important for preventing chronic diseases such as cancer, cardiovascular disease, cognitive function, and osteoporosis, as well as improving antioxidant

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levels and controlling body weight (Ali *et al.*, 2020). Tomato requires warm, clear dry conditions and an altitude ranging between 700 and 2000 meters above sea level. The optimum growing temperature in the central lowlands of Ethiopia ranges between 24 °C and 28 °C during the day and 14 °C and 17 °C at night. High temperatures above 40 °C during the day and 22 °C at night can cause flower drops. Friable and sandy loam soil with a pH of 5.8-6.8 is favorable for high fruit yield (Lemma, 2002). However, despite the importance of tomato in Sierra Leone diet, yet the production is still low. Soils of Sierra Leone have inherently low fertility and do not receive adequate nutrient replenishment. With many farmers typically applying insignificant amounts of fertilizers, coupled with continuous cropping, soil degradation and declining soil fertility continue to pose major threat to sustainable food production by smallholders (MAFFS, 2009). Coupled with other constraints including soil moisture stress, low nutrient capital, erosion risks, low pH with aluminium (Al) toxicity, high phosphorus (P) fixation, low levels of soil organic matter, poor farming methods and a loss of soil biodiversity, food security may not be achieved in the near future unless urgent intervention measures are undertaken (WFP, 2009).

Being resource limited, most smallholders cannot afford the conventional soil fertility management strategies dominated by high use of inorganic fertilizers and agrochemicals considering their escalating prices. Therefore, many of these farms are dependent on short-term natural fallow to maintain soil fertility. Crop production is mainly rainfed on the uplands and the low lands support short duration crops and vegetables in the dry season. With the majority of soils being Oxisols and Ultisols that contain oxides of iron and aluminium and are acid, the most serious crop production problems on these soils are that of deficiencies in plant available phosphorus and low inherent fertility. High level of deforestation, poor management and lack of inputs has led to a decline in productivity, soil erosion, and loss of vegetation (MAFFS, 2009). Soil fertility plays an important role in sustaining crop productivity of any area, particularly in situations where input of nutrients application differs and the information on the nutritional status can go a long way to develop economically viable alternatives for management of deficient nutrients in the soil. Deficiencies of available major and micronutrients are widespread in soils of Sierra Leone.

Tomato is cultivated mostly on subsistence basis in rural areas. Mineral fertilizers are commonly applied by growers to maximize yields. However, in Nigeria, most rural farmers avoid the use of fertilizers, including N.P.K. 15:15:15, on their tomato farms. This is because fertilizers are scarce and expensive. Also, the price of tomato is usually low, partly because of lack of an affordable and effective means of preservation. The low price discourages the use of high cost fertilizer input. Rural farmers prefer, instead, to use fertilizers for other crops like yam, maize, cassava where the investment makes economic sense (Ogunwole *et al.*, 2006).

Organic fertilizers are farmyard manure (FYM), sheep manure (SM), poultry manure (PM), and compost among others has been used for crop production for centuries. The use of these forms of fertilizers certainly pre-date chemical (mineral) fertilizers, which is of more recent development in comparison with organic fertilizers. Organic fertilizers are more environmentally friendly, since they are of organic sources. Contrary, observations show that continuous use of mineral fertilizers creates potential pollution effect on the environment (Oad *et al*., 2004).

The use of mulches offers great hope because of their moisture-conserving ability and also, their moderate soil temperature (Ogundare *et al*., 2015). Mulching serves various purposes, increases soil temperature, reduces water evaporation, enhances fertilizer efficiency, improves solar light irradiation efficiency, improves soil physical and chemical properties, and improves soil microbial activity (Van Der Zee *et al*., 2017). The application of chemical fertilizers is currently one of the most commonly used methods in intensive agriculture (Da Costa *et al*., 2013). However, the long-term application of chemical fertilizers can cause many negative effects. For example, most of the nutrients added to the soil are not absorbed by plants. Studies have shown that more than 50% of the nitrogen and 90% of the phosphorus in chemical fertilizers are lost to the atmosphere or water sources (Simpson *et al*., 2011), resulting in greenhouse gas emissions, water eutrophication, and other environmental issues (Lam *et al*., 2017).

Chemical fertilizers are not the most appropriate solution to overcome these constraints, Use of chemical fertilizers is also expensive and a threat to human health (Zulfiqar *et al*., 2019). To maximize the efficiency of photosynthesis and minimize the risk of disease, each tomato leaf must have plenty of room and be supported up off the ground (Gopinath *et al*., 2017). The use of organic fertilizers is environmentally friendly since they are from organic sources and the best solution for increasing tomato yield is to use organic fertilizers (Oyewole *et al*., 2012). In general, the role of mulching, and organic fertilizer on tomato growth and yield properties has not been studied in the study area. Hence, this study was conducted with the objectives of evaluating the influence of mulching, and organic manures application on the growth and yield component of tomatoes in the study area.

2. Material and Methods

2.1 Experimental setup

The study was conducted in the School of Agriculture and Food sciences research site of the Njala University during the second planting seasons 2024. Njala University is located on an elevation of 54 m above sea level on latitude 8°6N and longitude 12°W of the equator. The effects of mulching, and organic manure were investigated using the tomato variety of Plum Tomato. The experiment was laid out in a Randomized Complete Block Design (RCBD), a factorial experiment, replicated three times. The gross plot size was 187 m^2 (17m × 11m) the bed size of (5m × 3m) 15 m^2. The recommended rate of poultry manure (10 t ha^{-1}), cow dung (20 t ha^{-1}), were used for the experiment.

The treatments consist four treatment combination including control. The transplanted tomato seedlings were planted directly with a spacing of 70 cm × 30 cm within rows and between plants. The spacing between blocks and plots was 1m and 0.5 m apart, respectively.

2.2 Statistical analysis

All data collected were subjected two-way analysis of variance (ANOVA) using the STATISTICA software version 12 (Stat Soft Inc., Tulsa, OK, USA) and means were separated using the DUNCAN MULTIPLE RANGE TEST (DMRT) at 0.05 level of significant.

3. Results and Discussion

3.1 Physical-chemical properties of soil sample of the experimental site

Both the physical and chemical properties of the soil used in the study were analyzed and shown in **Table 1**. The physical properties show that the soil is a sandy loam as it contains more than 50% of sand. The content of the essential nutrients, which are N, P, K as well as organic matter, are all very low. These conditions generally indicate that the soil was in a poor state especially when the pH is low (acidic soil pH 4.45).

Table 1: Physiochemical properties of the soil (0-30 cm)

Parameter	Unit	Value
Texture	---	Sandy loam
Clay	(%)	14.20 (1.2)
Sandy	(%)	53.50 (1.9)
Silt	(%)	32.30 (1.05)
Nitrogen	(%)	0.32 (0.00)
Organic	(%)	0.75 (0.05)
Ratio C/N	---	2.34 (0.02)
Phosphorus	Ppm	4.60 (0.1)
Potassium	(g kg^{-1})	0.25 (0.02)
Sodium	(g kg^{-1})	0.07 (0.01)
Calcium	(g kg^{-1})	0.23 (0.01)
Magnesium	(g kg^{-1})	0.17 (0.01)
Zinc	(g kg^{-1})	0.29 (0.02)
Copper	(g kg^{-1})	1.42 (0.01)
Iron	(g kg^{-1})	2.26 (0.01)
pH- Water	(g kg^{-1})	4.45 (0.1)

Note: Values in parenthesis represent the standard error of mean.

3.2 Relationship between soil fertility parameters and yield and quality of tomato

Relationships among the various elements that determine soil fertility and the yield and certain quality characteristics of tomato are given in **Table 2**. From the table, it could observe that tomato yield has a highly significant correlation with most of the factors that determine soil fertility which include nitrogen percent, phosphorus percent, potassium percent, organic matter content, calcium percent and pH. The positive correlation between the soil factors and characteristics and some quality characters of tomato indicates that for the crop to effectively produce a high yield, the soil factors that significantly influence yield must be taken into consideration during the production process.

Table 2: Correlation among soil factors with yield and quality components

Soil Factor	Yield (Kg ton^{-1})	Dm%
Nitrogen (N)	0.464**	-0.005
Phosphorus (P)	0.270**	0.003
Potassium (K)	0.438**	0.076
Organic matter	0.120**	-0.075
pH	0.146**	-0.002
Calcium (Ca)	0.370**	-0.082

Dm% - Dry matter percentage; **- significant at 0.01 probability level.

3.3 Effect of different rate of poultry manure and different mulching materials on the growth of tomato

From **Table 3** below, the result below shows statistically significant ($P<0.05$) variation due to the effects of treatments on the plant height, vine length, leaf number, and leaf area at 4 weeks after transplanting. The maximum plant height (16.76 cm), higher vine length (1.11), leaf number (10.6) and broader leaf area (16.83) while the least value was obtained from 0t/ha control. This agreed with the work of Direkvandi *et al*. (2008) and Ayeni (2014) who reported a significant increase in plant height and number of branches as a result of the application of poultry manure. The result further shows that the use of mulches offers great hope because of their moisture-conserving ability and also, their moderate soil temperature (Ogundare *et al*., 2015). The present investigation also agreed with the findings of Ilodibia and Chukwuma (2015) who reported a significant increase in plant height, number of branches, and number of leaves as a result of the application of poultry manure. Higher soil temperatures increase nutrient availability, enhance nutrient uptake by roots, increase the number and activity of soil microorganisms, and speed up plant germination and growth (Farias-Larios *et al*., 1998). Similar results were obtained by Kayum *et al*. (2008), that mulching had significant effects on plant growth components. However, result shows a significant ($P<0.05$) differences on the use of different mulch materials on the growth of tomato at different growth stage. At 4WAT, tomato plant mulch with rice straw materials recorded higher plant height (8.67), highest vine branches (8.57), higher leaves per plant (10.47) and broader leafs (9.37) followed all planted mulch with white plastic which recorded the second taller plant, leaves number, higher vine branches and broader leaf compared to control treatment with no mulch which recorded the least at 4WAT. It has been shown that straw mulching can improve the net photosynthetic rate (Pn) of functional leaves of winter wheat (Zhai *et al*., 2021).

However, at 6 weeks after transplanting, result shows a significant ($P<0.05$) variation due to the effects of treatments and mulch applied on the plant height, vine branches, number of leaves, and leaf area per plant at 4, 6 and 8 Weeks after transplanting. From the result, 20 t ha^{-1} of poultry manure has higher plant height 33.58 cm, higher vine branches 2.45, higher number of leaves recorded per plant 14.9, and broader leaf area 27.49 cm^2 (**Table 4**). The result further shows that the use of mulches offers great hope because of their moisture-conserving ability and also, their moderate soil temperature (Ogundare *et al*., 2015). This has also been demonstrated by several researchers that use of organic inputs such as crop

Table 3: Growth response of tomato as influence by organic manure and mulching application at 4WAT

Treatment	Plant Height (cm) 4WAT	Vine Branches (cm) 4WAT	Leaves Number 4WAT	Leaf Area (cm^2) 4WAT
0 t ha^{-1}	10.49e	0.53d	2.90d	8.41d
5 t ha^{-1}	12.77d	0.74bc	4.30c	13.26c
10 t ha^{-1}	14.41c	0.72bc	5.92bc	13.08c
15 t ha^{-1}	15.021b	0.88b	7.01b	15.64b
20 t ha^{-1}	16.76a	1.11a	10.6a	16.83a
Mulching Materials				
Control	5.45	4.56	5.44	5.61
Elephant Glass	7.43	6.20	5.61	6.24
White plastics	7.30	7.83	7.37	8.57
Rice straw	8.67	8.57	10.47	9.37
F-Statistics				
CV	12.70	8.02	7.21	10.12
LSD (5%)	1.22	1.89	0.89	1.40

Note: Values followed by the same letter(s) in a column are not significantly different at $p = 0.05$ according to Least Significant Difference (LSD).

Table 4: Growth response of tomato to organic manure and mulching application at 6WAT

Treatment	Plant Height (cm) 6WAT	Vine Branches (cm) 6WAT	Leaves Number 6WAT	Leaf Area (cm^2) 6WAT
0 t ha^{-1}	13.62d	1.28b	6.90d	22.06b
5 t ha^{-1}	18.04c	1.48b	7.70c	23.91b
10 t ha^{-1}	23.11b	1.55b	9.40c	24.69b
15 t ha^{-1}	32.87ab	2.20a	12.46b	25.27b
20 t ha^{-1}	33.58a	2.45a	14.9a	27.49a
Mulching Materials				
Control	10.23d	6.46c	18.08bc	9.08b
Elephant Glass	13.01c	9.22c	29.02b	16.02ab
White plastics	14.23b	10.44b	28.80b	16.22ab
Rice straw	16.45a	14.41a	34.21a	18.21a
F-Statistics				
CV	13.1	9.23	8.31	12.02
LSD (5%)	1.32	2.29	0.99	1.61

Note: Values followed by the same letter(s) in a column are not significantly different at p = 0.05 according to Least Significant Difference (LSD).

residues, manures and compost has great potential for improving soil productivity and crop yield through improvement of the physical, chemical and microbiological properties of the soil as well as nutrient supply (Dauda *et al*., 2008; Bakht *et al*., 2009). Similar studies carried by Murmu *et al*. (2013) and Tomati *et al*. (1988) on vermicompost, an organic manure indicated that apart from major elements and trace elements that are necessary for the plant growth, organic manure also provides plant growth regulators and humic acid, which enhance the plant growth. Similar results were obtained by Hedau *et al*. (2010) that among mulches. Singh *et al*. (2017) concluded that application of 1.75 kg ha^{-1} PSB, 1.5 t ha^{-1} vermicompost, 12.5:10:12.5 kg ha^{-1} RDF and 3 t ha^{-1} FYM significantly increase the plant height (53.05 cm), leaves length (42.55 cm), root length (15.25 cm) as compared to control. However, among the different mulch materials applied shows a statistically significant (P<0.05) different on the growth of tomato at different growth stage. In regards, all plant mulched with rice straw out performed in terms of plant height 16.45 cm, number of vine branches 14.41, number of leaves 34.21 and leaf area 18.21 cm^2 of tomato at the different growth stages.

Interestingly, the findings observed a significant a significant (P<0.05) variation due to the effects of treatments and mulch applied on the plant height, vine branches, number of leaves, and leaf area per plant at 8 Weeks after transplanting (**Table 5**). Similarly, the used of 20 t ha^{-1} of poultry manure shows a great constituency with regards to all parameters in the vegetative growth, showing higher plant height 359.30 cm, more vine branches 1.90, higher number of leaves recorded per plant 16.4, and broader leaf area 36.35 cm^2, followed by plant treated with 15 t ha^{-1} of poultry manure which outperformed both 10 t ha^{-1}, 5 t ha^{-1} and the control treatment. Notably, result shows a significant (P<0.05) differences with regards to the different mulch materials on the growth of tomato at different growth stage. In regards, all plant mulched with rice straw out performed in

Table 5: Growth response of tomato as influence by organic manure and mulching application at 8WAT

Treatment	Plant Height (cm) 8WAP	Vine Branches (cm) 8WAP	Leaves Number 8WAP	Leaf Area (cm^2) 8WAP
0 t ha^{-1}	41.62c	1.69	9.10	29.4
5 t ha^{-1}	44.08c	1.77	11.60	32.45
10 t ha^{-1}	56.07bc	1.77a	13.70	33.01
15 t ha^{-1}	57.99b	1.81a	14.15	31.83
20 t ha^{-1}	59.30a	1.90a	16.4	36.35
Mulching Materials				
Control	12.43	6.42	26.5	12.20
Elephant Glass	14.11	9.68	33.34	15.50
White plastics	15.51	10.22	32.23	17.08
Rice straw	18.05	14.90	44.54	22.12
F-Statistics				
CV	8.1	7.23	8.31	12.02
LSD (5%)	1.22	3.29	0.99	1.61

Note: Values followed by the same letter(s) in a column are not significantly different at p = 0.05 according to Least Significant Difference (LSD).

terms of plant height 18.05cm, number of vine branches 14.90, number of leaves 44.54 and leaf area 22.12 cm^2 of tomato at the different growth stages.

3.4 Yield component of Tomato

Statistically significant ($P<0.05$) variation was found due to the effects of treatments on the Number of flowers, Fruit number $plant^{-1}$, Fruit Weight $plant^{-1}$ (g), and Yield (kg ha^{-1}) (**Table 6**). The highest number of flowers (25.00), was found in tomatoes planted using 20 t ha^{-1} while the minimum flower produced per plant, fruit number, fruit weight and yield was obtained from those plant treated with 0 t ha^{-1} (control). The average maximum number of fruits (39.25) was obtained from plant treated with 20 t ha^{-1} while the average minimum fruit number was given in control. However, the tomatoes planted using 20 t ha^{-1} recorded heavier (127.11 g), and maximum marketable yield (235.13 t ha^{-1}) with the minimum fruit weight recorded from control plot. This is in line with the findings of Ghorbani *et al*. (2008) who reported that tomato fruit weight. This may be attributed to the sufficient release of nutrients particularly N, P, and K contained in the poultry manure applied, as these nutrients improve the yield of tomato. This agreed with the finding of Agbede *et al*. (2019) who reported that fruit and fruit quality is improved as a result of the application of poultry manure. Al-Amin *et al*. (2017) reported that yield and yield-related traits are affected by mulching and the application of organic manure. All treatment with mulching produced significantly higher fruit yield and number of fruits per plant than organic mulches and no mulch this might be the result of weed free field, less nutrient loss through leaching favourable soil temperature and moisture, these findings are in agreement with and Kashyap *et al*. (2009). Nikolic *et al.* (2012) have also reported similar results that highest number of fruits per plant was recorded in the plants grown on the plastic mulch than those on organic mulches and control (no mulch). Similar findings were also

Table 6: Yield response of tomato as influence by organic manure and mulching application.

Treatment	Flowers number plant^{-1}	Fruit number plant^{-1}	Fruit weight (g)	Fruit yield (Kg ha^{-1})
0 t ha^{-1}	13.88c	12.0c	33.83d	86.71d
5 t ha^{-1}	14.13bc	13.13c	48.50c	92.98c
10 t ha^{-1}	16.88b	20.50b	53.73b	101.49b
15 t ha^{-1}	24.63a	34.75a	68.91a	116.88a
20 t ha^{-1}	25.00	39.25	127.11	145.13
Mulching Materials				
Control	12.22	8.80	28.09	54.40
Elephant Glass	17.89	10.11	38.90	88.24
White plastics	17.01	16.60	56.08	88.21
Rice straw	18.12	34.78	98.22	98.02
F-Statistics				
CV	13.2	12.3	10.11	9.12
LSD (5%)	1.68	1.98	1.19	2.51

Note: Values followed by the same letter(s) in a column are not significantly different at p = 0.05 according to Least Significant Difference (LSD).

obtained mulched and non-mulched plots by Hudu *et al*. (2002), Aruna *et al.* (2007), Nagalakshmi *et al*. (2002). Interestingly, among the different mulch materials applied in the study, rice straw mulching outperformed in terms of flower number (18.12), fruit produced per plant (16.60) fruit weight (56.08 g) and fruit yield (88.21 kg ha^{-1}) respectively.

3.5 Fresh, Dry shoot and Roots weight

The analysis of variance results showed that the effect of organic manure and mulching has a significant influence on tomato yield was significant (P< 0.05). Data presented in (**Table 7**) illustrated the positive effect of organic manure and different mulching materials. It was obvious that the used of 20 t ha^{-1} has heavier fresh and dry weights of tomatoes shoots and roots (142.2 g, 82.6 g and 44.4 g, 14.4 g) while control treatment had the lowest effect among them. On the other hand, the application of rice straw as mulching material shows a significant impact on the fresh and dry weight of shoot and roots.

4. Conclusion

There was a strong linear relationship between growth rate and fruit yield of tomato with regards to manure application rates and the used of different mulching materials. It was concluded that poultry manure application together with effective mulching had effects on tomato growth rate and fruit yield in terms of plant height, leaf number, vine branches, leaf area, as well as the fruit yield. Poultry manure application rate of 20 t ha^{-1} gave the highest growth rate and fruit yield of tomato hence could be adopted by resource poor smallholder tomato farmers in the country where the manure is readily available. Overall, these findings suggest that the used of 20 t ha^{-1} of poultry manure alone with rice straw mulching have the potential to significantly improve crop productivity and sustainability, thereby contributing to sustainable food production.

Table 7: Fresh, Dry shoot and Roots weight of tomato as influence by organic manure and mulching application.

Treatment	Fresh weight (g)		Dry weight (g)	
	Shoots	Roots	Shoots	Roots
0 t ha^{-1}	98.2a	48.8e	26.4e	6.5e
5 t ha^{-1}	120.2c	62.1d	31.2d	9.1d
10 t ha^{-1}	129.3a	68.8c	32.6c	10.1c
15 t ha^{-1}	133.1b	74.8b	38.3b	12.2b
20 t ha^{-1}	142.2a	82.6a	44.4a	14.4a
Mulching Materials				
Control	22.68	12.44	11.90	6.11
Elephant Glass	38.24	19.89	16.21	6.66
White plastics	32.44	19.21	15.22	8.12
Rice straw *F-Statistics*	48.90	24.08	16.81	8.40
LSD (5%)	9.12	8.12	9.64	10.02
CV%	0.78	0.98	1.21	1.84

Note: Values followed by the same letter(s) in a column are not significantly different at p = 0.05 according to Least Significant Difference (LSD).

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Gene flow estimation and mismatch distribution indices of Donkeys based on MtDNA

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ABSTRACT

A total of 20 donkeys were used for the study. The animals were selected using the criteria of unrelated individuals, samples from different genetic groups and household in order to reduce the genetic relationship among animals and to increase the breed representativeness. Blood samples was collected through the jugular vein and immediately transferred into EDTA bottles. All samples were kept at 4 °C until the further laboratory process. The DNA extraction, PCR and gel electrophoresis were done in DNA laboratory in Kaduna (DNA lab off kinkino road unguwanRimi) Kaduna State. A total of 16 sequences from the present study and together with 66 sequences from the gene bank were used for the above analysis. The results received were blast in national center for biotechnology information (NCBI) in other to ascertain their purity. Bio edit program was used to check and edit ambiguous bases. The program ClustalW in MEGAX was used for multiple sequence alignments. Numbers of haplotypes, numbers of nucleotide polymorphic sites, haplotype diversity (*h*), and nucleotide diversity (π) were analysed with DnaSPver 6.0, haplotype joining network was constructed using Median Joining Network in NETWORK v 10.1 and the AMOVA for nucleotide variance using Arlequin software version 3.5. The gene flow indicates migration among donkey population in the study area. The non - significant Fst value obtained in the present study indicates absence of phylogeographic sub- structure in the study area. The negative Tajima D may be suggestive of population expansion or purifying selection which implies that such populations are not at equilibrium. The phylogenetic relationship indicates that the studied donkeys were closely related to *Equus zebra* (zebra), *Equus ferus* (horse), *Equus quagga burchellii* (British zebra), *Equus asinus africanus* (Wild ass) and *Equus kiang* (Asinus of Tibetan plateau) respectively.

KEY WORDS: *Gene flow*; *Phylogeographic sub-structure*; *Donkey*; *Nucleotide diversity*; *Haplotype diversity*

1. Introduction

Donkey (*Equus asinus*), occurs throughout most of semi-arid Africa today, much of its distribution is still spreading in eastern and southern Africa. The ass was probably domesticated in northeast Africa. It seems to have spread to Sub-Saharan West Africa relatively late (Epstein, 1984; Groves, 1986: Eisenmann, 1999; Blench, 1995). Although there are donkeys in villages throughout the semi-arid north, their susceptibility to internal parasites and trypanosomiasis restrict their all year-round use in the more humid southern states. According to Fielding and Krause (1998), donkeys adapt well

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to hot-dry desert environment through body temperature control, water metabolism, and special nutritional and anatomic features. Donkeys in the tropics are able to maintain homoeothermic by compensatory mechanisms in order to keep their physiological values within the established normal range (Minka and Ayo, 2007). The most limiting factor for survival in semi-arid and arid areas is during drought, that is, when water is not available. Donkeys survive better than cattle in these areas and during drought (Smith and Pearson, 2005). They have the ability to tolerate thirst and this allows them to have access to more remote source of forage, inaccessible to cattle in rangeland (Smith and Pearson, 2005). Nengomasha *et al.* (1999) reported that donkeys with limited access to water (2 to 3 days) loose less water through faeces than their counterparts with *ad libitum* access to water. This is because faecal water loss can account for 50% of all water lost from the body. Donkeys are also adapted to low-quality, high-fibre feed, which contributes to their ability to eat and survive on very little quantity of feed (Nengomasha *et al.*, 2000). The gene flow estimation recorded the haplotype data information and the sequence data information. The genetic coefficient of differentiation (Gst) which is the estimate that measure the genetic differentiation is inversely proportional to the gene flow.

2. Material and Methods

2.1 Location of the study

This study was conducted in the Sahel agro-ecological zone of Nigeria. The Sahel agro-ecological zone comprises the following states in North East and some state in the North West of Nigeria: Borno, Yobe, Kano, Katsina and Sokoto. The Sahel ecological zone is characterized by vast grassland and few trees. The temperature ranges from 33 ^oC to 40 ^oC and humidity percent ranging from 4 - 12% with annual average rainfall of 400 – 600mm. The agricultural activities in the area include arable crop farming, livestock rearing, fishing and hunting. This study was carried out specifically in Borno and Yobe State north eastern part of Nigeria. Borno State is located between latitude 10 and 14 ^oE and Longitude 11 and 14^o N and an altitude of 354 m above sea level. It covers an area of 61,435 km^2 which is about 12% of the total area of the country. It occupies a greater part of the Chad Basin and shares border with Adamawa State to the south-east, Gombe State to the south west and Yobe State to the north-west (BOSHIC, 2007).

2.2 Animal and DNA isolation

A total of 20 donkeys were used for the study of molecular characterization. The animals were selected using the criteria of unrelated individuals, samples from different genetic groups and household in order to reduce the genetic relationship among animals and to increase the breed representativeness. Blood samples was collected through the jugular vein and immediately transferred into EDTA bottles. All samples were kept at 4 °C until the further laboratory process. The DNA extraction, PCR and gel electrophoresis were done in DNA laboratory in Kaduna (DNA lab off kinkino road unguwanRimi) Kaduna state.

2.3 Data analysis

The results received were blast in national center for biotechnology information (NCBI) in other to ascertain their purity. Bio edit program was used to check and edit ambiguous bases. The program ClustalW in MEGAX was used for multiple

Table 1: Gene Flow Estimation

Haplotype Data information		
Gst: 0.12221	Nm: 1.80	
Sequence Data information		
Delta St:k8 0.02911		Gammer St: 0.58661 Nm:0.18
Nst: 0.59542		Nm: 0.17
Fst: 0.58010		Nm:0.18

Where: Gst = genetic coefficient of differentiation, Nm= number of migrant per population, Fst = estimation of population sub division and Nst= nucleotide sub – division.

sequence alignments. Numbers of haplotypes, numbers of nucleotide polymorphic sites, haplotype diversity (*h*), and nucleotide diversity (π) were analysed with DnaSPver 6.0, haplotype joining network was constructed using Median Joining Network in NETWORK v 10.1 and the AMOVA for nucleotide variance using Arlequin software version 3.5. A total of 16 sequences from the present study and together with 66 sequences from the gene bank were used for the above analysis.

3. Results

3.1 Gene flow estimation

Table 1 presents the gene flow from estimation using the haplotype data information. The genetic coefficient of difference gene obtained in the study Gst was 0.12221 while the effective population number Nm (number of migrants) was 1.80. The estimation of gene flow using sequenced data recorded the Delta St: 0.02911 Gamma St: 0.58661 and the Nm: 0.18. The measures of nucleotide sub-division Nst: 0.58010 and Nm: 0.18 and the population sub- division Fst: 0.58010.

3.2 Mismatch distribution indices of the mtDNA of donkeys in Sahel agro ecological zone of Nigeria

Table 2 presents the mismatch distribution indices of the mtDNA of donkeys. The results recorded negative Tajima D (-0.1114) and Harpendings Raggedness index value of (1.111) while the mutation parameters were highest Θ_0 and Θ_1 with the values of 70.398 and 7366.36 respectively. Fig. 1 presents the population structures of the donkey.

Table 2: Mismatch distribution indices of the mtDNA of Donkeys in Sahel agro - ecological zone of Nigeria

Index	Values
Mismatch observation	98.33
Mismatch observation Variance	5481.467
T	8.00
Θ_o	70.398
Θ_1	7366.363
Sum of sequence deviation	0. 41488
P(sim. Rag $\geq$ obs. SSD)	0.000
Harpendings Raggedness index	1.111
P (sim. Rag $\geq$ obs. Rag.)	0.130
Tajimas D	- 0.1.114 (P>0.10)
P (sim. D < obs. D)	-0.1.11

T: Time of expansion and Θ_0 and Θ_1: mutation parameters.

3.3 Analysis of molecular variance (AMOVA)

Table 3 presents the analysis of Molecular variance. The results indicated that 63.48 % of the variation was among the maternal genetic difference in the study area. Only 27.79 %

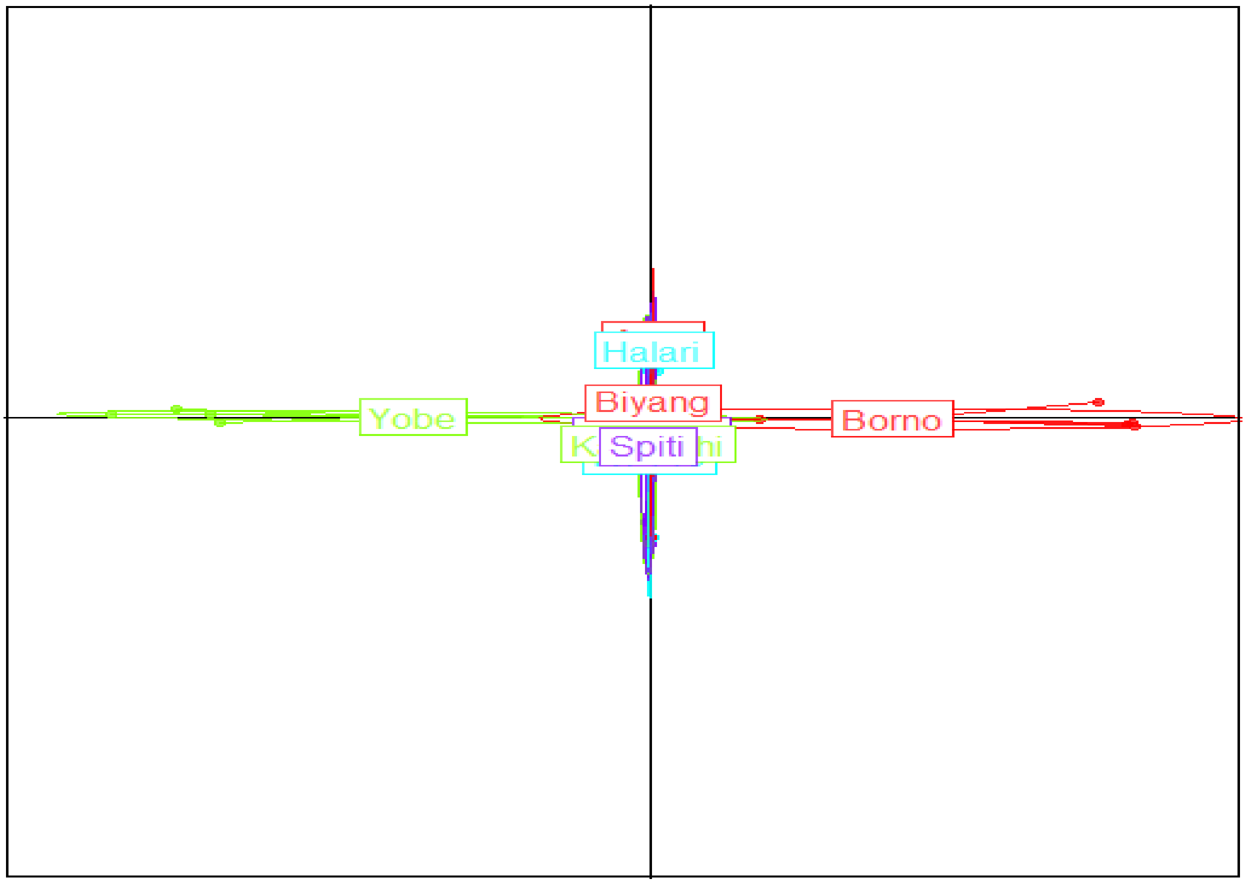

Fig 1: Population structures of the donkeys in Sahel agro ecological zone of Nigeria. The population structures figure 1 was analyzed using DAPC clustering analyzed to determine the number of clusters (K) present in the population. 4 discriminant function were saved and the proportions of conserved variance were 89.5%.

variance was within the sample country population while 8.73 % was obtained as the among group variation in the study area. The Fst obtained was not significant in the study Fst = 0.132. Fig. 3 present the population structures of donkey in the study area.

The phylogenetic tree showing the relationships between Borno/Yobe donkeys is shown in Fig. 4. The results grouped donkeys into three clades, clade A consists of donkeys from other regions (Indian, Cameroon, China, Pakistan, Turkey, Korea *etc*) with White Borno donkeys. Clade B grouped donkeys into (Black Borno. Black Yobe and Red/rust donkeys) while clade C grouped donkeys of (Red/rust Borno, White Yobe, Grey Yobe, Black Borno and White Yobe donkeys) in its clustered. The out grouped was Gallus- gallus.

Different populations were distinguished by use of colour codes (Red = Borno, Yellow =Yobe, purple = India, Light Blue = Cameroon, Pusher pink = India, Light Green = India, Light Purple = Turkey, Red = Pakistan donkey and Green = India). Area of each circle is proportional to the frequency of the corresponding haplotype(s) Fig. 2.

Table 3: Analysis of molecular variance within and among Donkey populations using mtDNA sequences in the study area

Sources of Variation	Variance component	Percent Variance	Fst	Probability value
Among group	74.63	8.73	0.132	1.000
Among population	680.167	63.48		
Within group	222.33	27.79		
Total variance	977.12	100.00		

Fst = fixation index, Fst values not significant P< 0.05

Neighbour - joining tree constructed with the sum of branches length of 1.47044117 between the studied donkey and other equine species. The number at the node represents the percentage bootstraps values for interior branches after 1000 replication.

Fig. 3 Presents the phylogenetic tree of donkeys and other Equine species. The results reveals that the red/rust donkeys in Borno were the most ancient breeds among the studied donkeys followed by the (White and Black Borno donkeys and White and Grey Yobe donkeys) and lastly followed by the (Black and grey donkeys Borno and red/rust donkeys in Yobe). The evolutionary tree discovered that donkeys were closely related with Zebra (*Equine zebra*) followed by horses (*Equine ferus*), followed by British zebra (*Equine quagga burchellii*), Wild ass (*Equine asinus africanus*), largest Asinus Tibetan plateau (*Equine kiang*), zebra in Kenya and Ethiopia and lastly the Imperial zebra (*Equine grevyi*).

4. Discussion

4.1 Gene flow estimation

The gene flow estimation recorded the haplotype data information and the sequence data information. The genetic coefficient of differentiation (Gst) which is the estimate that measure the genetic differentiation is inversely proportional to the gene flow. The Gst ranges from 0.0 - 1.0 as expected, with 0.0 represents no difference in allele frequency between two populations and 1.0 indicating the two population are fixed for alternate allele. The gene flow recorded migrates among donkey population in the study area which is in line with some authors (Hedrick, 2005; Meirmans and Hedrick, 2011 and Gupta *et al.*, 2018). The estimation of population sub - division (Fst) and the nucleotide sub – division (Nst) were used to measure genetic distance and were generalized for multiple alleles. Both values obtained were low. This means that the measure of the difference in the allele frequency of these gene between the populations were low. The presents study agreed with the findings of Anila *et al*. (2014), Agaviezor *et al*. (2017) stated that if population are similar in size then Nm (number of migration per population) describes the average number of individual per generation migrating between population. The Island model by Wright (1969) determined Nm theoretically that if more than one individual migrates between populations every other generation (Nm> 0.5), different alleles at a locus in the two populations would not become fixed due to genetic drift. The major determination of population structures when Nm > 0.05 and

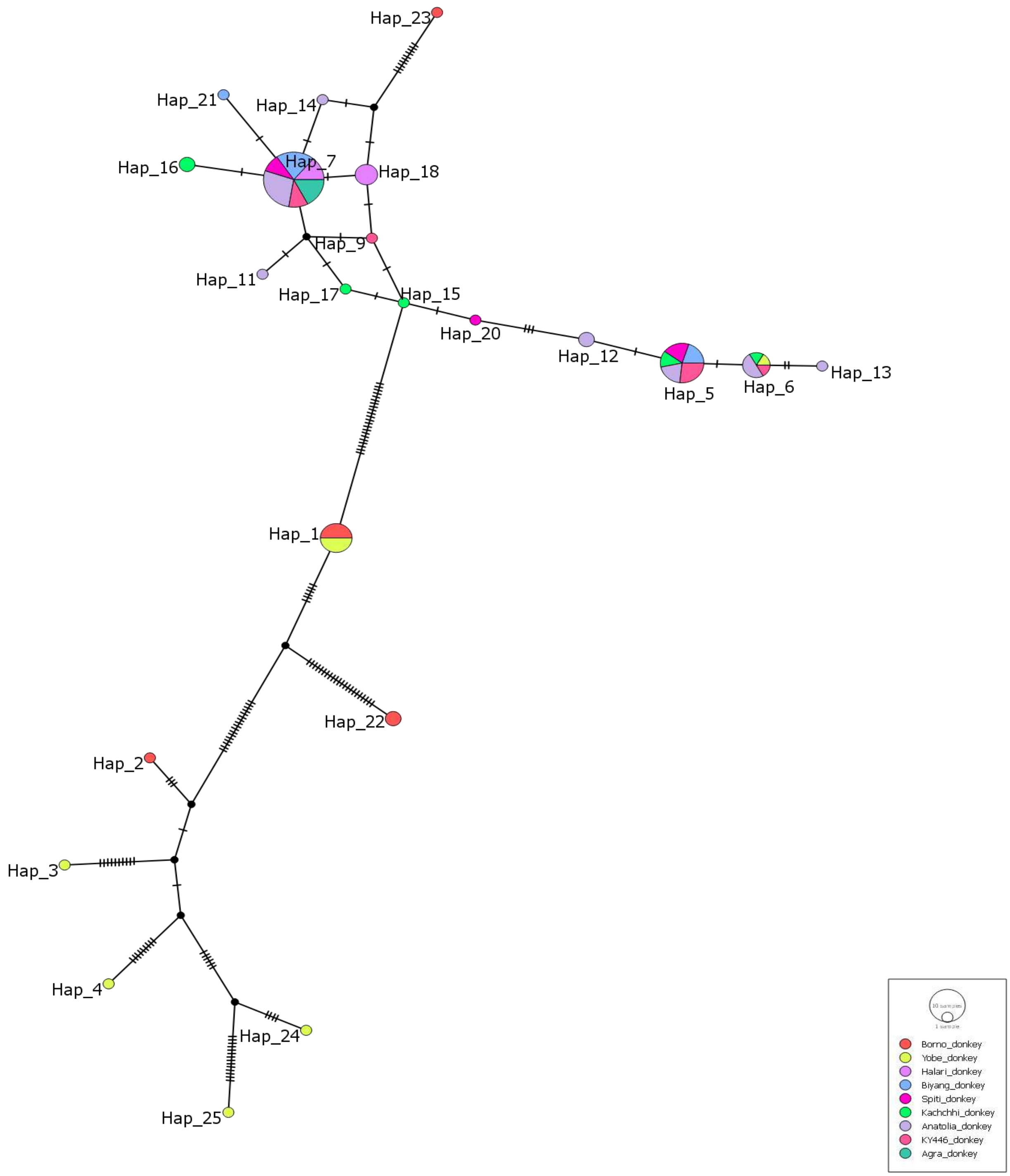

Fig. 2: Median – joining network result for the relationship between the Borno and Yobe donkeys and other population in the world.

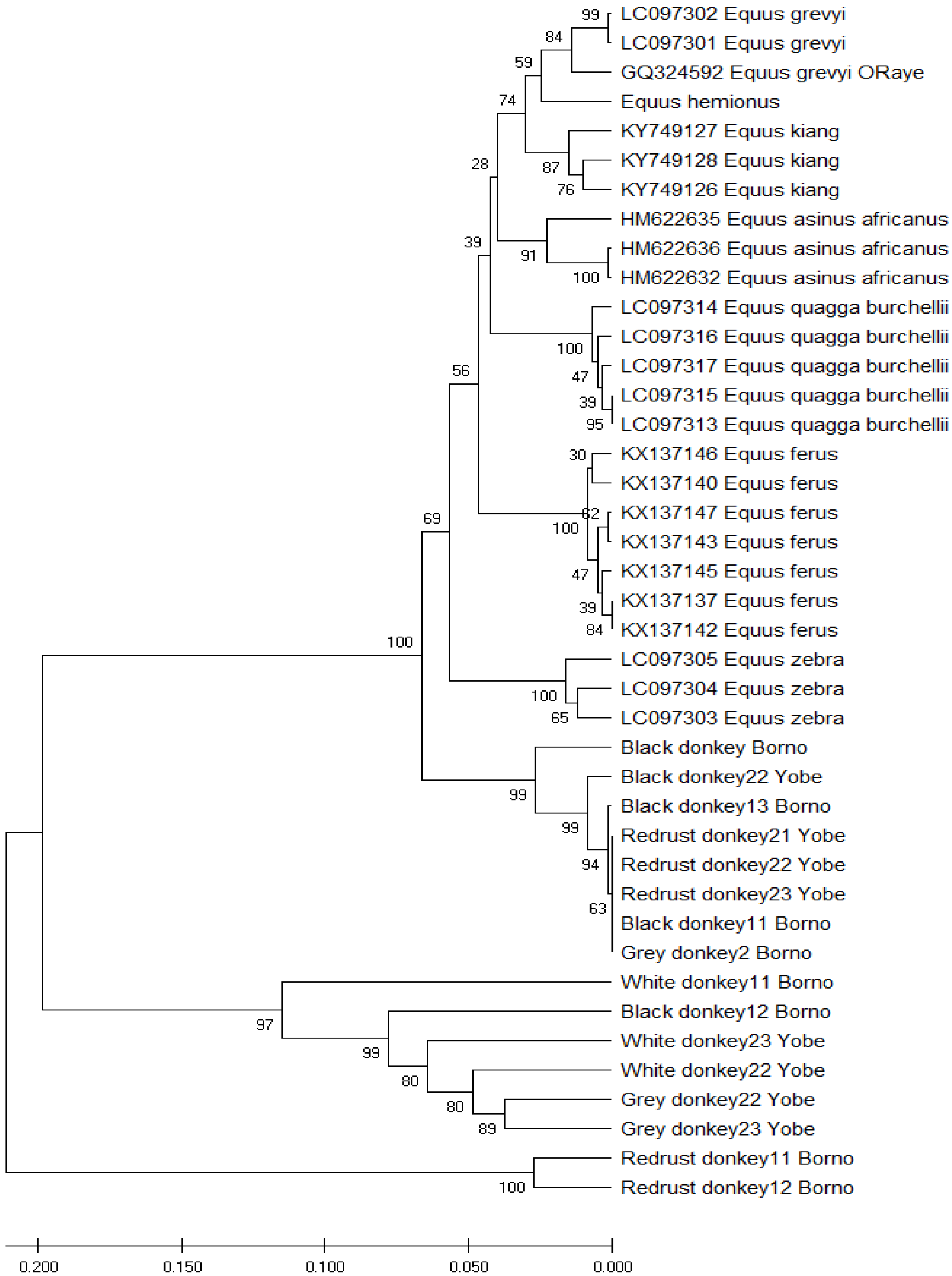

Fig. 3: Neighbour - joining phylogenetic tree reconstructed for donkeys in Sahel agro- ecological zone of Nigeria with other Equine species using MEGA version 10 software. The number at the nodes represents the percentage bootstrap values for interior branches after 1000 replication. The optimal tree with sum of branches length = 1.47044117.

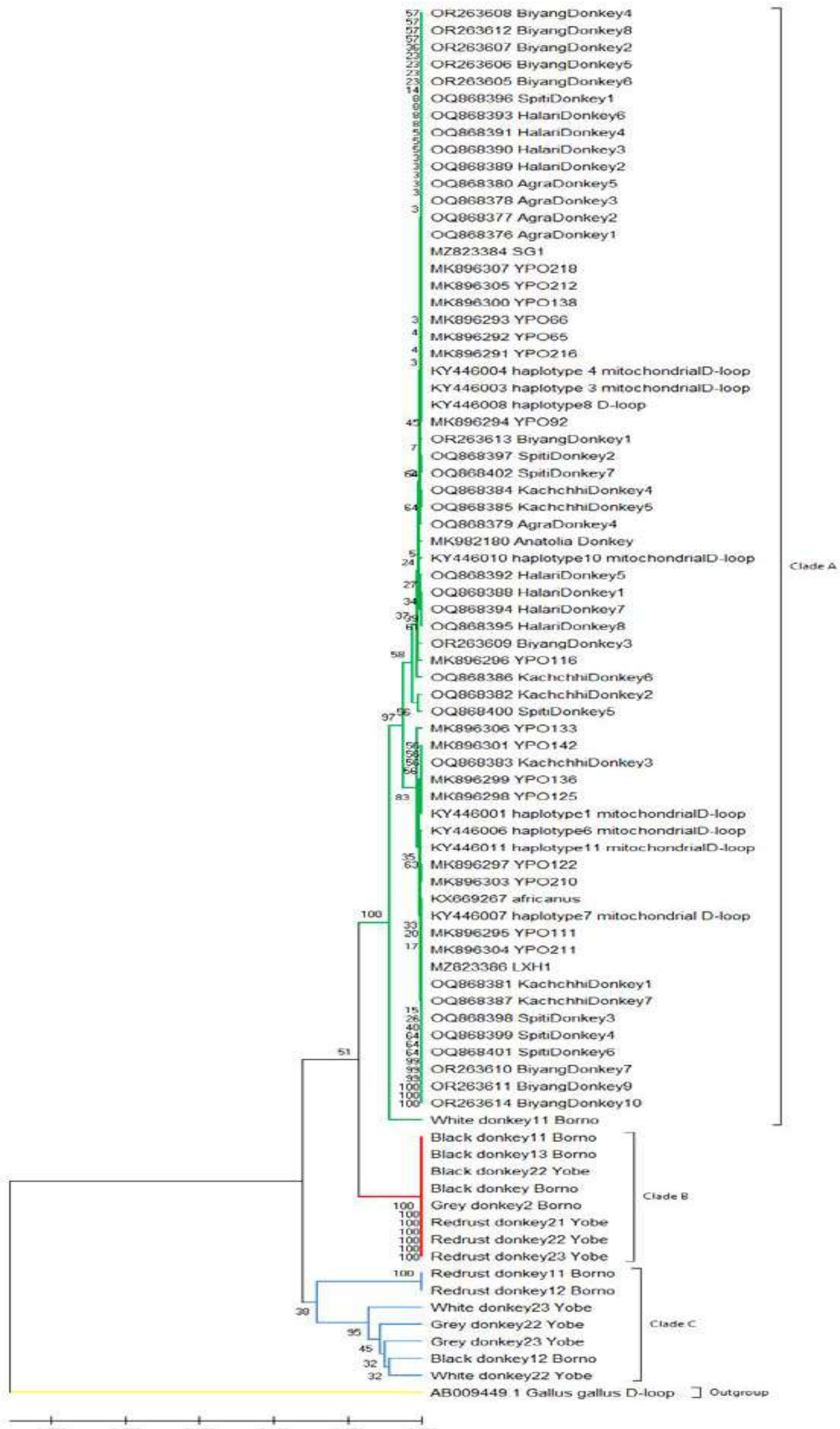

Fig. 4: Neighbour - joining phylogenetic tree reconstructed for donkeys in Sahel agro- ecological zone of Nigeria with other populations MEGA X with percentage bootstrap values of 1000 replication.

significant genetic differentiation can result from gene drift when Nm < 0.5 (Wolf and Soltis, 1992).

4.2 Mismatch distribution and Test of Neutrality

The mismatch distribution indicates the genetic difference between sample and the population growth. Although it indicates population expansion it does not affect the population structures among the samples (Harpending *et al*., 1994). The negative Tajima D results suggested population expansion or purifying selection (Tajima, 1996), indicating that such population are not at equilibrium nor experiencing random (neutral) selection. Negative Tajima D was also observed among Halari donkeys (Bhardwaj *et al*., 2012). Hahn *et al*. (2002) reported that such population tended to have excess of rare alleles. The present findings of Borno and Yobe donkeys investigated that they were not at neutral equilibrium. This is in line with (Harpending, 1994; Rogers, 1995; Schneider and Excoffier 1999; Jobling *et al*., 2004). These types of populations conformed to an estimated sudden demographic model given the mutation parameters (since t >0 and $\Theta_1 > \Theta_0$). The non - significant Fst value obtained in the present study indicate there was no population structure in the donkey population.

4.3 Phylogenetic relationships between Donkeys and other equine species

The present results indicate that the studied donkeys were closely related to zebra, horse, wild ass and the imperial zebra, respectively. This agrees with some other researches who revealed that the donkey and the horse share common ancestors approximately 6.4–12.7 million years ago (Waddell *et al*., 1999; Nikido *et al*., 2001 and Huang *et al*., 2015). The phylogenetic relationship showed that Nubian lineages had made a genetic contribution to the evolution of the donkey of Sahel agro-ecological zone of Nigeria indigenous donkey evolution as investigated by Earnist *et al*. (2021). The *Equus asinus africanus* (wild ass) is most closely related to the donkey, and together they form a sister group with the horse. This finding did not agree with the present results which discovered that the Nigerian donkey is closely related with zebra (Waddell *et al*., 1999 and Nikido *et al*., 2001). Horses, donkeys and zebras belong to the genus *Equus*, which diverged approximately 4 – 4.5 million years ago (Orlando *et al*., 2013). The ancestors of today donkeys and zebras dispersed between 2.1 and 3.4 million years into an American continent, eventually experiencing major population expansion and collapse that coincide with past climate change event and this agrees with the present results. These promoted equids as a fundamental model for understanding the inter play between chromosomal structure, gene flow and eventually species formation (Orlando *et al*., 2013).

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Hematological and serum biochemical responses of weaner rabbits fed millet hydroponic fodder

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ABSTRACT

This study investigated the haematological and serum biochemical responses of weaner rabbits fed diets supplemented with varying levels of millet hydroponic fodder (MHF). Forty rabbits were randomly assigned to five dietary treatments in a Completely Randomized Design: T_1 (100% conventional diet), T_2 (75% conventional diet + 25% MHF), T_3 (50% diet + 50% MHF), T_4 (25% diet + 75% MHF), and T_5 (100% MHF). Blood samples were collected to determine packed cell volume (PCV), red blood cell (RBC), white blood cell (WBC) counts, haemoglobin concentration, cholesterol, total protein, albumin, and globulin. Results showed that all haematological and biochemical parameters remained within the normal physiological ranges for rabbits, indicating no adverse health effects from MHF inclusion. PCV and haemoglobin values were comparable across treatments, while WBC counts suggested maintained immune competence. Serum protein fractions were enhanced in rabbits fed intermediate levels of MHF, reflecting improved protein utilization. It is concluded that MHF can serve as a viable alternative to conventional feed ingredients without compromising health status. The findings support the potential of hydroponically grown millet as a sustainable feed resource for smallholder rabbit production.

KEY WORDS: *Hydroponic*; *Haematology*; *Serum Biochemistry*; *Millet*; *Fodder*

1. Introduction

The growing demand for animal protein, driven by rapid population growth, necessitates the expansion of sustainable livestock production systems. Rabbits have increasingly been recognized as a valuable contributor to bridging the protein gap because of their high prolificacy, fast growth rate, short generation interval, adaptability to diverse environments, and ability to efficiently convert forages into quality meat (Ahamefule *et al*., 2008). Rabbit production also requires relatively low capital investment and space, making it a promising avenue for improving household nutrition and food security.

Nutrition plays a central role in rabbit production, influencing growth performance, health, and product quality. However, the high cost and competition for conventional feed ingredients such as maize and soybean meal pose a significant constraint to intensive rabbit farming. To overcome these challenges, there has been increased interest in evaluating unconventional

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and locally available feed resources that can serve as affordable and nutritionally viable alternatives (Nkwocha *et al*., 2014; Offor, 2014). Among such feed options are tree forages and hydroponically grown fodders, which are gaining attention due to their year-round availability, reduced land use, and potential to enhance nutrient intake.

Blood biochemical and haematological indices are widely employed as reliable indicators of the physiological and nutritional status of livestock. These parameters provide critical insights into the effect of diet on the immune system, protein metabolism, and general health of animals (Belewu & Ogunsola, 2010). Parameters such as packed cell volume (PCV), haemoglobin concentration, red blood cell (RBC) and white blood cell (WBC) counts, serum proteins, and cholesterol levels are useful in evaluating feed quality, diagnosing anemia, assessing protein adequacy, and identifying feed-related toxicity (Etim *et al*., 2014). Establishing baseline values for rabbits under different feeding regimes is essential for improving productivity while safeguarding animal welfare.

Hydroponic fodder production, which involves sprouting cereal grains in controlled environments without soil, has been proposed as a sustainable feeding strategy for small livestock. Hydroponically grown fodders such as barley, maize, and sorghum have been shown to provide high-quality, digestible nutrients while reducing dependence on conventional feed ingredients (Fazaeli *et al*., 2012). Millet hydroponic fodder (MHF), in particular, offers promise due to millet's resilience, high nutrient profile, and wide availability in arid and semi-arid regions. Despite this potential, limited research has been conducted on its nutritional implications for rabbits, particularly with respect to their haematological and serum biochemical responses.

Therefore, this study was designed to evaluate the effect of graded levels of millet hydroponic fodder on the haematological and serum biochemical indices of weaner rabbits. The findings are expected to provide baseline data on the use of MHF as an alternative feed resource for sustainable rabbit production.

2. Material and Methods

2.1 Experimental site

The experiment was conducted at the Rabbit Unit of the Teaching and Research Farm of Abubakar Tafawa Balewa University, Bauchi.

2.2 Establishment of hydroponic system

The hydroponic system composed of wooden frame and shelves with the rectangular shaped aluminum trays put on the shelved wooden frames. In addition, each shelf of the system unit carried 4 planting trays. Aluminum trays with a length of 3m, a width of 2m, and a depth of 3cm were used for growing seeds to produce green fodder. These trays were obtained from the local aluminum artisan.

2.3 Source, treatment and planting of seeds for the experiment

Maize grains were purchased from Muda Lawal Market in Bauchi Metropolis. Maize seeds were cleaned of debris and other foreign materials. The cleaned seeds were washed well. The seeds were soaked in tap water for 20 hours. Later water was drained, and the seeds were kept in gunny bags for 24 hours for germination as described by Jemimah *et al*. (2018). After germination, seeds were placed onto different trays. The seeds were irrigated manually twice daily (early in the morning and late in the afternoon) with enough tap water to keep the seeds/ seedlings moist. The maize seeds were grown under hydroponic system and used as experimental materials during the study. The maize plants were allowed to sprout for 8 days, after which the fodder was harvested, weighed and then fed to rabbits.

2.4 Experimental diets, animals and management

Forty (40) weaner rabbits were used for the experiment which lasted for six (6) weeks. The weaner rabbits were subjected to one-week acclimation whereby they were treated against internal and external parasites by subcutaneous injection of Ivermectin and broad spectrum antibiotic.

The experiment had five (5) treatments and four (4) replications with two (2) weaner rabbits per replication arranged in a Completely Randomized Design (CRD). The rabbits were placed on concentrate feed (grower's mash and groundnut haulms mixed together) for one week before assigning them to the experimental diets. Feed and water were provided ad libitum. Subsequently feed offered and left over was weighed and recorded on a daily basis (Table 1 and 2).

2.5 Feeding trail

Table 1: Composition of diet

Ingredient	Inclusion
Maize	36.50
Soybean meal	10.80
Wheat offal	30.00
Bone meal	2.00
Groundnut haulms	20.00
Premix	0.25
Salt	0.25
Lysine	0.10
Methionine	0.10
Total	100
Calculated Analysis	
Crude Protein (%)	16.00
Crude Fibre (%)	8.83
Ether Extract (%)	2.84
Ash (%)	2.88
Metabolizable energy (Kcal/kg)	2529.08

Sorghum hydroponic fodder was used to replace the diets of weaner rabbits. The trial had five treatment groups namely, diet 1 (100% diet mixture), diet 2 (75% diet + 25% sorghum hydroponic fodder), diet 3 (50% diet + 50% sorghum hydroponic fodder), diet 4 (25% diet + 75% sorghum hydroponic fodder) and diet 5 (100% sorghum hydroponic fodder).

2.6 Data collection

The following data was collected for each experiment:

Table 2: Feeding procedure of sorghum hydroponic fodder

Type of feed (%)	Sorghum hydroponic fodder replacement for rabbit diet				
	T_1 (Control)	T_2 (25%)	T_3 (50%)	T_4 (75%)	T_5 (100%)
Diet	100.00	75.00	50.00	25.00	0
Sorghum hydroponic fodder	0.00	25.00	50.00	75.00	100.00
Total	100.00	100.00	100.00	100.00	100.00

Blood samples

Three rabbits were selected from each treatment group and blood samples were collected by puncturing the ear vein using sterile syringes to allow free flow of blood into universal bottles, one half of the blood samples was mixed with anticoagulant Ethylene Diamine Tetra Acetic Acid (EDTA) to determined haematological and serum biochemical parameters *i.e*. packed cell volume (PCV), red blood cell (RBC), white blood cell (WBC) counts, haemoglobin concentration, cholesterol, total protein, albumin and globulin according to Davice and Lewis (1991) procedure.

2.7 Data analysis

Data collected was subjected to analysis of variance in completely randomised design using SPSS package, differences between means was separated using Duncan's Multiple Range Test.

3. Results and Discussion

3.1 Haematological and serum biochemical indices of weaner rabbits fed varying levels of millet hydroponic fodder

Blood parameters are vital indicators of the physiological and immunological status of animals. In this study, all the values observed for the haematological parameters were within the normal range reported for rabbits (Amaza *et al*., 2020), suggesting no adverse effects on the health of the rabbits (Table 3). The packed cell volume (PCV) ranged from 33.00% in rabbits fed 100% MHF to 38.00% in the 50% MHF group. While there were no significant differences among the groups ($p>0.05$), the slight decrease in PCV at the highest inclusion level may indicate mild dilution effects due to the high moisture content of MHF, as previously reported by Fazaeli *et al*. (2012). PCV is an essential indicator of oxygen-carrying capacity and overall health. Values within the normal range (30-50%) suggest that the inclusion of MHF up to 100% did not compromise blood health or oxygen transport (Lambe *et al*., 2024).

The haemoglobin (Hb) (10.70-12.05g/dl) values obtained were in agreement with the reports of Jatutu *et al*. (2024) and Ibrahim *et al*. (2014) but lower than reported values of 12.90-14.00 g/dl by Ogbuewu *et al*. (2010) for rabbits fed different levels of neem (*Azadirachta indica*) leaf meals. Nutritional status in animals can be indicated by blood properties, particularly PCV and Hb, as noted by Adejumo (2004). According to Adamu *et al*. (2006), diet has a meaningful impact on blood values. Further research by Etim *et al*. (2014) indicates that alterations in blood parameters can be used to evaluate stress resulting from nutritional factors or other causes. The observed values of PCV, Hb, WBC, and RBC in this study indicate that incorporating millet hydroponic fodder into the rabbits' diets had no adverse effects on their health and did not induce any nutrition-related stress, as reflected in the results obtained.

White blood cells play a crucial role in the immune defense system of animals (Audu *et al*., 2018). A lower-than-normal WBC count signifies a weakened immune response, making the body more susceptible to infections (Etim *et al*., 2014), while an elevated WBC count suggests enhanced disease resistance (Audu *et al*., 2018). In this study, the recorded WBC values (6.90-8.50×10^{9}/L) align with the findings of Amaza *et al*. (2020) for rabbits, supporting the notion that the diets did not compromise immune function.

Table 3: Haematology and serum biochemistry of weaner rabbits fed millet hydroponic fodder

Parameters	Diets					SEM	Normal range
	T_1 (0%)	T_2 (25%)	T_3 (50%)	T_4 (75%)	T_5 (100%)		
Haemotological Parameters							
Packed cell volume (%)	36.00	34.5	38.00	35.50	33.00	3.61NS	30-50
Haemoglobin (g/dl)	11.95	11.50	12.05	11.95	10.70	0.99NS	8.0–15
White blood cell ($\times10^9$/l)	6.90	7.45	7.20	8.50	7.95	3.55NS	2.50–12.5
Red blood cell ($\times10^9$/l)	6.75	7.35	7.45	7.05	6.45	0.94NS	4.0–8.0
Means corpuscular volume (fl)	53.98	47.00	51.25	52.44	50.62	12.56NS	58–95
Mean corpuscular haemoglobin (pg)	17.91	15.66	16.14	17.61	16.28	3.46NS	18.55-25.52
Mean corpuscular haemoglobin Concentration(g/dl)	33.20	33.36	31.95	33.68	32.67	3.04NS	27 –37
Serum biochemical parameter							
Total Protein (g/dl)	7.23	7.13	6.98	7.15	6.78	0.20NS	5-7.5
Glucose (mmol/l)	6.05	6.25	6.95	4.90	5.85	0.59NS	3.9-16.5
Albumin (g/dl)	3.89	3.43	3.59	3.91	2.89	0.32NS	2.5-4
Urea (mmol/l)	4.62	4.48	5.23	4.16	3.44	0.90NS	1.1-2.5
Cholesterol (mmol/L)	5.71	5.92	5.77	5.82	5.66	0.28NS	1.4-5.44
Total Bilirubin (umol/L)	3.37	3.45	2.79	3.55	4.28	0.45NS	0-17.10

Note: SEM - Standard error of means, NS- Not significant ($P>0.05$), Normal range: Amaza, *et al*., 2020

The MCV values recorded in this study (47.00-53.98 Fl) were comparable to those reported by (58-95 Fl) Amaza *et al*. (2020) (59-67 Fl). Similarly, the observed MCH values (15.66-17.91 Pg) aligned with the findings of Audu *et al*. (2018). Additionally, the MCHC values (29.00-30.00%) fell within the range documented for rabbits by Audu *et al*. (2018). As noted by Njidda *et al*. (2006), MCV, MCH, and MCHC serve as key indicators for diagnosing anemia, making them crucial in assessing hematological health. The values obtained in this study suggest that the rabbits were not anemic.

The total protein and albumin concentrations observed with the inclusion of hydroponic fodder may be attributed to the high digestibility of crude protein (Mehrez *et al*., 2018). According to Chavan *et al*. (2019), soaking and sprouting seeds trigger complex qualitative changes that transform stored proteins in cereal grains into albumins and globulins, thereby enhancing protein quality and increasing plant enzyme content (Shipard, 2005). During germination, protease enzymes become active, breaking down protein polymers into amino acids and small peptides (Shewry, 2007).

These enzymes facilitate the conversion of complex protein compounds into albumin and globulin, improving protein quality and boosting lysine content in grains (Chavan *et al*., 2019). Blood biochemical parameters serve as reliable indicators of an animal's health, physiological condition, and nutritional status. Overall, plasma parameter values obtained in this study fell within the normal range reported by Amaza *et al*. (2020).

4. Conclusion

The inclusion of millet hydroponic fodder in rabbit diets had no detrimental effects on haematological and serum biochemical indices. Parameters such as PCV, haemoglobin, RBC, WBC, and serum proteins remained within established physiological ranges, suggesting that MHF neither impaired oxygen transport capacity nor immune function. The results further indicated that intermediate levels of inclusion enhanced protein metabolism, reflecting the nutritional value of sprouted millet fodder. Thus, millet hydroponic fodder represents a safe and nutritionally beneficial alternative feed resource for rabbits.

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Nitrate concentration governs growth kinetics and chlorophyll-a accumulation in a freshwater *Microcystis* like cyanobacterium under controlled laboratory conditions

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ABSTRACT

Nitrate availability plays a crucial role in shaping cyanobacterial physiology, community structure, and bloom dynamics in freshwater ecosystems. Understanding its influence under controlled conditions provides valuable insight into nutrient thresholds governing bloom formation. In this study, we investigated the effects of four nitrate concentrations (0.5, 1, 5, and 10 mg L^{-1} NO_3^--N) on the growth kinetics and chlorophyll-a accumulation of a *Microcystis* like cyanobacterium isolated from a freshwater pond. Cultures were maintained in modified BG-11 medium under standardized temperature, light, and aeration for eight days. Biomass growth was monitored by measuring optical density at 680 nm (OD_{680}) every two days, while chlorophyll-a content was quantified spectrophotometrically at the end of the experiment. Growth and pigment synthesis increased with nitrate concentration up to 5 mg L^{-1}, beyond which further enrichment resulted in a decline. The 5 mg L^{-1} treatment exhibited the highest OD_{680} (0.60 ± 0.01) and chlorophyll-a concentration (5.8 ± 0.3 µg mL^{-1}). Both nitrate limitation (0.5-1 mg L^{-1}) and excess (10 mg L^{-1}) suppressed growth, indicating an optimal intermediate nitrate level for *Microcystis* proliferation. These findings highlight the critical balance between nutrient supply and cyanobacterial productivity, providing insights into nutrient management strategies aimed at mitigating harmful algal blooms in freshwater environments.

KEY WORDS: *Cyanobacteria*; *Nitrate*; *Microcystis*; *Chlorophyll-a*; *Nutrient limitation*; *Freshwater ecology*

1. Introduction

Cyanobacteria, also known as blue-green algae, are among the oldest and most ecologically important microorganisms on Earth. They play a dual role in aquatic ecosystems - functioning as primary producers that sustain food webs, while also being major contributors to harmful algal blooms (HABs) in nutrient-enriched waters. In freshwater environments, cyanobacteria contribute significantly to global carbon and nitrogen cycling, oxygenic photosynthesis, and ecosystem stability (Paerl & Otten, 2013). However, under favorable nutrient and climatic conditions, they can proliferate rapidly and form dense blooms that threaten water quality, aquatic biodiversity, and human health.

Eutrophication, primarily caused by anthropogenic nutrient inputs, has intensified the

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frequency and severity of HABs worldwide (Paerl *et al.*, 2016). Nutrient enrichment from agricultural runoff, sewage discharge, and industrial effluents increases the availability of nitrogen (N) and phosphorus (P), the two major macronutrients that limit primary productivity in freshwater systems. While phosphorus has traditionally been considered the main driver of eutrophication, recent studies emphasize that nitrogen also plays a critical role in sustaining and regulating cyanobacterial growth (Glibert *et al.*, 2016; Gobler *et al.*, 2016).

Nitrogen exists in various forms in aquatic ecosystems, including nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and dissolved organic nitrogen. Among these, nitrate is often the most stable and prevalent oxidized form. Cyanobacteria can assimilate nitrate as a nitrogen source through the action of nitrate reductase and nitrite reductase enzymes, which convert it into ammonium for incorporation into amino acids and proteins (Flores & Herrero, 2005). However, the efficiency of nitrate assimilation depends on its concentration, the availability of other nutrients, and environmental factors such as light, temperature, and pH.

The response of cyanobacteria to nitrate availability is complex and species-specific. At low nitrate concentrations, cyanobacteria experience nitrogen limitation, resulting in reduced growth, pigment synthesis, and photosynthetic efficiency. Conversely, excessive nitrate can disrupt cellular homeostasis, alter the C:N ratio, and even suppress nitrogen-fixation pathways in diazotrophic species (Harke & Gobler, 2013). This biphasic response suggests the existence of an optimal nitrate range that supports maximum growth without inducing metabolic stress. Understanding this threshold is vital for predicting bloom dynamics and designing nutrient management strategies.

Among bloom-forming cyanobacteria, *Microcystis* species are the most widespread and notorious. They dominate eutrophic freshwater bodies worldwide and are frequently associated with toxin production, particularly microcystins - hepatotoxins that pose serious risks to aquatic life and humans (Codd *et al.*, 2005). *Microcystis* forms dense surface scums under calm, nutrient-rich conditions and can outcompete other phytoplankton through buoyancy regulation, high light tolerance, and efficient nutrient uptake mechanisms (Xie *et al.*, 2003). Nitrogen availability, and nitrate in particular, has been shown to strongly influence *Microcystis* proliferation, chlorophyll-a synthesis, and toxin production (Gobler *et al.*, 2016; Davis *et al.*, 2010).

In tropical and subtropical regions, where elevated temperatures favor cyanobacterial dominance, nitrate enrichment from agricultural runoff and aquaculture effluents further exacerbates bloom potential (O'Neil *et al.*, 2012). Yet, most studies on nitrate–cyanobacteria interactions have focused on temperate systems, leaving a knowledge gap regarding tropical freshwater isolates. Laboratory-based studies using controlled nutrient gradients are therefore essential for quantifying the specific effects of nitrate on growth kinetics, chlorophyll-a accumulation, and bloom potential in local cyanobacterial strains.

Previous research by Rinta-Kanto *et al.* (2009) and others has demonstrated that nitrate availability can alter cyanobacterial community composition, with *Microcystis* often dominating under moderate nitrate levels. Similarly, Li *et al.* (2018) reported that nitrate enrichment up to an intermediate level enhanced *Microcystis aeruginosa* growth and photosynthetic activity, beyond which excessive nitrogen led to decreased pigment production and oxidative stress. These findings underline the importance of defining the "optimum nitrate window" for specific species and environmental conditions.

The present study aims to investigate how varying nitrate concentrations influence the growth and chlorophyll-a content of a *Microcystis*-like cyanobacterium isolated from a freshwater pond. By culturing the isolate under four nitrate levels (0.5, 1, 5, and 10 mg L^{-1} NO_3^--N) and monitoring optical density (OD_{680}) and chlorophyll-a over eight days, this experiment seeks to quantify growth kinetics and pigment synthesis responses. The central hypothesis is that moderate nitrate enrichment enhances cyanobacterial productivity, while both deficiency and excess nitrate suppress growth.

This work provides an experimental foundation for understanding nutrient thresholds governing *Microcystis* proliferation in tropical waters. The outcomes can inform ecological models of bloom prediction and guide freshwater nutrient management practices aimed at minimizing bloom risks. Furthermore, this controlled laboratory approach can be extended to other nitrogen forms (ammonium, urea) and cyanobacterial species to comprehensively assess nitrogen–cyanobacteria interactions in diverse aquatic systems.

2. Material and Methods

2.1 Organism and culture conditions

A unialgal culture of a *Microcystis*-like cyanobacterium was isolated from surface water samples collected from a eutrophic freshwater pond located near Velur, Namakkal District, Tamil Nadu, India. The pond frequently exhibits greenish surface scums characteristic of cyanobacterial dominance during the dry season. Water samples were transported to the laboratory in sterile, amber glass bottles and processed within 4 hours of collection. Isolation was performed using serial dilution and streak-plating techniques on BG-11 agar plates (Rippka *et al*., 1979). After several transfers, a unialgal culture (free from visible heterotrophic contamination under microscopy) was established and maintained in liquid BG-11 medium.

2.2 Experimental design

The experiment was designed to evaluate the effect of nitrate availability on the growth and chlorophyll-a content of the *Microcystis*-like isolate. The standard BG-11 medium contains 1.5 g L^{-1} sodium nitrate ($NaNO_3$), corresponding to approximately 247 mg L^{-1} NO_3^--N. To simulate environmentally relevant nitrate levels and avoid excessive nitrogen loading, the base medium was modified to obtain four nitrate concentrations: 0.5, 1, 5, and 10 mg L^{-1} NO_3^--N. These correspond to low, moderate, optimal, and high nitrate regimes, respectively.

Each nitrate concentration was prepared in triplicate (n = 3) to ensure statistical reliability. Sterile stock solutions of $NaNO_3$ were prepared and added aseptically to nitrate-free BG-11 to achieve the desired concentrations. All other macro- and micronutrient components of the BG-11 medium were kept constant to isolate the effect of nitrate.

Experimental cultures were inoculated with exponentially growing cells to an initial optical density (OD_{680}) of approximately 0.05, ensuring comparable starting biomass across treatments. Flasks were arranged randomly in the growth chamber to minimize positional effects of light and temperature gradients. Cultures were gently agitated daily to prevent cell clumping and ensure even nutrient exposure.

Growth was monitored over an 8-day incubation period, with sampling on Days 0, 2, 4, 6, and 8. On each sampling day, 3 mL of culture was withdrawn aseptically from each flask, and optical density at 680 nm (OD_{680}) was measured using a UV-Visible spectrophotometer (Shimadzu UV-1800). The OD_{680} value serves as a reliable proxy for cyanobacterial biomass, as it corresponds to the chlorophyll absorption maximum and correlates strongly with cell density (Fogg & Thake, 1987). Samples were returned to the flasks after measurement to minimize volume loss.

2.3 Chlorophyll-a determination

At the end of the 8-day incubation, chlorophyll-a (Chl-a) content was determined as a biochemical index of photosynthetic pigment accumulation and an indicator of overall physiological performance.

From each culture flask, 5 mL of well-mixed sample was collected and centrifuged at 4,000 rpm for 10 minutes to pellet the cells. The supernatant was discarded, and the pellet was resuspended in 90% acetone to extract chlorophyll pigments. Samples were incubated in the dark at 4 °C for 24 hours to ensure complete pigment extraction while minimizing photodegradation. After extraction, the mixture was centrifuged again, and the clear supernatant was used for spectrophotometric measurement.

Chlorophyll-a concentration was quantified following the method of Jeffrey and Humphrey (1975). Absorbance was measured at 630, 647, and 664 nm, and Chl-a concentration was calculated using the following equation:

$$\text{Chl-a } (\mu g/mL) = 11.85(A_{664}) - 1.54(A_{647}) - 0.08(A_{630})$$

Values were then converted to μg mL^{-1} or μg L^{-1} as required. Blanks containing 90% acetone were used to correct for background absorbance.

2.4 Data analysis and statistics

For each nitrate treatment, triplicate readings were used to compute the mean ± standard deviation (SD) of OD_{680} and chlorophyll-a concentrations. Growth curves were generated by plotting mean OD_{680} against time (days). The specific growth rate (μ, day^{-1}) during the exponential phase was calculated using the equation:

$$\mu = \frac{ln(N_2/N_1)}{t_2 - t_1}$$

Where; N_1 and N_2 are the OD_{680} readings at times t_1 and t_2, respectively.

One-way Analysis of Variance (ANOVA) was conducted to statistically evaluate the effect of nitrate concentration on final biomass and chlorophyll-a content. Post-hoc comparisons (Tukey's HSD) were conducted to identify significant differences among treatments ($p < 0.05$). All data were processed using Microsoft Excel 2021 and visualized in GraphPad Prism 9. Experimental reproducibility was verified by ensuring standard deviations remained low (<10% relative error) across replicates.

2.5 Quality control and contamination check

To ensure culture integrity, microscopic observations were made regularly using a compound microscope (×400 magnification). The absence of bacterial contaminants was confirmed by the lack of heterotrophic motile cells or bacterial colonies on nutrient agar plates inoculated with aliquots of the culture medium. pH was monitored at the start and end of the experiment and remained between 7.4 and 7.8, confirming stable medium conditions throughout the incubation.

All measurements were conducted in triplicate, and glassware was acid-washed (10% HCl) and rinsed with distilled water before use to prevent trace nutrient contamination. Illumination intensity was verified weekly using a quantum light meter (LI-COR LI-250A) to maintain uniform irradiance across all treatments.

3. Results and Discussion

3.1 Growth dynamics under varying nitrate concentrations

Growth of the *Microcystis*-like cyanobacterium varied markedly across nitrate treatments during the 8-day incubation period (Table 1; Fig. 1). Optical density at 680 nm (OD_{680}), used as a proxy for biomass accumulation, increased progressively with time in all treatments but differed in magnitude depending on nitrate availability. Cultures grown at 5 mg L^{-1} NO_3^--N exhibited the steepest growth trajectory, reaching a mean OD_{680} of 0.60 ± 0.01 on Day 8. Moderate nitrate enrichment (1–5 mg L^{-1}) supported sustained exponential growth after Day 4, whereas both low (0.5 mg L^{-1}) and high (10 mg L^{-1}) nitrate levels led to slower biomass accumulation and earlier plateauing of growth curves.

At Day 2, growth differences among treatments were minimal ($p > 0.05$), with OD_{680} values ranging between 0.12 and 0.16. By Day 4, the 5 mg L^{-1} treatment began to diverge significantly (0.32 ± 0.01) from the 0.5 mg L^{-1} group (0.24 ± 0.02). A clear nitrate-dependent response was evident by Day 6, when the 5 mg L^{-1} treatment reached an OD_{680} of 0.48 ± 0.02, nearly double that of the 0.5 mg L^{-1} condition (0.27 ± 0.01). Excess nitrate (10 mg L^{-1}) did not enhance growth; instead, a modest decline in OD_{680} relative to the 5 mg L^{-1} group indicated a potential inhibitory effect of high nitrate concentration on cell division or pigment formation.

Growth curves (Fig. 1) clearly illustrate the sigmoidal pattern typical of cyanobacterial batch culture. The lag phase extended through the first two days, followed by a pronounced exponential phase between Days 2-6, and finally a stationary phase beyond Day 6 in low and high nitrate treatments. In contrast, the 5 mg L^{-1} treatment sustained exponential growth until Day 8, indicating enhanced nutrient utilization efficiency under moderate nitrate supply.

Table 1: Mean optical density (OD_{680}) of *Microcystis*-like cyanobacterium under different nitrate concentrations over 8 days (mean ± SD; n = 3).

Day	0.5 mg L^{-1}	1 mg L^{-1}	5 mg L^{-1}	10 mg L^{-1}
0	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00
2	0.14 ± 0.01	0.15 ± 0.01	0.16 ± 0.01	0.15 ± 0.01
4	0.24 ± 0.02	0.28 ± 0.01	0.32 ± 0.01	0.27 ± 0.02
6	0.27 ± 0.01	0.38 ± 0.02	0.48 ± 0.02	0.40 ± 0.01
8	0.35 ± 0.02	0.49 ± 0.01	0.60 ± 0.01	0.46 ± 0.03

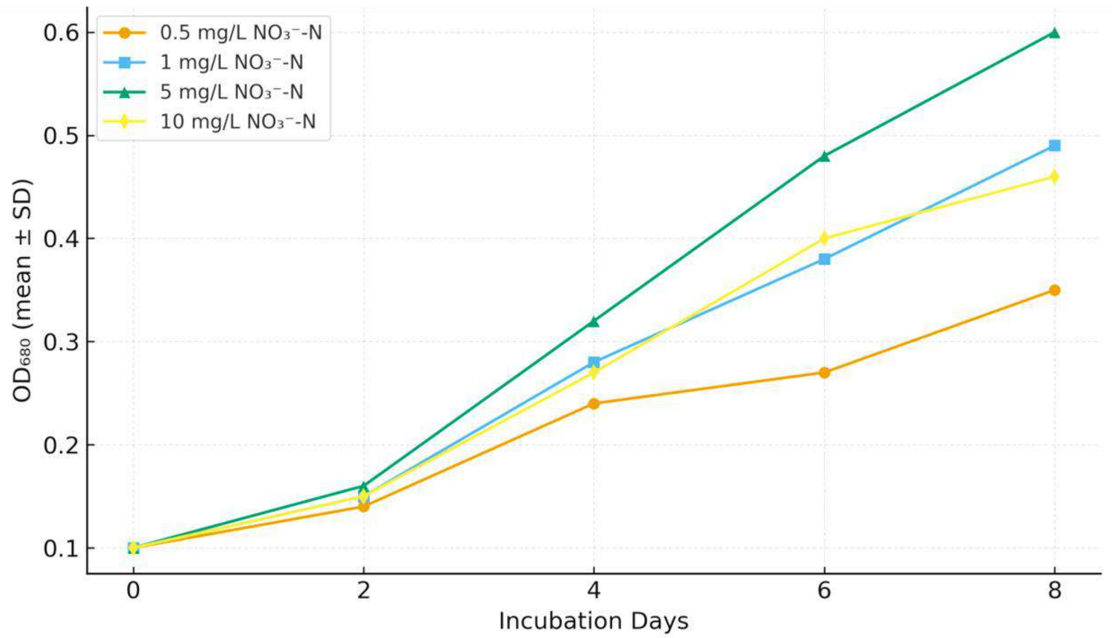

Fig. 1: Growth curves (OD_{680}) of *Microcystis*-like cyanobacterium under different nitrate concentrations (0.5–10 mg L^{-1} NO_3^--N) over an 8-day incubation. Data represent mean ± SD (n = 3).

3.2 Chlorophyll-a concentration

Chlorophyll-a concentrations at Day 8 followed a similar trend to optical density measurements (Table 2). The 5 mg L^{-1} treatment exhibited the highest pigment accumulation (5.8 ± 0.3 µg mL^{-1}), corresponding to a 65 % increase relative to the 0.5 mg L^{-1} treatment (3.5 ± 0.2 µg mL^{-1}). The 1 mg L^{-1} group recorded intermediate values (4.8 ± 0.2 µg mL^{-1}), while pigment content declined slightly under nitrate excess (10 mg L^{-1}; 4.2 ± 0.3 µg mL^{-1}). These results confirm that chlorophyll synthesis in the *Microcystis*-like strain is optimized within a narrow nitrate concentration range centered around 5 mg L^{-1}.

The pattern indicates that both nitrate limitation and oversupply negatively influence pigment formation, potentially due to metabolic stress or imbalanced nitrogen assimilation. The decline in chlorophyll at 10 mg L^{-1} may result from osmotic or oxidative stress, which has been reported in other cyanobacteria exposed to nutrient surfeit (Glibert *et al.*, 2016; Paerl & Otten, 2013).

Table 2: Chlorophyll-a concentrations (µg mL^{-1}) in *Microcystis*-like cyanobacterium after 8 days under varying nitrate levels (mean ± SD; n = 3).

Nitrate (mg L^{-1} NO_3^--N)	Chl-a (µg mL^{-1})	Relative increase (%)
0.5	3.5 ± 0.2	–
1.0	4.8 ± 0.2	+37
5.0	5.8 ± 0.3	+65
10.0	4.2 ± 0.3	+20

3.3 Relationship between nitrate concentration and biomass yield

A unimodal relationship was observed between nitrate concentration and final biomass yield of the

Microcystis-like cyanobacterium. Biomass, expressed as final optical density (OD_{680}), increased with nitrate concentration from 0.5 to 5 mg L^{-1} NO_3^--N, beyond which a decline was observed at 10 mg L^{-1}, indicating growth inhibition at excess nitrate levels. Polynomial regression analysis of Day-8 OD_{680} values (Fig. 2) revealed the following empirical relationship:

$$OD_{680} = -0.00826C^2 + 0.09327C + 0.35094$$

Where *C* represents nitrate concentration (mg L^{-1} NO_3^--N). The fitted curve indicates a maximum biomass yield at approximately 5–6 mg L^{-1} nitrate, consistent with the observed peak in chlorophyll-a accumulation. This unimodal response reflects an optimal nitrate window for growth, with both nitrate limitation and excess negatively affecting biomass production.

3.4 Visual culture characteristics

Cultures grown under 5 mg L^{-1} nitrate were bright green and homogeneous, indicating active photosynthetic activity and stable cell suspension. The 0.5 mg L^{-1} treatment appeared pale green, while the 10 mg L^{-1} cultures developed a slight yellowish hue toward Day 8, possibly reflecting pigment degradation or reduced phycobiliprotein content under nutrient imbalance.

Moderate nitrate levels (5 mg L^{-1} NO_3^--N) supported the highest growth of *Microcystis*, confirming that its growth is strongly nitrate-dependent yet sensitive to oversupply. At very low nitrate concentrations (0.5 mg L^{-1}), nitrogen limitation restricted protein and chlorophyll synthesis, while excessive nitrate levels (10 mg L^{-1}) likely caused ionic stress or reduced nutrient uptake efficiency.

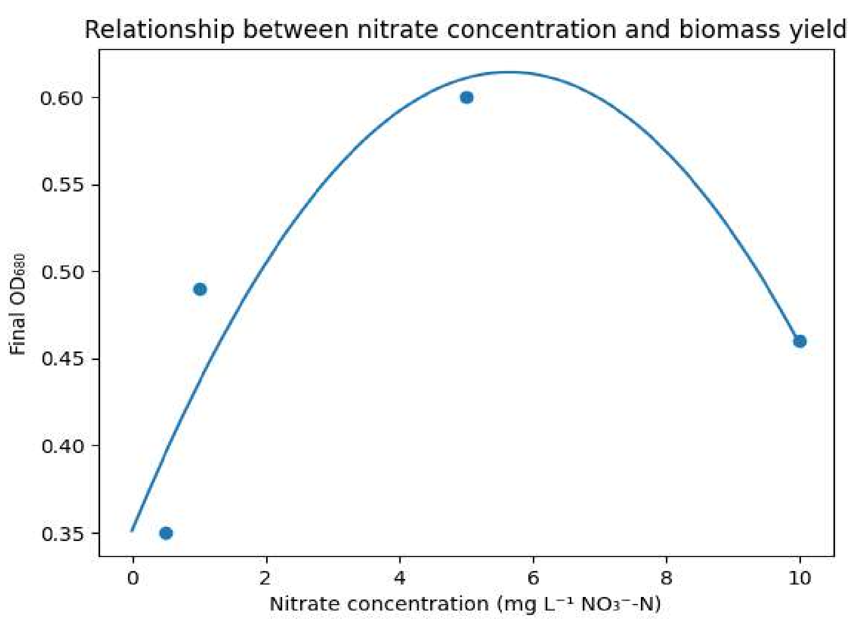

Fig. 2: Nitrate concentration–biomass response curve illustrating the unimodal relationship between nitrate availability and final optical density (OD_{680}) of the *Microcystis*-like cyanobacterium. The curve represents the fitted polynomial regression model.

Chlorophyll-a concentration showed a strong positive correlation with biomass (r ≈ 0.98), indicating stable pigment-to-biomass ratios up to the 5 mg L^{-1} treatment; however, beyond this concentration, pigment synthesis efficiency declined, suggesting a metabolic imbalance under nutrient oversaturation.

Ecologically, these results reflect field observations where cyanobacterial blooms commonly occur under moderate nutrient enrichment rather than extreme eutrophication, supporting the view that bloom formation thresholds align with intermediate nitrate levels that optimize growth and photosynthesis. Excessive nitrate inputs may instead favor other phytoplankton taxa or trigger feedback inhibition mechanisms (Glibert *et al*., 2016).

This laboratory study demonstrates that nitrate concentration critically governs cyanobacterial growth and pigment synthesis. The optimal nitrate concentration for maximum biomass accumulation was approximately 5 mg L^{-1} NO_3^--N. These findings provide insight into nutrient thresholds influencing *Microcystis* proliferation and can inform nutrient management strategies to mitigate bloom risks.

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Haematological indices and serum biochemistry of exotic finishers turkey fed flashed-dried Cassava pulp as a replacement for Maize

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ABSTRACT

One hundred and twenty (120) day-old British United Turkey (BUT) poults were purchased from a reputable farm in Nigeria to evaluate haematological indices and serum biochemistry of exotic finisher turkeys fed graded levels of flashed-dried cassava pulp (FDCP) as a replacement for maize. Finisher turkeys were carried over from starting phase to finishing phase and randomly assigned into four (4) dietary treatments in a completely randomized design (CRD). Thirty (30) turkeys were apportioned into four (4) treatments and replicated six (6) times with five (5) turkeys per replicate. The test diets (FDCP) were formulated to partially replaced maize at level of 0, 5, 10 and 15%. Water and feed were supplied *ad-libitum*. At 15th weeks of the research, 3 mls blood sample was collected via the wing vein into vials containing ethylene diamine tetra-acetic acid (EDTA) for determination of haematological indices. Another set (3 mls) blood sample was collected into heparinized tubes for serum analysis using standard procedures. Data were analyzed by using SPSS, (2021). The Higher (56.00%) significant ($p<0.05$) packed cell volume (PCV), 14.75 g dl^{-1} haemoglobin (Hb), and 4.05 × 10^{12} l red blood cell (RBC) were observed from finisher turkeys fed with 5% FDCP while the least (39.50%), 11.25 g dl^{-1} and 3.20 × 10^{12} l were noticed from 10% FDCP. The highest (3.90%) albumin was observed from both 5% and 10% FDCP while the lowest (3.30%) was observed from turkeys placed on (0% FDCP). Turkeys on 10% FDCP had highest 178.00 (mg dl^{-1}), 138.00 (mg dl^{-1}) and 12.05 mg dl^{-1} triglyceride, cholesterol and uric acid while those on 0% FDCP had least 124.10 mg dl^{-1}, 84.10 mg dl^{-1} and 10.25 mg dl^{-1} respectively. The highest 146.00 (U/L) aspartate transaminase (AST) was obtained from turkeys fed on 10% FDCP while the least value of 133.50 (U/L) was obtained from 5% FDCP. This finding indicate that incorporating FDCP up to 15% in turkey diets did not negatively impact the blood profiles of turkeys during the finishing stage, therefore, addition of FDCP up to 15% level in the diets of turkey finisher and finding beyond 15% level of inclusion are recommended.

KEY WORDS: *Flashed-dried cassava pulp*; *Turkeys*; *Haematological parameters*; *Serum blood*

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1. Introduction

Non-conventional feedstuffs include feed resources that are not usually used in commercial poultry nutrition. Examples of non-conventional feedstuffs include perennial crop seeds, waste products of seeds/animals, industrial waste from agro-allied industries, and by-products of plant and animal sources (Amandeep, 2016; Adelowo *et al.*, 2019). Utilization of inexpensive and readily available unconventional feed ingredients as substitute or replacement for conventional feedstuffs is becoming increasingly common, is being researched and documented as a promising and sustainable way to reduce and increase the prices of products to benefit of poultry farmers and make more affordable poultry products available to customers (Uchegbu *et al.*, 2017).

Maize, an energy ingredient in domesticated animal feed is expensive due to high demand for human consumption and commercial use (Bot *et al.*, 2013). Consequently, the advantage of cassava as a main ingredient in both small-scale and commercial livestock production has recently increased over the use of maize (FAO, 2013; Oppong, 2013). Cassava is a perennial, tuberous woody plant from the Euphorbiaceous family. There are two types of cassava; the sweet type, which is consumed by humans and animals, and the bitter type, which has high levels of hydrogen cyanide (HCN) and is not suitable for human consumption (Ogbuewu *et al.*, 2017). Global estimates by FAO (2013) showed that about 2,762,000 tonnes of cassava was used as animal feed.

According to PWC (2020), the supply and demand for cassava starch and high quality cassava flour in Nigeria is 290,000 tonnes annually. This corresponds to an annual production of 485,000 tonnes of cassava pulp and an estimated 870,000 tonnes of waste. Undoubtedly, this poses a serious environmental risk to the communities surrounding the production sites. Developing appropriate technologies to integrate cassava starch by-products into livestock feeding programs are therefore essential (Aro *et al.*, 2010).

2. Material and Methods

2.1 Experimental area

The experiment was carried out at the Poultry Unit of the Directorate of University Farms (DUFARMS), Federal University of agriculture, Abeokuta, Ogun-State, Nigeria. The farm is located in the tropical rainforest vegetation zone of South-Western Nigeria.

2.2 Sourcing of the flashed-dried cassava pulp (FDCP)

The FDCP (test ingredient) was obtained from Psaltry industry, a starch processing industry along Maya Ado-Awaye Road, Iseyin Local government area, Oyo-State, Nigeria.

2.3 Experimental diets and design

Four iso-proteinous and iso-caloric starter diets were formulated, such that FDCP replaced maize at 0, 5, 10 and 15% levels in diets 1, 2, 3, and 4 respectively. The experiment was arranged in a Completely Randomized Design (CRD). The gross composition of the experimental diet is presented in **Table 1**.

Table 1: Gross composition (%) of experimental diets for finishing turkeys (13–16 weeks)

Ingredients (kg)	FDCP levels of replacement			
	0%	5%	10%	15%
Maize	60.00	55.00	50.00	45.00
FDCP	0.00	5.00	10.00	15.00
Full fat soybean meal	8.00	9.50	11.00	12.50
Soybean meal	16.00	16.00	16.00	16.00
Wheat offal	8.00	6.50	5.00	3.50
Fish meal (72 % CP)	2.50	2.50	2.50	2.50
Lime stone	2.00	2.00	2.00	2.00
Bone meal	2.30	2.30	2.30	2.30
Lysine	0.20	2.00	0.20	0.20
Methionine	0.50	0.50	0.50	0.50
Vitamin/mineral Premix	0.25	0.25	0.25	0.25
NaCl	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00
Calculated values				
ME (MJ kg^{-1})	12.10	12.08	12.06	12.04
Crude protein (%)	19.36	19.23	19.10	19.00
Calcium (%)	1.71	1.71	1.71	1.72
Phosphorous (%)	0.59	0.59	0.59	0.58
Lysine (%)	0.98	0.95	0.92	0.90
Methionine (%)	0.78	0.77	0.76	0.74

Note: FDCP = Flash Dried Cassava Pulp; ME = Metabolizable Energy; NaCl = Sodium chloride

2.4 Experimental design and turkeys' management

One hundred and twenty (120) day-old British United Turkey (BUT) poults were sourced from a reputable farm in Nigeria and were brooded for twenty eight (28) days by using commercial pre-starter turkey. At the end of 28-day brooding period, thirty (30) growing turkeys were assigned per treatment and replicated six (6) times with five (5) growing turkeys per replicate, experimental turkey starters were randomly assigned into four (4) dietary treatments in a completely randomized design (CRD) and carried over to finishing phase. Brooding was done on deep litter pens, each pen (dimension 2.0 m × 1.5 m) containing 5 birds. Electricity and charcoal pots were the sources of heat. Birds were provided water and feed *ad libitum*. Vaccination and medication protocols were strictly followed.

2.5 Data collection

At 15th weeks of the experiment, 3 ml blood sample was collected via the wing vein into vials containing ethylene diamine tetra-acetic acid (EDTA) as anti-coagulant for the determination of haematological parameters, another 3mls blood sample was obtained through the same route into plain bottle without EDTA for serum biochemistry assay.

2.6 Statistical analysis

One-way analysis of variance (AOAC) was performed on all collected databy using SPSS

2021. Duncan's multiple range test (1955) was used to differentiate significant ($p<0.05$) means between variables.

2.7 Statistical models

One-way $Yij = \mu+T_i+\mathcal{E}_{ij}$

where:
Yij = Observed value of dependent variable
μ = Population mean
Ti = Effect of treatment (0, 5, 10, 15%)
$\mathcal{E}_{ij}$ = Random residual error

3. Results and Discussion

Haematological parameters of turkeys finisher fed experimental diets (13-16 weeks) are presented in **Table 2**. Flash-dried cassava pulp diet showed a significant ($p<0.05$) differences in packed cell volume, haemaglobin, red blood cells (RBC), neutrophils, lymphocytes, mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC) while white blood cells, eosinophils, basophytes and monocytes were not affected ($p>0.05$). Packed cell volume showed the highest (56.00%) significant ($p<0.05$) difference with finisher turkeys fed with 5% FDCP while the lowest (39.50%) was observed on 10% FDCP. Haemoglobin showed the highest (14.75 g dl^{-1}) significant ($p<0.05$) difference from finisher turkeys placed on 0% FDCP, 5% FDCP were statistically ($p>0.05$) equivalent with 0%FDCP, conversely, finisher turkeys fed 10% FDCP showed the least (11.25g dl^{-1}) significant ($p<0.05$) difference. Turkeys finisher fed on 5% FDCP showed a highly (4.05 × 1012 L) significant different ($p<0.05$) in the RBC while 10% FDCP showed the lowest (3.20 × 1012/l). Neutrophils showed a highly (35.50%) significant ($p<0.05$) effect from 0% FDCP while the least (27.50%) was observed from 10% FDCP. Lymphocytes recorded the highest (70.50%) significant difference ($p<0.05$) from finisher turkeys fed 10%

Table 2: Haematological indices of finisher turkeys fed experimental diets (13-16 weeks)

Parameters	FDCP levels of replacement					
	T_1 (0%)	T_2 (5%)	T_3 (10%)	T_4 (15%)	SEM	P-value
Packed cell volume (%)	46.00^b	56.00^a	39.50^d	41.50^c	1.35	0.000
Haemoglobin (g dl^{-1})	14.75^a	14.15^a	11.25^c	13.00^b	0.30	0.000
Red blood cell ($\times 10^{12}$/l)	3.80^{ab}	4.05^a	3.20^c	3.50^b	0.08	0.000
White blood cell ($\times 10^9$/l)	15.20	14.95	14.90	15.10	0.14	0.879
Neutrophils (%)	35.50^a	31.00^b	27.50^c	31.50^b	0.76	0.000
Lymphocytes (%)	63.00^c	66.50^b	70.50^a	67.50^{ab}	0.74	0.001
Eosinophils (%)	0.50	0.50	0.50	0.50	0.10	1.000
Basophytes (%)	0.50	0.50	0.50	0.00	0.10	0.206
Monocytes (%)	0.50	1.00	1.00	0.50	0.14	0.368
MCV (fl)	121.60^b	138.55^a	123.63^b	117.20^b	2.06	0.000
MCH (pg)	38.93^a	35.02^b	35.17^b	36.72^b	0.45	0.001
MCHC (g dl^{-1})	32.05^a	25.27^d	28.46^c	31.33^b	0.57	0.000

$^{a, b, c, d}$ = Means within the same row with different superscripts are significantly different ($P<0.05$). SEM = Standard error of the mean, MCV = Mean corpuscular volume, MCH = Mean corpuscular haemoglobin, MCHC = Mean corpuscular haemoglobin concentration

FDCP while the least (63.00%) significant different ($p<0.05$) was recorded from finisher turkeys fed 0% FDCP. MCV had the highest (138.55 fl) significant effect ($p<0.05$) in the finishing turkeys fed with 5% FDCP, while the lowest (117.20 fl) significant impact ($p<0.05$) was observed at 15% FDCP but 0% FDCP, 10% FDCP and 15% FDCP showed statistically ($p>0.05$) similar values. The highest (38.93 pg) significant ($p<0.05$) difference MCH was obtained on 0% FDCP while the lowest (35.02 pg) was noticed on 5% FDCP and a similar ($p>0.05$) difference was noticed on 10% FDCP, 15% FDCP and 5% FDCP. MCHC showed the highest (32.05 g dl^{-1}) significant change ($p<0.05$) on finisher turkeys fed 0% FDCP while the least (25.27 g dl^{-1}) was obtained from 5% FDCP.

4. Discussion

Finishing turkeys fed 10% FDCP recorded lower PCV, Hb and RBCs. Adejumo (2004) discovered an association between nutritional status, diet quality and their haematological traits, particularly PCV and Hb. Daramola *et al.* (2005) stated that PCV is useful for determining amount of protein and predicting the quality of protein supplementation in various physiological states.

The PCV, Hb and RBC across dietary treatments in this finding fluctuated and within standard values reported by Adedokun *et al.* (2017). The normal ranges of PCV, Hb, and RBC of finishing turkeys fed varying levels of FDCP diets in this study is an indication of the cell's enhanced capacity to transport oxygen, which results in improved nutrient availability, growth and productivity of the finishing turkeys and showed absence of deleterious effect by consumption of FDCP diets up to 15% inclusion levels. But heamoglobin and red blood cells observed were contradicted with the report of Makinde and Inuwa (2015), who reported insignificant differences when turkeys were subjected to agro industrial by-products.

Neutrophils are part of white blood cell, one of the most important haematological parameters for assessment of the health status of a healthy bird (Ukoha *et al.*, 2022). This study showed that the health of turkeys' improved during the finishing phase and that the FDCP diet had the nutrients and capacity to fight against invasive disease.

The observed lymphocyte levels ranged from 63.00–70.50% and fell in the range of 66.67-70.67% in healthy birds as opined by Ukoha *et al.* (2022). Average erythrocyte size is calculated using the MCV and hemoglobin content per blood cell is assessed using the MCH while MCHC is used to calculate the haemoglobin content of red blood cells in relation to their size. The MCV, MCH and MCHC values were within standard values of 90-140 fl, 33-47 pg $cell^{-1}$ and 26-35 g dl^{-1} reported by Bounous and Stedman, (2000). As a result, finishing turkeys in this study did not experience adverse health effects from graded levels of FDCP feed.

Table 3 displays significant ($p<0.05$) differences in albumin, triglyceride, cholesterol, uric acid, aspartate transaminase (AST) and density bilirubin while globulin, glucose, alanine transaminase (ALT), total bilirubin and creatinine did not significantly ($p>0.05$) altered. The highest (3.90 g dl^{-1}) significant ($p<0.05$) albumin was recorded from finisher turkeys fed with 5% FDCP and 10% FDCP while the least was recorded from 0% FDCP and statistically ($p>0.05$) similar with those turkeys fed with 15% FDCP. Turkey on 5% FDCP recorded the highest (178.00 mg dl^{-1}) triglyceride while the least (124.10 mg dl^{-1}) was obtained from turkeys fed with 0% FDCP. The highest (138.00 mg dl^{-1}) significant ($p<0.05$) cholesterol was observed from turkey fed with 5% FDCP but not significant affected ($p>0.05$) with turkeys placed on 15% FDCP while the least (84.10 mg dl^{-1}) was obtained from 0% FDCP and was statistically ($p>0.05$) similar with those turkeys fed on 10% FDCP. Uric acid from finisher turkeys fed 0% FDCP, 10% FDCP and 15% FDCP was statistically equivalent ($p>0.05$) but significant lower ($p<0.05$) than the values (12.05 mg dl^{-1}) obtained from 5% FDCP. Finisher turkeys fed 10% FDCP revealed highest (146.00 U/L) significant ($p<0.05$) aspartate transaminase while 0% FDCP, 5% FDCP and 15% FDCP were statistically ($p>0.05$) similar, with least (133.50 U/L) found from the finisher turkeys fed on 5% FDCP.

The albumin values (3.30-3.90 g dl^{-1}) of finishing turkeys obtained were within the normal values of 3.00-5.50 g dl^{-1} reported by Jeanetter, (2020) but higher than values of 2.39–2.44 g dl^{-1} opined by Okrathok *et al.* (2018) when laying hens were fed fermented cassava pulp as a replacement for maize. The albumen concentration observed in finishing turkeys fed control diet was statistically comparable to that of turkeys fed 15% FDCP, suggesting that the turkeys' nutritional needs and overall health were met by the amount of protein in their experimental diets during the last phases of their lives.

Triglycerides found in this finding are in consistent with the results of Sugiharto *et al.* (2019) who obtained elevated triglycerides in broilers fed fermented cassava pulp at finishing phase. Cholesterol values (84.10–138.00 mg l^{-1}) obtained from finishing turkeys was higher than established values of 75.00-89.25 mg dl^{-1} by Okrathok *et al.* (2018) who reported a non-significant different when replaced maize with fermented cassava pulp in the laying hens' diet. Uric acid is waste product of protein metabolism and high value is toxic to the body. The uric acid observed in this study showed that finisher turkeys

Table 3: Serum biochemistry of finisher turkeys fed experimental diets (13-16 weeks)

Parameters	FDCP Levels of replacement					
	0%	5%	10%	15%	SEM	P – value
Total protein (g dl^{-1})	4.85	5.45	5.35	4.60	0.13	0.066
Albumin (g dl^{-1})	3.30^{b}	3.90^{a}	3.90^{a}	3.50^{b}	0.07	0.000
Globulin (g dl^{-1})	1.50	1.60	1.40	1.10	0.09	0.187
Glucose (g dl^{-1})	99.80	113.60	137.95	114.15	5.17	0.060
Triglyceride (mg dl^{-1})	124.10^{b}	178.00^{a}	133.00^{b}	158.10^{a}	5.59	0.000
Cholesterol (mg dl^{-1})	84.10^{b}	138.00^{a}	93.00^{b}	118.10^{a}	5.59	0.000
Uric acid (mg dl^{-1})	10.25^{b}	12.05^{a}	10.55^{b}	10.70^{b}	0.21	0.004
AST (U/L)	134.50^{b}	133.50^{b}	146.00^{a}	134.00^{b}	1.51	0.002
ALT (U/L)	50.00	45.50	51.50	49.00	1.03	0.208
ALP (U/L)	24.50	27.50	27.00	23.00	0.68	0.052
TBL (mg dl^{-1})	0.91	0.93	0.91	1.01	0.02	0.224
DB (mg dl^{-1})	0.26	0.28	0.22	0.33	0.03	0.030
Creatinine (mg dl^{-1})	1.82	2.25	1.79	1.05	0.18	0.127

$^{a, b}$ = Means within the same row with different superscripts are significantly different (P<0.05), SEM = Standard error of the mean, AST = Aspartate transaminase, ALT = Alanine transaminase, ALP = Alkaline phosphate, TBL= Total bilirubin, DB = Density bilirubin.

fed on varied FDCP diets were favorably with those turkeys on 0% FDCP except turkeys placed on 5% FDCP diet. The higher uric acid revealed by finisher turkeys on 5% FDCP could not be traced to FDCP diets used for this finding but other environmental factor. There was no discernible trend in the creatinine levels across the dietary treatment groups. The amount of muscle waste was indicated by a higher creatinine level, this shows that the experimental turkeys in this research survived at the expense of their body reserves, which may have led to weight loss. FDCP diets are better than the control diets due to the quality of total protein, albumin, glucose, triglyceride and cholesterol obtained at finishing phase of the experiment. Improved values observed with finishing turkeys fed varied FDCP indicated that the finishing turkeys were making good use of the sufficient quantity of protein in the experimental diets.

Serum enzymes levels are important for determining if the liver is working properly (Ambrosy *et al*., 2015) and have proven to be of great value in the assessing clinical and experimental liver injury (Olawale, 2019). An increase in the concentrations of serum enzymes could be caused by damage or injury to the liver. The AST values determined in this study (133.50–146.00 U/L) were below values of 164.75–191.25 (U/L) reported by Okrathok *et al*. (2018) when cassava was substituted for maize in the diets of laying hens. But fell within normal range values of 50.00–270.00 (U/L) established by Coles, (2007). An increase in AST value above the normal range indicates liver injury, shock or chronic liver problems (Basten, 2010), hence, AST observed in this finding showed normal liver function. ALP is an indicator of liver health and can also be used to assess renal function (Basten, 2010). It can be found in the bile, bone and kidney. ALP levels (23.00–27.50 U/L) from this finding were lower than normal range values (568-831 U/L) opined by Meluzzi *et al*. (1992). This could be due to the age of the finishing turkeys, as ALP levels were reported to be higher in young animals due to rapid bone growth (Kaneko *et al*., 2010). Thus, varying FDCP diets used in this research did not injure liver of the finishing turkeys, therefore, this suggest that FDCP can be used in the diets of turkeys at finishing phase with little or no risk of toxicity to the liver.

5. Conclusion

This finding suggests that using flashed-dried cassava pulp at levels up to 15% in turkey diets is safe and does not compromise the health status of the turkeys at the finishing stage.

Studies investigating the effects of flashed-dried cassava pulp inclusion above 15% in turkey finisher diets are needed to determine optimal substitution levels for maize and potential impacts on performance and health.

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Characterization and micronutrient content of soils of similar lithology under different Land Use Types in Aboh-Mbaise, Imo State, Nigeria

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ABSTRACT

This study was conducted to evaluate the physicochemical properties and micronutrient content of soils under selected land use types in Mbaise, Imo State. Three land use types namely fallow land, cassava cultivation and oil palm plantation were used for the study. The surface samples 0 -30 were collected. A total of nine samples were collected from the three land use types. Result showed that mean sand content ranged from 708.4 – 729.6 g kg^{-1}, mean silt content ranged from 28.4 – 47.2 g kg^{-1} and mean clay content ranged from 223.2 – 262.9 g kg^{-1}. Mean bulk density ranged from 1.39 – 1.46 Mgm^{-3}. Mean moisture content ranged from 20.69 – 23.30 % while mean total porosity ranged from 44.82 – 48.87 %. There was significant difference in silt content, clay content, bulk density, total porosity and moisture content among the soils of the studied land use types. The mean pH (water) ranged from 5.48 - 6.02. Average organic carbon ranged from 5.9 – 9.1 g kg^{-1}. Average total nitrogen varied from 0.74 – 1.08 g kg^{-1}. Mean available phosphorus ranged from 38.97 – 95.07 mg kg^{-1}. Average calcium-magnesium ratio varied from 0.18 -1.17. Mean total exchangeable bases (TEB) varied from 3.03 -9.00 cmol kg^{-1}. Mean effective cation exchange capacity (ECEC) varied from 5.08 – 10.25 cmol kg^{-1} while mean carbon-nitrogen ratio varied from 6.53 – 11.57. There was significant difference in soil chemical properties among the soils of the studied land use types with the exception of total nitrogen, calcium, potassium, sodium and total exchangeable acidity. Micronutrient of the soils showed that Average copper (Cu) ranged from 0.106 – 0.173 mg kg^{-1}, mean manganese (Mn) 1.66 -3.30 mg kg^{-1}, mean iron (Fe) ranged from 1.94 -2.63 mg kg^{-1} and mean zinc (Zn) ranged from 0.063 – 0.108 mg kg^{-1}. There was significant difference in manganese content among the soils of the studied land use types. There was a significant positive correlation between organic carbon and moisture content, clay, total nitrogen, available phosphorus, ECEC, Cu, Mn and Zn (r = 0.34, 0.49, 0.56, 0.48, 0.35, 0.50, 0.32 and 0.44 $p \leq 0.05$) respectively.

KEY WORDS: *Soil characteristics*; *Micronutrients*; *Land use*; *Parent material*; *Imo State*

1. Introduction

Land use has been categorized into major kind as rain-fed agriculture, grassland, fish pond, forestry, grazing and tourism and into primary or compound kinds in which more than one kind of land use is practiced (FAO, 2002). Land use affects soil fertility and productivity. These

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manifests as changes in soil properties such as nutrient content (N, P, K, Ca, Mg, and S etc), pH, organic matter, ECEC, soil structure (Akamigbo and Asadu, 2001). The main problem associated with inappropriate land use changes are land degradation and soil quality deterioration through loss of vegetative cover, top soil moisture, infiltration capacity, water storage, soil organic matter, fertility resilience, natural regeneration capacity and a lower water table in which these factors are critical for soil health. Agricultural sustainability needs a periodic evaluation of soil fertility status. This is imperative in understanding factors which cause serious constraints to increase crop production under different land use and for adoption of suitable land management practices. Information so generated could also be useful in adjusting present land use types or in the development of appropriate land use policy for a given area. This is particularly important in south-eastern Nigeria, where demographic factors, poor land management and inherent low soil fertility (Enwezor *et al*., 1990) under different land uses often result to poor crop yield.

Essential micronutrients are not usually applied to the soil through common fertilizers, yet about two to six times in quantity of these micronutrients are removed annually from the soil than is applied (Lawal *et al*., 2012). The practice of fertilizer application in Nigeria in general and southeast in particular is in favour of nitrogen (N), phosphorus (P), and potassium. (K). The increase in the use of NPK fertilizers lacking in micronutrients has no doubt increased crop production, but it brought with it a host of other problems associated to micronutrient deficiencies (Ahukaemere *et al*., 2014). In order to get the full potentials of soils, it is imperative to take the inventory of their nutrient status which includes the essential micronutrients.

The study is aimed at determining the inherent characteristics of the soils under different land use in the studied area as this will help to know the level of soil fertility of the area under study.

2. Material and Methods

The study was conducted at Aboh Mbaise, Imo state. It lies between latitudes 5° 27' N and 7˚ 14' E. Soils of the area are formed from coastal plain sands. It is a lowland area with humid tropical climate having a rainfall of over 2500 mm and mean annual temperature of 26–29 ℃. Tree plants such as palm tree, raffia palms, and other cash crops dominate the vegetation popularly referred to as the rainforest belt of Nigeria (Onwudike, 2010). Farming is a dominant socio-economic activity of the study area (Onwudike *et al*., 2015). Farmers still stick to traditional slash – and – burn system of clearing and soil fertility regeneration is by natural bush fallow where soils are allowed to regain their lost nutrients without intentional input from farmers (Onweremadu, 2007). Reconnaissance field survey of the area was carried out. Representative soil sampling sites were selected based on vegetation and cultivation history. The representative land use was selected (fallow land, cassava cultivated land and oil palm plantation). From each land use three surface soil samples were collected from the depth of 0–30 cm using a soil auger (Wildings, 1985). The soil samples collected were air dried, sieved using 2 mm sieve prior to analysis. The laboratory analysis of the soils studied was carried out and the following parameters were determined, Soil particles size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962; Van Reeuwijk, 1992). Bulk density was determined using the core method (Grossmans and Reinsch, 2002). Total porosity was computed from the values of bulk density and particle density (Brady and Weil, 2002) as

$$Tp = \left(1 - \frac{pb}{ps}\right) \times \frac{100}{1} - - - - - - - - - - - -1$$

Where Tp = total porosity, pb = bulk density, ps = particle density assumed to be 2.65 g cm^{-1} for tropical soils. Moisture content was determined by Gravimetric method (Obi, 1990). It was computed as follows;

$$\%MC = \frac{W_2 - W_3}{W_3 - W_1} \times \frac{100}{1} - - - - - - - - - -2$$

W_1 = Weight of moisture can
W_2 = Weight of air-dried soil + moisture can
W_3 = Weight of oven-dry soil + moisture can

Soil pH was determined in water at a ratio of 1:1 (soil: liquid ratio) using a glass electrode (Van Reeuwijk, 1992). Organic carbon was determined by wet oxidation method as described by (Walkley and Black, 1934). Organic matter was then determined by multiplying the organic carbon with a value of 1.724 (Van bemmmelen factor). Total nitrogen was determined using the micro kjeldahl method as described by (Black, 1965). Available phosphorus was determined by Olsen method as described by (Emteryd, 1989). An exchangeable base was determined by extraction using 1N NH_4OAC neutral solution (Thomas, 1982), exchangeable calcium and magnesium in the extract were analyzed using atomic absorption spectrophotometer while sodium and potassium were analyzed by flame photometer (Chapman, 1965: Rowell, 1994). Exchangeable acidity was determined by leaching the soil sample with potassium chloride solution and titrating with sodium hydroxide as described by (Mclean, 1982). Base saturation was determined by summation. The effective cation exchange capacity (ECEC) was determined by the addition of all the exchangeable acidity and exchangeable bases.

ECEC = Exchangeable acidity + Exchangeable bases. Base saturation was determined by calculation using the formulae

$$\%BS = \frac{TEB}{ECEC} \times \frac{100}{1} - - - - - - - - - - - -3$$

The available micronutrients (Cu, Mn, Fe and Zn) were extracted with 0.1 N HCl and determined by the use of Atomic Absorption Spectrophotometer (AAS).

2.1 Data analysis.

The experiment was replicated three times. Descriptive statistical tool was used in analyzing collected data. Analysis of variance (ANOVA) at p = 0.05 probability level was used to determine variation among soil data and mean separated using least significant difference (LSD). Correlation analysis was used to determine relationship between soil properties.

3. Results and Discussion

3.1 Soil physical properties of the studied land use types

The results of the physical properties of the studied soils are shown in Table 1. Cassava cultivated soil (SUC), the mean textural distribution was 708.4 g kg^{-1}, 28.4 g kg^{-1} and 269.6 g kg^{-1} for sand, silt and clay respectively. Soil under fallow land (SUF), the mean textural fraction was 709.6 g kg^{-1}, 47.2 g kg^{-1} and 249.4 g kg^{-1} for sand, silt and clay respectively, while soil under oil palm plantation (SUO), the textural fraction was 729.6 g kg^{-1}, 47.2 g kg^{-1} and 223.2 g kg^{-1} for sand, silt and clay respectively. The textural class ranged from sandy loam to sandy clay loam. The sand fraction is higher than the other fractions in all the soils however, the sand fraction is not significant in all the soils. This is attributed to the parent material from which the soils are formed which is coastal plain sands (Enwezor *et al*., 1990). However, there was significant difference in the silt and clay fractions. It therefore implies that such soils have high infiltration capacity which usually leads to detachment, erosion and leaching of essential nutrients. This generally creates an avenue for infertility of the soils. The mean silt/clay ratio are soil under cassava 0.11, soil under fallow 0.23 while soil under oil palm 0.22. The highest was recorded on soil under fallow and the lowest on soil under cassava. The low silt/ clay ratio is an indication that there is advanced stage of weathering in the soils. According to Eshett, (1990) soils with low silt/clay ratio show high weathering in the soils. In tropical soils, silt and silt/clay ratio is being used to evaluate the degree of weathering and low silt or silt/clay ratio is being recognized as indicators of advanced weathering (Stewart *et al*., 1970). The bulk density varied from 1.43 - 150 Mg m^{-3} for soils under cassava cultivation, 1.39 -140 Mg m^{-3} for soil under fallow land and 1.43 – 1.49 Mg m^{-3} for soil under oil palm plantation. The highest mean bulk density occurred in soil under oil palm plantation (1.46 Mg m^{-3}) while the lowest mean bulk density occurred under fallow land (1.39 Mg m^{-3}). There was significant difference in bulk density among the soils. The result followed the order soil under oil palm > soil under cassava > soil under fallow. Soils with low bulk density can increase root penetration, soil aeration and nutrient uptake. Therefore crops grown on soil under fallow will have easy root penetration, adequate aeration and will be able to take up water and other nutrients than the other land use types. This can be attributed to the fact that soil under fallow land has high organic carbon when compared to the other land uses. However, values of the bulk densities were above the critical limit of 1.3 Mgm^{-3} recommended for tuber and cereal crops (Kayombo and Lal, 1984). This result is contrary to Onwudike *et al*. (2016) who reported bulk

Table 1: Physical properties of studied soils

Sample	Replicate	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	SCR	BD (Mg m^{-3})	VMC (%)	TP (%)
SUC	1	706.0	30.8	263.2	SCL	0.12	1.43	24.00	46.11
	2	749.6	27.2	223.2	SCL	0.12	1.46	18.65	44.89
	3	669.6	27.2	302.2	SCL	0.09	1.50	19.43	43.48
	Mean	708.4	28.4	262.9		0.11	1.44	20.69	44.82
SUF	1	689.6	7.2	302.2	SCL	0.02	1.40	25.16	47.25
	2	729.6	87.2	183.2	SL	0.48	1.39	21.40	47.62
	3	709.6	47.2	243.2	SCL	0.19	1.39	23.33	47.62
	Mean	709.6	47.2	244.9		0.23	1.39	23.30	47.49
SUO	1	769.6	47.2	183.2	SL	0.26	1.49	21.10	55.14
	2	709.6	67.2	223.2	SCL	0.30	1.45	23.56	45.36
	3	709.6	27.2	263.2	SCL	0.10	1.43	21.22	46.11
	Mean	729.6	47.2	223.2		0.22	1.46	21.96	48.87
	LSD 5%	NS	0.23*	1.34*		0.02*	0.02*	1.12**	0.68*

Note: *=significant, ** = highly significant density of below 1.3 Mg m^{-3} for soils under palm plantation, cassava farm land and fallow land in the area. Total porosity of the soils ranged from 43.48 – 46.11 % for soil under cassava, 47.25 – 47.62 % for soil under fallow and 25.36 – 55.14 % for soil under oil palm. There was significant difference in total porosity among the soils. The highest porosity occurred on soil under oil palm and the lowest on soil under cassava. This finding agrees with Onwudike *et al*. (2016) who stated that highest and lowest total porosity were recorded by oil palm and cassava respectively in soils of Mbaise, Imo State, Southeastern, Nigeria.

3.2 Chemical properties of the studied land use types

The result of chemical properties of the studied soils under different land use types are presented in Table 2. The mean pH (water) for all the land use types ranged from 5.48–6.02. The highest was recorded in soil under fallow while the lowest was recorded in soil under cassava. The soils of the various land use types were moderately acidic. This result agrees with Onwudike *et al*. (2015), Onwudike *et al*. (2016) and Mbah, (2006) who obtained similar result in the region. The highest soil pH in fallow land could be as a result of litter falls which through its decomposition increases soil organic matter and exchangeable bases in the process reducing the accumulation of hydrogen and aluminium ions on soil exchange complex (Onwudike, 2010). The acidic nature of these soils could be due to the excessive rainfall of the area which leads to leaching away of nutrients or eroding away of essential nutrients for crop growth. When basic cations are leached away, they are replaced with hydrogen and aluminium ions which lead to an increase in the pH of the soil. Crop grown on such soils may not do well due to high Al^{3+} content in the soil. This result agrees with Nkwopara *et al*. (2022) on eroded and non eroded soils of Urualla, Imo State. An increase in the base saturation of the soil improves the nutrient content of the soil thereby reducing acidity (Enwezor *et al*., 1990). The mean soil organic carbon ranged from 5.9–9.1 g kg^{-1}. Onwudike *et al*. (2015) observed the range of 5.4 – 13.2 g kg^{-1} in selected land use types in the area. The highest soil organic carbon was observed in the fallow land (9.1 g kg^{-1}), followed by oil palm plantation (9.0 g kg^{-1}) and the least was 5.9 g kg^{-1} in cassava cultivated land. This finding is in agreement with Onwudike *et al*. (2016) who observed similar result in the area. The highest organic carbon recorded in the fallow land could be attributable to the presence of litter and leaf drop from surrounding canopies that has undergone decomposition and also protecting the soil surface from rainfall impact and also expected increase in soil biodiversity Miller and Gardiner, (2001). Woldeamlak and Stroosnijder (2003) observed that conversion of forest vegetation to agricultural land leads to decline of the soil organic carbon content. This could be the reason for the low content of organic carbon observed in cassava cultivated land compared to the other land use types. The mean total nitrogen ranged from 0.74 to 1.08 g kg^{-1}. The highest value of (1.08 g kg^{-1}) was observed in soil under fallow and the lowest value of (0.74 g kg^{-1}) was recorded on soil under oil palm plantation. Fallow land recorded the highest mean available phosphorus of (95.67 mg kg^{-1}) and the least (38.97 mg kg^{-1}) was in cassava cultivated land. The high total nitrogen and available phosphorus observed in fallow land could be attributed to litter fall and higher soil organism that help in the decomposition of organic matter since organic matter and nitrogen have a positive correlation (Onwudike, 2010).

Table 2: Chemical properties of the studied land use types

Land use	Rep	pH (H_2O)	OC (g kg^{-1})	TN (g kg^{-1})	AVP (mg kg^{-1})	Ca	Mg	K	Na	Al^{3+} Cmol kg^{-1}	H+	TEA	TEB	ECEC	BS (%)
SUC	1	4.66	7.6	0.92	41.30	0.30	7.30	0.11	0.20	-	1.52	1.52	7.91	9.43	83.7
	2	5.97	6.6	0.85	44.80	1.60	0.50	1.08	0.20	0.21	1.71	1.92	3.36	5.24	63.6
	3	5.82	3.6	1.01	30.80	0.10	1.17	0.14	0.28	0.34	2.26	2.60	1.69	4.29	39.4
	Mean	5.48	5.9	0.93	38.97	0.67	2.99	0.44	0.23	0.18	1.83	2.01	4.32	6.33	68.2
SUF	1	5.77	8.0	1.22	67.20	0.50	2.17	0.14	0.20	0.24	1.36	1.60	3.01	4.61	65.3
	2	6.33	8.2	1.15	137.90	4.30	2.33	0.46	0.25	-	0.80	0.80	7.34	8.14	90.2
	3	5.95	11.2	0.87	81.90	8.50	6.00	0.49	1.65	-	1.36	1.36	16.64	18.00	92.4
	Mean	6.02	9.1	1.08	95.67	4.43	3.50	0.36	0.70	0.08	1.17	1.25	9.00	10.25	87.8
SUO	1	5.85	17.2	0.83	124.60	0.85	1.67	0.09	0.20	0.31	1.45	1.76	2.81	4.57	61.5
	2	5.78	2.8	0.68	107.80	-	1.67	0.14	0.21	0.55	1.65	2.20	2.02	4.22	47.9
	3	5.92	7.0	0.71	39.90	0.10	3.00	0.92	0.24	0.30	1.90	2.20	4.26	6.46	65.9
	Mean	5.85	9.0	0.74	90.77	0.32	2.11	0.38	0.22	0.39	1.67	2.05	3.03	5.08	59.6
	LSD (0.05)	0.12*	0.002*	NS	3.64**	NS	0.12*	NS	NS	0.01*	0.02*	NS	0.14*	0.13*	6.04**

Note: *=significant, ** = highly significant, NS = Not significant
SUC = Soil under cassava, SUF = Soil under fallow, SUO= Soil under oil palm, OC=Organic carbon, TN= Total nitrogen, AVP= Available phosphorus, TEA= Total exchangeable acidity, TEB = Total exchangeable bases, ECEC= Effective cation exchange capacity, BS = Base saturation.

High available phosphorus in the fallow land could be attributed to high soil pH values and soil organic carbon which reduces phosphorus fixation in the soil (Mbah, 2006). The mean exchangeable cations were low in the three land use types with the highest values recorded in fallow with the exception of potassium. Exchangeable Ca, Mg, K and Na in fallow land were 4.43, 3.50, 0.36 and 0.70 cmol kg^{-1} respectively. In cassava cultivated land the values were 0.67, 2.99, 0.44 and 0.23 cmol kg^{-1} respectively while in oil palm plantation the values were 0.32, 2.11, 0.38, and 0.22 cmol kg^{-1} respectively. The low exchangeable bases in these soils could be attributed to high rainfall which leads to accelerated runoff and leaching down the subsoil. Higher exchangeable bases in soil under fallow land could be as a result of the macro and micro climate that hinder the impact of rain drops on this soil (Brady and Weil, 2002). On the exchangeable Al and H, fallow lands recorded the lowest values of mean exchangeable Al and H with values 0.08 and 1.17 cmol kg^{-1} respectively. In cassava cultivated land the values were 0.18 and 1.83 cmol kg^{-1} respectively. While in oil palm plantation the values were 0.39 and 1.67 cmol kg^{-1} respectively. Lower values of exchangeable Al and H in fallow land could be due to high soil pH , organic carbon and vegetation cover that reduces run off of plant nutrients thereby reducing accumulation of Al and H ions on exchange complex (Brady and Weil, 2002) .This findings agree with Onwudike *et al*. (2016) who recorded similar result in the area. Fallow land recorded the lowest value of mean total exchangeable acidity of 1.25 cmol kg^{-1} while the highest value of 2.05 cmol kg^{-1} was recorded in oil palm plantation. Fallow land recorded the mean highest total exchangeable bases (TEB), Effective cation exchange capacity (ECEC) and base saturation (BS) of 9.00 cmol kg^{-1}, 10.25 cmol kg^{-1} and 82.63 % respectively and the lowest was on oil palm plantation with values 3.03 cmol kg^{-1}, 5.08 cmol kg^{-1} and 58.43 % respectively. High TEB, ECEC and BS in fallow land could be as a result of increase in exchangeable bases and organic carbon obtained from mineralization of litter falls in fallow land.

3.3 Selected elemental ratio of the studied land use types

The result of selected elemental ratio of the studied soils under different land use types are presented in Table 3. The mean carbon-nitrogen ratio (C/N) ranged from 6.53 - 11.57. The highest occurred in soil under oil palm plantation while the lowest occurred in soil under cassava cultivation. Nkwopara *et al*. (2019) observed the range of 10.17 – 10.44 in selected eroded and non-eroded sites in the region. Carbon-nitrogen ratio of soil less than 24 leads to net mineralization of nitrogen while carbon-nitrogen ratio of soils greater than 24 leads to net immobilization of nitrogen (USDA-NRCS, 2011). This shows that there is net mineralization of nitrogen in the soils of the various land use types. Secondly, according to Hazelton and Murphy, (2007), C/N values lower than 25 as observed in the present study indicated that decomposition proceeds at a maximum rate possible under hot conditions which is characteristic of the environment of the study. Average calcium-magnesium (Ca:Mg) ratio ranged from 0.18–0.23. The highest occurred in soil under cassava cultivation while the lowest occurred in soil under fallow. Nkwopara *et al*. (2021) observed the range of 1.20 – 1.78 in oil palm, plantain and cassava land uses in the region. Ca:Mg values lower than 3:1 are characteristics of unfertile soils (Landon, 1991).

Considering the values recorded in the soils of the land use types, they are low in fertility. The low Ca:Mg ratio indicates possible Ca deficiency and phosphorus inhibition (Udo *et al*., 2009).

Table 3: Selected elemental ratio of the studied land use types

Land use	Rep	C/N ratio	Ca/Mg ratio
SUC	1	8.26	0.04
	2	7.76	3.20
	3	3.56	0.09
	Mean	6.53	1.11
SUF	1	6.56	0.20
	2	7.13	1.85
	3	12.87	1.42
	Mean	8.85	1.17
SUO	1	20.72	0.51
	2	4.12	-
	3	9.86	0.03
	Mean	11.57	0.18
	LSD (0.05)	0.11**	NS

Note: *=Significant, ** = Highly significant,
NS = Not significant
SUC = Soil under cassava,
SUF = Soil under fallow,
SUO= Soil under oil palm,
C/N ratio = Carbon-nitrogen ratio,
Ca/Mg ratio = Calcium- magnesium ratio.
Rep = Replicate

3.4 Micronutrients content of studied land use types

The results of the micronutrients content of the soils are shown in Fig 1. The mean available copper (Cu) content ranged from 0.106–0.173 mg kg^{-1}. The highest was observed in soil under oil palm while the lowest occurred in soil under fallow. The values of copper obtained in this study were low compared to the critical value of 2.0 mg kg^{-1} reported by Sim and Johnson (1991). Generally, available Cu obtained in this study was low when compared with the value reported by Lawal *et al*. (2012); Adeboye, (2011) in hydromorphic soils of Nigeria but within the range reported by Ahukaemere *et al*. (2014) in paddy soils of Abia state, southeastern Nigeria. The mean available manganese (Mn) of the soils varied between 1.66 and 3.30 mg kg^{-1}. The highest value of (3.30 mg kg^{-1}) was recorded in oil palm while the lowest (1.66 mg kg^{-1}) was obtained in fallow land. There was significant difference in manganese content of the various land use types. The values of manganese obtained in the study were high compared to the critical value of 1.00 mg/kg reported by Udo *et al*. (2008). With this result, all the soils are therefore regarded as having adequate available Mn. Similar findings have been reported by Ahukaemere *et al*. (2014) on paddy soils of Abia state, southeastern, Nigeria. High availability of manganese in these soils may be attributed to pH, clay and organic matter content of the soils. The mean available iron (Fe) content of the soils ranged from 1.94 – 2.63 mg kg^{-1}. The highest value of (2.63 mg kg^{-1}) occurred in soil under oil palm while the lowest value of (1.94 mg kg^{-1}) was obtained under cassava cultivation. No significant difference was observed in the iron content of the soils of the different land use types studied. The values of Fe obtained in this study were low compared to the critical value of 4.5 mg kg^{-1} reported by Lindsay and Norvell (1978). This result is contrary to result by Ahukaemere *et al*. (2014) who reported values of iron higher than the critical value of 4.5 mg kg^{-1} on paddy soils of Abia state, Southeastern, Nigeria. The mean available zinc (Zn) content of the soils ranged from 0.063 – 0.108 mg kg^{-1}. The highest value of (0.108 mg kg^{-1}) was obtained in fallow land while the lowest value of (0.063 mg kg^{-1}) was observed under cassava cultivation. The values of available zn obtained in this study was below the critical level of 0.8 mg kg^{-1} reported by Lindsay and Norvell

(1978) and 0.5 mg kg^{-1} reported by Udo *et al.* (2008). The zinc contents of the studied soils were rated low and are not adequate for crop production. This result is contrary to Ahukaemere *et al.* (2014) on paddy soils of Abia state, southeastern Nigeria.

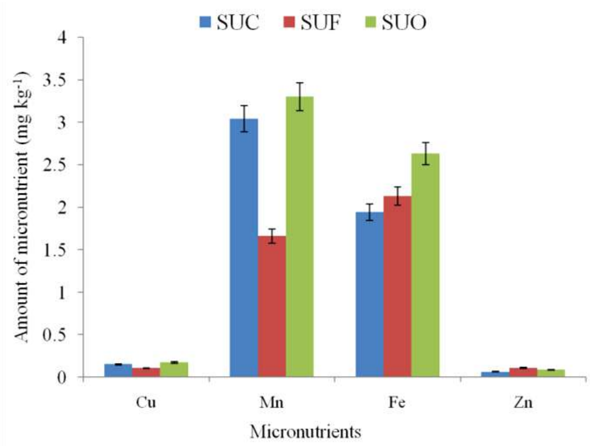

Fig. 1. Available micronutrients of studied land use types

3.5 Relationship between organic carbon and selected properties of the studied soils

The relationship between organic carbon and soil properties are shown in Table 4. Result showed that there was significant positive correlation between organic carbon and moisture content, clay silt, total nitrogen, available phosphorus, effective cation exchange capacity, copper, manganese and zinc (r = 0.34, 0.49, 0.33, 0.56, 0.48, 0.35, 0.50, 0.32 and 0.44 $p \leq 0.05$ respectively. While organic carbon had a non significant positive relation with sand, pH (water), and iron (r = 0.12, 0.24 and 0.02 $p \leq 0.05$) respectively. This implies that increase in organic carbon will result to increase in these properties of the soil.

4. Conclusion

Land use types affected the physicochemical properties as there were significant difference in the properties of the soils studied with the exception of sand content, total nitrogen, calcium, sodium, calcium-magnesium ratio and total acidity. Available micronutrients were higher in soils under oil palm plantation with the exception of zinc content. With the exception of Mn, all the other micronutrients are low and had no significant difference with land use types. However, for optimum crop production, the soils require fertilizers that contain micronutrients while intensive cropping in the soils after a few years without organic and inorganic fertilizer that

Table 4: Simple correlation of organic carbon with selected soil properties (n=9)

Soil properties	r	Level of significance at 5 %
Organic carbon and moisture content	0.34	significant
Organic carbon and clay	0.49	significant
Organic carbon and silt	0.33	significant
Organic carbon and total nitrogen	0.56	Highly significant
Organic carbon and available phosphorus	0.48	significant
Organic carbon and ECEC	0.35	significant
Organic carbon and copper	0.50	Highly significant
Organic carbon and manganese	0.32	significant
Organic carbon and zinc	0.44	significant
Organic carbon and sand	0.12	Not significant
Organic carbon and pH (water)	0.24	Not significant
Organic carbon and iron	0.02	Not significant

is enrich with manganese may apparently lead to mn-deficiency.

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Edible oil coatings influenced biochemical properties of fruits of two sweet orange (*Citrus sinensis*) cultivars stored under ambient conditions in Nigeria

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ABSTRACT

Postharvest losses of sweet orange fruits in Nigeria are considerable and often impacts negatively on economic returns and food security. Edible oil coatings have the potential to extend shelf life and enhance postharvest fruit quality. This study evaluated the effect of edible coatings of Moringa and sesame seed oils on biochemical quality of sweet orange fruits stored under ambient conditions. Harvested fruits of Ibadan sweet and Valencia cultivars were coated with Moringa seed oil (MSO) and Sesame seed oil (SSO) at three concentrations (0%, 1% and 2%) to determine the effect on biochemical attributes of fruits over a 30 day period. The experiment was a 2×2×3 factorial laid out in Completely Randomized Design (CRD) and replicated 3 times. Results indicated significant influence of treatments on biochemical attributes evaluated. Ibadan sweet had higher pH, reducing sugar and Vitamin C while Valencia recorded higher titratable acidity (TA) and total soluble solids (TSS). Fruits coated with SSO had lower TA and TSS but higher pH except on day 30, while those treated with MSO had comparatively higher TA, TSS, Vitamin C and reducing sugar. There was a clear pattern of increase in Vitamin C as oil concentration increased. Generally, TA and TSS increased as storage duration increased while pH, reducing sugar and Vitamin C content deceased with time. Fruit coating improved postharvest quality of orange fruits with MSO doing better than SSO. These can therefore be used to preserve postharvest quality of sweet orange fruits.

KEY WORDS: *Sweet orange*; *Citrus sinensis*; *Edible oil coatings*; *Biochemical changes*; *Storage*

1. Introduction

Citrus *spp.* (Rutaceae) is believed to be the most widely produced fruits in the world. In 2017, production was put at 146,599,168 tons with oranges accounting for 50% of total citrus production. Other citrus species under production are mandarin and tangerines (22.8%), lemons and limes (11.7%), and grapefruit and shadok. (6.2%) (FAO, 2017). Among factors accounting for its importance are the high concentration of ascorbic acid in the fruit pulp and the high industrial potential (Davies and Albrigo, 1994). Internationally, citrus fruit market consists of the processed fruit, represented mainly by extracted orange juice, and the fresh fruit market (Olife *et*

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al., 2015). Although juice extraction, holds precedence over fresh whole fruit for direct consumption. Spain is the leading country for exports of fresh produce (FAO, 2013).

Major citrus producing countries in the world are China, followed by Brazil, USA, India, Mexico and Spain (FAOSTAT, 2017). In Nigeria, there is a sizeable level of production of citrus especially sweet oranges. Nigeria has been ranked 9th in global citrus production. Much of the production resides within the middle belt region (Aiyelaagbe *et al*., 2001), with Benue state taking the overall lead (Avav and Uza, 2002). Although produce from the country does not feature in the international market (UNCTAD, 2010), there however, seem to exist an informal market in citrus fruits between Nigeria and some of her neighbours particularly Niger and Chad. This is in addition to a more or less robust internal market for fresh fruits. At any rate, as obtain elsewhere, citrus cultivation has both financial and nutritional benefits to the producers (Otieno, 2020).

Postharvest fruit losses are a problem globally, being more serious in developing than the developed countries (Hodges *et al*., 2011). This is particularly true of perishable commodities such as fruits and vegetables (Aulakh *et al*., 2013). In Nigeria, there are substantial post harvest losses of fresh fruits including citrus. Measures commonly employed elsewhere in control of postharvest food losses such as chemical preservatives, refrigeration, controlled and modified atmosphere packaging (Zhang and Quantick, 1997) may not be applicable in the Nigerian rural context due to unreliable power supply. Use of chemical preservatives is laden with consumer safety concerns.

In the light of the above, a search for effective options that are cheap, safe and familiar at the rural level has become impetrative. Edible oil coatings have been credited with extending shelf life of fruits (Park, 1999), improving appearance and consumer appreciation of treated fruits (Perez-Gago *et al*., 2006), and exhibiting microbial action against decay organisms. Moringa and sesame seeds are commonly found in Nigeria. However, the use of their oil extracts in preservation of fresh fruits has not been studied, at least not to any appreciable degree. The objective of this study therefore was to investigate effects of moringa and sesame seeds oils on biochemical changes of two sweet orange varieties stored under ambient conditions.

2. Material and Methods

Mature fruits of sweet orange varieties - Ibadan sweet and Valencia - were harvested from a private farm in Vandeikya Local Government Area of Benue State. Each variety was harvested from one stand and fruit placed in plastic crates and transported under cool weather to Makurdi for the storage trial in April, 2018.

Sufficiently dried seeds of Moringa (*Moringa oleifera*) and sesame (*Sesamum indicum*) were subjected to local cold press extraction method to extract the oil. A 1g carboxyl methyl cellulose (CMC) was dispersed in 100ml distilled water with glycerol at 0.5% (v/v) was added as plasticider. The dispersion was heated at 85 °C for 5 minutes with subsequent cooling at room temperature (Sayanjali *et al*., 2011). Sesame seed oil (1% and 2% v/v) and moringa seed oil (1% and 2% v/v) were incorporated into CMC coating solutions. Orange fruits were previously immersed in sodium hypochlorite solution (1% v/v) for 5 minutes and then washed with potable water and left for 1hr to air dry. The fruits were then immersed for three minutes in the coating solutions containing different combinations of CMC essential oil concentrations (0, 1 and 2 %) and gently shaken with a glass stem for 1 minute. The fruits were dried on a nylon filter to drain the excess liquid and packed in a netted plastic container. These were stored under ambient conditions in the laboratory.

The experiment was a 2×2×3 factorial made up of variety (Ibadan Sweet and Valencia), edible oil type (Moringa seed oil, MSO, and Sesame seed oil, SSO) and oil concentration (0%, 1% and 2%). Factorial combinations were arranged in completely randomized design (CRD) with 3 replicates. The 0% acted as the control and was made up of distilled water only. Each experimental unit had 36 fruits giving a total of 1296 fruits. Biochemical changes, namely, total soluble solids, ascorbic acid, reducing sugar, pH and titratable acidity were monitored at 5-day intervals up to 30 days of fruit storage.

Biochemical changes were estimated based on standard procedures as outlined by the Association of Official Analytical Chemists (AOAC, 2005). The total soluble solids (SS) (°Brix) content was determined with a digital refractometer (Model HI 96801, Hanna Instruments, São Paulo, Brazil), and the result was expressed as °Brix (Meng *et al.*, 2008).

Determination of titratable acidity (TA) was done with phenolphthalein as an indicator with 0.1 N NaOH, and the result was expressed as mmolHþ/100 g of fruit (Meng *et al.*, 2008).

Reducing sugar was determined by titrating 100 ml of diluted juice against Fehling's solution till the appearance of brick red precipitates. A pH meter (Model No HANNA B 417) was employed for determination of pH value. Ascorbic acid content was measured using 2, 5-6 dicholorophenol indophenols' method described by A.O.A.C (2005).

Analysis of Variance (ANOVA) was performed on all data collected using Genstat statistical software. Significant means were separated using the least significant difference (F-LSD) procedure at 5% probability level.

3. Results and Discussion

Key weather variables that prevailed during the period of the experiment are summarized in Table 1. Temperature varied from 29.8 to 34.0 °C. Relative humidity ranged from 65.8 to 80.6%. Unlike temperature, RH generally increased from the beginning of the study to the end. Table 2 is a summary of the main effects of variety, oil type and concentration on total soluble solids (TSS) content of stored sweet orange fruits. Valencia Late had a significantly higher TSS (°Brix) compared to Ibadan sweet. Throughout the duration of the experiment, oil type did not have consistent influence on fruit TSS. At 10 days of

Table 1: Temperature and Relative Humidity during the period of storage

Weather variables	Days in storage						
	0	5	10	15	20	25	30
Av. Temp (°C)	32.75	34.04	32.75	30.52	29.80	31.2	30.14
R. H (%)	65.8	64.28	67.92	78.32	79.46	77.56	80.56

Table 2: Effect of variety, oil type and concentration on Total Soluble Solids (TSS) (°Brix) of stored sweet orange fruits

Treatment	Days in storage						
	0	5	10	15	20	25	30
Variety							
Ibadan Sweet	12.0	11.4	10.7	11.8	13.0	12.7	13.1
Valencia Late	12.6	13.3	13.3	14.3	15.7	13.9	15.1
LSD $_{(0.05)}$	0.06	0.50	0.19	0.18	0.13	0.12	0.13
Oil Type							
MSO	12.3	12.3	12.1	13.0	13.5	13.4	14.7
SSO	12.3	12.3	11.8	13.1	15.2	13.3	13.5
LSD $_{(0.05)}$	NS	NS	0.19	NS	0.13	NS	0.13
Oil Concentration (%)							
0	12.3	12.1	11.8	13.3	15.4	14.5	14.6
1	12.3	12.2	11.9	13.1	14.1	11.9	13.2
2	12.3	12.7	12.3	12.8	13.5	13.6	14.5
LSD $_{(0.05)}$	NS	NS	0.23	0.23	0.16	0.14	0.16

NS – Non Significant; MSO – Moringa seed oil; SSO – Sesame seed oil

storage, fruits coated with MSO showed higher TSS values. Ten days later, the reverse was the case, although at the end of the storage period, MSO coated fruits recorded higher TSS values than those coated with SSO. Oil concentration showed significantly higher values at 10 – 30 days of storage. Interestingly, as from 15 days of storage, control fruits had higher TSS than coated ones. However, at the end of storage (30 days), uncoated fruits and those coated with 2 % edible oil gave statistically similar TSS values which were higher than those of the 1 % oil concentration.

Effect of the factors on reducing sugar content is presented in Table 3. Ibadan sweet showed superior reducing sugar levels throughout the period of the experiment except at 5 days of storage. From 5 – 15 days, MSO had more favourable effect on reducing sugar content than SSO. Though no significant effect on this quality was observed between MSO and SSO, it was evident that coated fruits gave statistically higher reducing sugar values than the uncoated ones throughout the storage period.

Varietal influence on titratable acidity (TA) was significant throughout the study duration. Generally, Valencia recorded higher levels of titratable acidity than Ibadan sweet (Table 4). Also fruits coated with MSO were generally higher in TA concentration except at 25 and 30 days of storage when those differences cancelled out. Coating of fruits also led to higher production of TA compared to those that were not coated. Influence of sweet orange variety, edible oil type and concentration on pH of stored fruits is presented in Table 5. Generally, fruits of Ibadan sweet variety had higher pH values than those of Valencia. Effect of oil type on pH of stored fruits was not consistent. It was observable that coating of fruits with edible oils at 1% and 2% gave rise to fruits with lower pH values.

All three factors – variety, edible oil type and concentration – significantly influenced vitamin C content of fruits throughout the period under

Table 3: Effect of variety, oil type and concentration on reducing sugar content (%) of stored sweet orange fruits

Treatment	Days in storage						
	0	5	10	15	20	25	30
Variety							
Ibadan Sweet	6.3	6.2	5.8	5.4	5.0	4.7	4.4
Valencia Late	5.4	6.3	5.0	4.7	4.3	4.0	3.6
LSD $_{(0.05)}$	0.06	0.08	0.09	0.05	0.06	0.13	0.07
Oil Type							
MSO	5.9	5.8	5.5	5.1	4.8	4.4	4.0
SSO	5.9	5.7	5.3	5.0	4.5	4.3	4.0
LSD $_{(0.05)}$	NS	0.08	0.09	0.05	NS	NS	NS
Oil Concentration (%)							
0	5.6	5.6	5.3	4.9	4.4	4.1	3.7
1	5.8	5.8	5.4	5.1	4.8	4.5	4.3
2	5.8	5.8	5.5	5.2	4.7	4.5	4.1
LSD $_{(0.05)}$	0.10	0.10	0.11	0.06	0.07	0.16	0.08

NS – Non Significant; MSO – Moringa Seed Oil; SSO – Sesame Seed Oil

consideration (Table 6). Ibadan sweet maintained a consistent lead in vitamin C content throughout the period of the experiment. MSO also showed a better ability to retain vitamin C content of fruits as storage progressed. Coating of fruits enhanced their ability to retain vitamin C. Generally, an increase in vitamin C reduction was observed as oil concentration moved from 0% to 2%.

Significant interaction was observed between

Table 4: Effect of variety, oil type and concentration on titratable acidity (%) of stored sweet orange fruits

Treatment	Days in storage						
	0	5	10	15	20	25	30
Variety							
Ibadan Sweet	0.68	0.86	1.65	1.16	1.10	1.13	0.96
Valencia Late	0.45	1.01	1.54	1.61	1.24	1.47	1.24
LSD $_{(0.05)}$	0.01	0.07	0.05	0.01	0.02	0.08	0.04
Oil Type							
MSO	0.57	0.99	1.61	1.39	1.32	1.30	1.09
SSO	0.57	0.88	1.58	1.38	1.02	1.29	1.09
LSD $_{(0.05)}$	NS	0.07	NS	0.01	0.02	NS	NS
Oil Concentration (%)							
0	0.57	0.90	1.38	1.79	1.19	1.29	0.85
1	0.57	1.10	1.61	1.25	1.06	1.49	1.52
2	0.56	0.81	1.79	1.12	1.26	1.11	0.92
LSD $_{(0.05)}$	NS	0.08	0.04	0.02	0.03	0.09	0.05

NS – Non Significant; MSO – Moringa Seed Sil; SSO – Sesame Seed Oil

Table 5: Effect of variety, oil type and concentration on pH of stored sweet orange fruits

Treatment	Days in storage						
	0	5	10	15	20	25	30
Variety							
Ibadan Sweet	4.1	4.1	3.6	3.8	3.8	3.9	3.9
Valencia Late	4.6	3.9	3.7	3.6	3.8	3.8	3.6
LSD $_{(0.05)}$	0.01	0.17	0.01	0.01	0.01	0.04	0.02
Oil Type							
MSO	4.4	4.0	3.6	3.7	3.7	3.7	3.8
SSO	4.4	4.0	3.6	3.7	3.8	4.0	3.7
LSD $_{(0.05)}$	NS	NS	NS	NS	0.01	0.04	0.02
Oil Concentration (%)							
0	4.4	4.1	3.7	3.5	3.8	3.8	3.9
1	4.4	3.8	3.6	3.8	3.8	3.6	3.6
2	4.4	4.1	3.5	3.8	3.8	3.8	4.1
LSD $_{(0.05)}$	NS	0.20	0.02	0.01	NS	0.04	0.02

NS – Non Significant; MSO – Moringa Seed Oil; SSO – Sesame Seed Oil

variety and oil concentration on vitamin C content of stored fruits (Table 7). Although vitamin C content of fruits increased with increase in oil content for both varieties, at 30 days of storage, 1 % oil concentration gave` significantly higher vitamin C content (28.6%) compared with the 2 % oil concentration (27.8%). Generally, there was an increase in TSS and TA as storage progressed while reducing sugar, pH and vitamin C content decreased with increase in time of fruit storage.

The higher TSS values of Valencia, as compared with Ibadan sweet conforms to established opinion. Valencia has been noted as the most widely cultivated sweet orange cultivar globally (Saunt, 1990). It has also been acclaimed the most preferred by consumers due to its attractive colour and high TSS and juice content (Davies and Albrigo, 1994). Processors also place high value on it as they utilize it in blending with lower quality juices to improve their taste. It is thus obvious that this variety could be consumed as fresh fruit and as processed juice. Since seeds coated with MSO had higher TSS at the end of the storage period, it is logical that this coating be adopted for better retention of TSS particularly when storage period is to be extended.

TA and pH followed similar pattern. Thus, surprisingly, Valencia had higher TA than Ibadan Sweet. Although the percentage fruit weight loss of the two varieties as earlier reported (Ugese *et al*., 2018) did not show statistical significance, it is very likely that juice volume of Ibadan Sweet was a bit higher than that of Valencia. As such for equivalent volume of juice tested, TA tended to be higher in Valencia than Ibadan Sweet. Unfortunately, juice volume was not measured in this experiment. Otherwise, results could purely be based on varietal differences that may have little or nothing to do with juice volume.

It is surprising that Ibadan Sweet contained statistically more Vitamin C than Valencia, which is acclaimed the most popular sweet orange variety worldwide (Saunt, 1990). This may give additional impetus to the rising popularity of Ibadan Sweet among Nigerian citrus growers particularly those in Benue State.

Table 6: Effect of variety, oil type and concentration on Vitamin C content (mg 100g^{-1}) of stored sweet orange fruits

Treatment	Days in storage						
	0	5	10	15	20	25	30
Variety							
Ibadan Sweet	87.8	62.1	57.9	47.6	42.6	32.2	26.9
Valencia Late	75.3	54.4	47.5	40.5	35.6	28.6	23.8
LSD $_{(0.05)}$	0.72	0.88	0.78	0.94	0.63	0.48	0.57
Oil Type							
MSO	81.5	59.3	53.0	45.2	40.8	31.9	26.5
SSO	81.5	57.1	52.3	43.0	38.4	29.0	24.2
LSD $_{(0.05)}$	NS	0.88	NS	0.94	0.62	0.48	0.57
Oil Concentration (%)							
0	81.5	54.9	50.6	39.9	36.9	28.6	23.1
1	81.5	58.9	52.5	45.1	40.1	30.3	26.1
2	81.5	60.8	55.0	47.2	40.2	32.3	26.5
LSD $_{(0.05)}$	NS	1.08	0.96	1.15	NS	0.59	0.69

NS – Non Significant; MSO – Moringa Seed Oil; SSO – Sesame Seed Oil

Table 7: Interactive effect of variety and oil concentration on Vitamin C content (mg 100g^{-1}) of stored sweet orange fruits

Variety	Oil Concentration (%)	Days in storage						
		0	5	10	15	20	25	30
Ibadan sweet	0	87.8	57.1	55.0	40.5	39.5	29.8	24.4
	1	87.8	63.3	56.9	50.5	44.5	32.0	28.6
	2	87.8	65.8	61.6	51.9	43.3	34.9	27.8
Valencia	0	75.3	52.6	46.2	39.2	34.9	27.5	22.4
	1	75.3	54.5	48.0	39.7	35.3	28.7	23.6
	2	75.3	55.9	48.3	42.6	37.1	29.7	25.3
LSD $_{(0.05)}$		NS	1.53	1.35	1.63	1.09	0.83	0.98

The usefulness of sweet orange is largely accounted for by its high content of vitamin C which is considered a very important anti-oxidant. MSO coating enhanced the levels of Vitamin C in fruits compared with SSO. Since citrus fruits are largely valued for their Vitamin C content, any coating material that minimises its degradation during storage is considered an asset. Vitamin C has been noted to be highly degradable in storage (Wilhelmina, 2005) and could be particularly so under ambient conditions.

Increase in TSS and TA with storage duration as obtained in this study is contrary to reports by Alhassan *et al*. (2014) and Faasema *et al*. (2011). It is however consistent with a number of other studies. Echeverria and Ismail (1987) observed biochemical changes in four varieties of citrus in storage. There was an increase in TSS of

"Hamlin" oranges, "Robinson" tangerines and Palestine limes. TSS of Marsh grapefruit however, remained unchanged. Similar observations have been made by Samad *et al*. (2019) in China lime (*Citrus aurantifolia*) and Rapisarda *et al*. (2008) in mandarin. Increase in TSS in storage could be due to a breakdown of organic compounds to simpler sugars (Faasema *et al*. 2011). Echeverra and Ismail (1987) found a positive correlation between TSS and sucrose content of Hamlin oranges. Sugars and acids are major constituents of citrus fruit that define its quality. However, they also serve as respiratory substrates. As such, their concentration during storage could depend on postharvest storage conditions such as storage duration, temperature humidity, and application of coatings, among others (Echeverría and Ismail, 1987). Variable postharvest storage conditions as well as genetic factors may therefore account for the seeming contradictory results that are often reported by different researchers.

Temperature has been noted as the most important environmental factor affecting the postharvest life of horticultural commodities due to its influence on respiration rate. For every 10 °C increase in temperature, there is a 2 to 3-fold increase in respiration rate which reduces shelf life of the produce by half or more. (Chowdhury, 2018). Marcilla *et al*. (2006) who stored citrus fruits at temperatures ranging from 3 – 25 °C reported that acidity of fruits stored at higher temperatures (20-25 °C) was lower than that of fruits stored at lower (5-15 °C) temperatures. It is probable that at higher temperatures, the organic acids were more rapidly used up in respiration, thereby lowering TA values. Temperature range in the course of the study reported herein was 29.80 – 34.04 °C. This is high enough to accelerate the process of biochemical reactions. But to what extent high temperatures accelerate conversion of organic acids to simpler sugars (increasing some biochemical traits) or takes them up in respiration (reducing some biochemical traits) seem not to have been clearly articulated. In other words, the pattern of biochemical changes in stored fruits arising from the influence of high temperatures does not seem to be universal. Suffice it to state that genotype, storage duration, coating or the absence of it, environmental factors during storage (Echeverría and Ismail, 1987), stage of fruit maturity at harvest (Alhassan *et al*., 2014), and their possible interactions may all influence the pattern of biochemical changes that occur.

A decrease in pH values of fruits as observed in this study is consistent with results obtained by Alhassan *et al.* (2014), although stage of harvest of fruits appeared to have influenced their results. For full ripe fruits, pH increased from 3.75 – 4.09. The pH of half ripe and mature green fruits witnessed a decrease from 4.03 – 3.84 and 4.03 – 3.88 respectively. There was a general decrease in vitamin C content of fruits as storage progressed. Samad *et al*. (2019) observed such trend in China lime (*Citrus aurantifolia*). Postharvest storage conditions have been known to increase losses of Vitamin C. In particular, higher temperatures and longer storage durations drastically depreciates Vitamin C content of fruits and vegetables (Lee and Kader, 2000). In a 21 days storage trial using evaporative cooling system, Idah *et al*. (2010) reported a decrease in ascorbic acid content from 7.52 to 0.49%. Total sugar content also decreased from 0.65 to 0.25%. In another study, Hamedani *et al.* (2012) observed a decrease in fruit quality parameters in storage namely, TSS, TA and ascorbic acid. It appears somewhat strange that Alhassan *et al.* (2014) and Faasema *et al.* (2011) rather found increases in ascorbic acid content of citrus fruits stored under ambient tropical conditions.

Generally, Vitamin C is highly susceptible to losses during postharvest handling and storage (Wilhelmina, 2005). The higher content and retention of Vitamin C by Ibadan Sweet variety compared with Valencia could be due purely to genotype (Lee and Kader, 2000). For most part of the storage period, coated fruits had lower TSS than uncoated ones or at least showed such tendency. Samad *et al.* (2019) found that fruits of China lime treated with garlic extract had lower TSS values than control fruits. In bell pepper, Abad Ullah *et al.* (2017) reports that coating of fruits drastically delayed increase in TSS compared with non-coating. In tomato, Ali *et al*. (2010) also found that coating fruits with 10% gum Arabic delayed increase in TSS of the fruit. Application of edible coatings led to higher TA values in contrast to the control.

Vitamin C retention was better when fruits were coated with edible materials. This is corroborated by reports of Samad *et al.* (2019) in China lime where considerably higher amounts of Vitamin C were obtained by treating fruits with garlic and ginger extracts. Similar observation was made in bell pepper coated with gum Arabic (Abad Ullah *et al.*, 2017), and in tomato (Eltoum and Babiker, 2014). Ayranci and Tunc (2004) ascribed such effects as they found in apricots and green peppers to be due to a reduction in oxidation of organic acids leading to enhanced levels of ascorbic acid in coated fruits. MSO enhanced vitamin C retention better than SSO. Since Vitamin C is crucial in defining nutritional quality of citrus, storage with MSO may be more beneficial.

In conclusion, TSS and TA were found to increase with time while pH, reducing sugar and ascorbic acid reduced as storage progressed. Essential oil coatings enhanced biochemical attributes of fruits with the 2% concentration exerting better effects. As such, the oils, particularly MSO can be utilized to delay postharvest quality deterioration of sweet orange fruits under ambient storage conditions.

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Geochemical elements and soil fertility in Kwara State: The role of parent materials, topography, and land use

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ABSTRACT

This study explores the soil nutrient status, geochemical composition, and fertility characteristics across Kwara State, Nigeria, to support sustainable soil management amid climate change challenges. A total of 266 soil samples were systematically collected using a uniform rigid grid sampling method and analysed through standard laboratory procedures. Statistical and geostatistical analyses, including descriptive statistics, interpolation, hierarchical clustering, and correlation analysis, were employed to examine spatial variability and interrelationships among soil properties. The results revealed mean and median soil pH values of 6.63 and 6.8, indicating moderately acidic to neutral conditions suitable for most crops. Soil organic carbon (SOC) levels were moderate, averaging 2.19%, suggesting fair organic matter content. Correlation analysis identified soil texture, organic matter, and pH as key determinants of nutrient availability. Linear discriminant analysis (LDA) further showed that variations in soil parent material, land use, and topography were primarily governed by particle size distribution, pH, and potassium (K^+) concentration. Sandy soils exhibited higher pH levels, promoting base cation availability but limiting certain micronutrients, while clay-rich soils demonstrated stronger nitrogen retention. Overall, organic matter was found to be vital for maintaining soil fertility. These findings provide essential guidance for developing site-specific soil management practices to improve agricultural productivity and sustainability in Kwara State.

KEY WORDS: *Soils*; *Parent material*; *Land use*; *Fertility*; *SOC*

1. Introduction

Soils play a fundamental role in regulating environmental processes, acting as both geochemical sinks and buffers that mediate the movement of chemical elements across the atmosphere, hydrosphere, and biosphere (Qi *et al*., 2009; Liu *et al*., 2018). Understanding the spatial distribution and concentration of geochemical elements in near-surface soils is critical for assessing agricultural productivity, environmental health, water quality, land-use planning, and industrial pollution control. Soil geochemistry is primarily influenced by the mineralogical and chemical composition of its parent material (Chen *et al*., 2008), but topography and land-use practices also play significant roles in shaping soil fertility and elemental variability.

Geochemical elements in soils originate largely from the weathering of parent materials and are modified by pedogenic processes. However,

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anthropogenic activities such as agriculture, mining, and urbanization can significantly alter the natural geochemical landscape, often resulting in the accumulation of heavy metals and other pollutants (Padarian *et al.*, 2022; Gayan *et al.*, 2023; Hartmann and Six, 2023). The interaction between natural and human-induced factors determines soil fertility and elemental bioavailability, which are crucial for sustaining plant growth, livestock quality, and food security (Edwin and Muthu, 2021). Establishing background concentrations of soil geochemical elements provides a baseline for distinguishing between natural enrichment and contamination.

Topography influences soil formation and element distribution by affecting erosion, leaching, and water retention patterns. In undisturbed ecosystems, soil trace element concentrations reflect parent material composition and environmental conditions, whereas in cultivated landscapes, fertilizers, pesticides, and agrochemicals introduce additional elemental inputs (Wiesmeier *et al.*, 2019). The intensification of agriculture, driven by population growth and rising food demand, has led to concerns about soil degradation and heavy metal accumulation, which can disrupt soil biological functions and pose risks to human and animal health through food chain contamination (Alloway, 1990; Miner, 2020).

This study investigates the spatial variability of soil textural, macro- and micronutrients across different geological formations and ecological regions of Kwara State, Nigeria. Given the region's diverse geology, climate, and land-use practices, we hypothesize that soil fertility and elemental distribution are primarily driven by parent material characteristics, modified by topographic influences and anthropogenic activities. By providing baseline data on soil geochemistry, this research aims to support sustainable land management strategies that enhance agricultural productivity while mitigating environmental risks.

2. Material and Methods

2.1 The study area

The study area encompasses Kwara State in Nigeria's north-central geopolitical zone (Fig. 1). The State is known for its unique ecological landscapes, diverse geological features, and significant agricultural activities, making it an ideal location for examining the impact of bedrock materials, land use, and topography on soil properties. Kwara State has a broad range of ecological zones, from the West Sudanian Savanna to the Guinean Forest-Savanna Mosaic, and even Montane Forests in the north eastern corner. Kwara's geographical coordinates lie between latitudes 8°30' and 11°30' North of the Equator and longitudes 3°E to 6°30' East of the Greenwich Meridian, covering approximately 36,825 square kilometres and divided into sixteen (16) Local Government Areas (LGAs) (Kwara State Government, 2024) (Fig. 2). The state's topography includes extensive savannas, forested highlands, and several rivers, such as the Niger and Awun, providing water for irrigation and domestic use. Kwara's unique vegetation zones foster a variety of crops and support diverse wildlife. However, the state also contends with ecological issues like soil erosion and deforestation, necessitating sustainable land management practices.

The State has a tropical savanna climate that feature distinct wet and dry seasons. It receives annual precipitation between 1,200 mm in the south and 1,000 mm in the north. Agriculture is the backbone of the state's economy, with production of staple crops like yams, cassava, maize, rice, and significant livestock production (National Bureau of Statistics, 2023). Atmospheric 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 to 34°C. Relative humidity in the wet season is between 75 to 80% while in the dry season it is about 65% (National Bureau of Statistics, 2023). The climate supports tall grasses interspersed with short scattered trees. The soils are formed majorly from basement complex rocks (metamorphic and igneous rocks) covering about 95% of the area, and sedimentary rock along the Niger River bank covering about 5% of the total area (Fig. 1). The metamorphic rocks include biotite gneiss, banded gneiss, quartzite augite

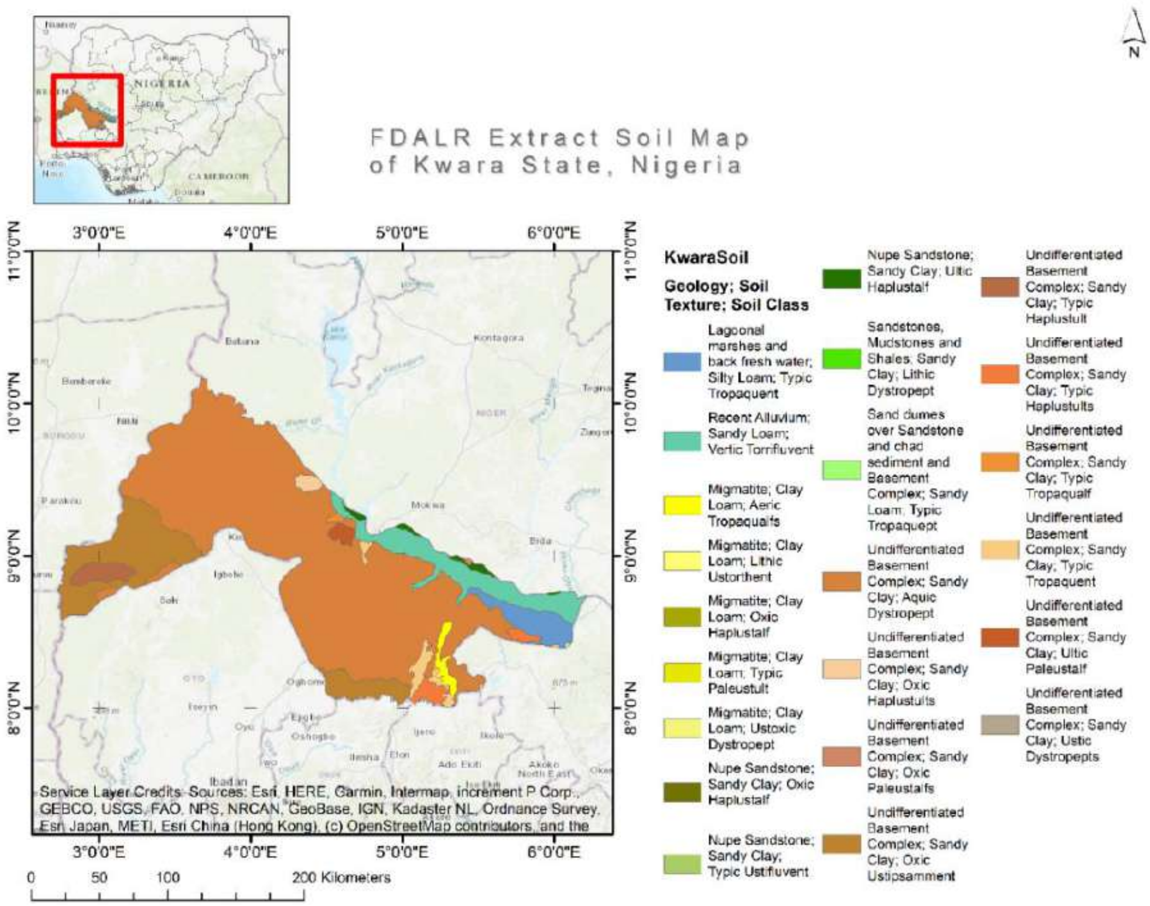

Fig. 1: Map of Kwara State showing the Federal Department of Agricultural Land Resources (FDALR) extract soil map of the state, indicating geology and soil types. Over 95% of soils in the state are developed over undifferentiated basement complex rocks, having predominantly loamy to sandy clay soil texture (FDALR, 1990).

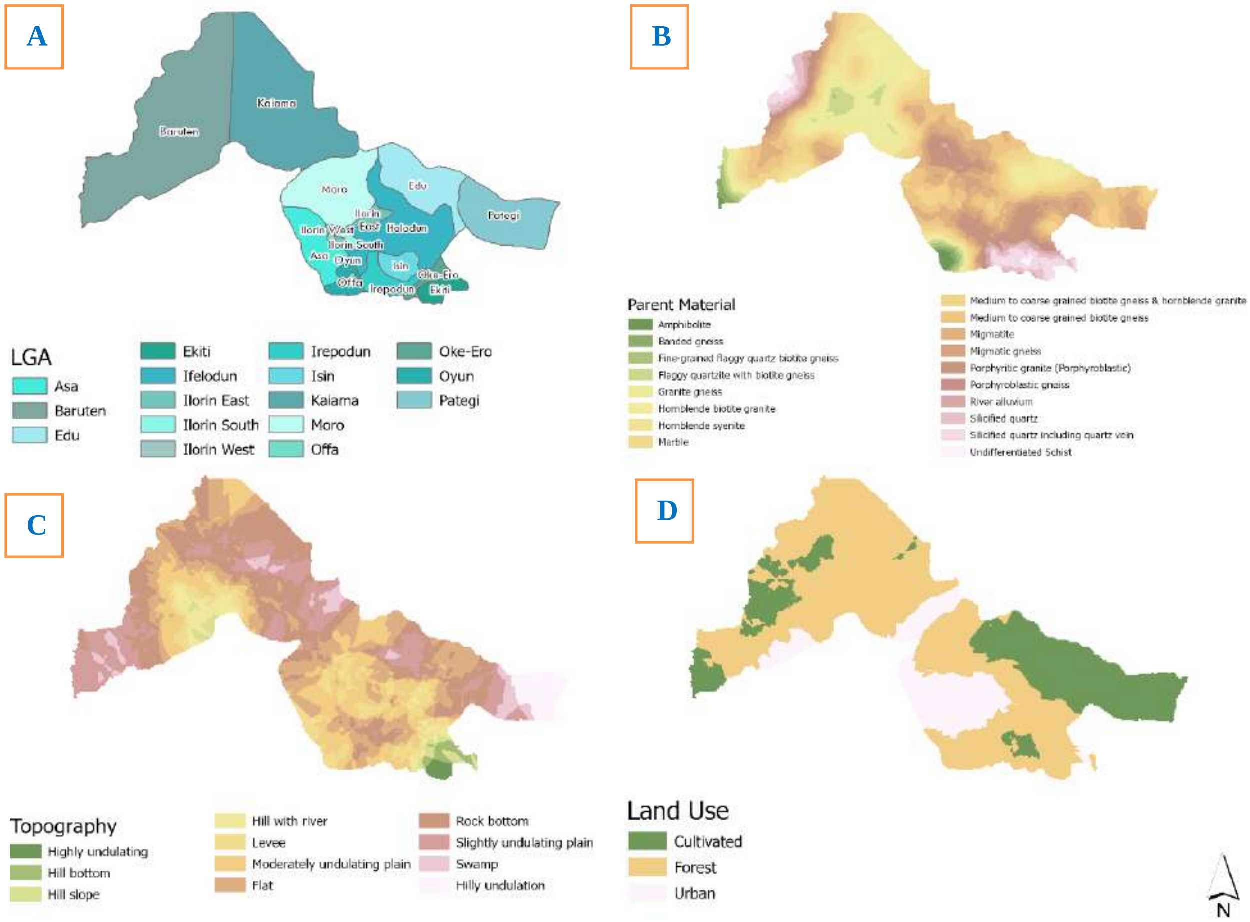

Fig. 2: A: Kwara State local government areas; B: Soil parent materials in the study area; C: Topography of the study area; D: Land use in the study area.

gneiss and granitic gneiss. The intrusive rock includes pegmatite and vein quartz (FDALR, 1990).

2.2 Field survey

This study employed a combination of remote sensing and geographic information system (GIS) to aid systematic ground-truthing and field sampling in the study area. The satellite data utilized were 5-meter resolution SPOT 5and the 30-meter resolution Landsat 8 ETM+ imageries resampled to 15 m using the panchromatic band. Landform information was derived from 30-meter resolution Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) Version 3 (ASTGTM). Land use data was sourced from the Vegetation and Land Use Project of the Forestry Management Evaluation and Coordinating Unit (FORMECU), 2025 under the Nigerian Federal Ministry of Environment. Digital geological data was obtained from geological maps produced by the Federal Geological Survey of Nigeria (Federal Ministry Mines and Steel

Development, Nigeria, 2025). Fieldwork involved systematic soil sampling for surface soil fertility analysis. Samples were collected at predetermined intervals across the study area using a rigid-grid sampling approach at a 10.6 km grid interval. All processing was done in the ArcGIS environment. Predetermined sampling points falling within highly urban areas and inaccessible points were excluded from the sampling process, and a total of 266 samples were collected.

In the field, sampling points were located using GPS-enabled handheld Android devices (phones/tablets). At each point, the soil was assessed using an orchard auger to a depth of 100 cm, and top soil samples were collected for the 0 - 30 cm depth. Sampling point characteristics were described *in situ* and recorded using the ODK software, which enabled real-time data transmission to a cloud-based database. Key physical and morphological characteristics assessed for each sample included soil colour, texture, structure, consistency, effective depth, stoniness, drainage status, and any included material - topographic, land use, erosion, and deposition characteristics were also recorded *in-situ*.

Photographs of the landscape and soil profiles were captured and stored using the ODK. For each sample, machine-readable QR codes were generated as a digital label, ensuring an efficient tracking of samples from the field to the laboratory for analysis and subsequent data storage. A composite of 3 samples was collected at each point using a modified African Soil Information Service (AfSIS) protocol (Walsh, 2023). Soils were sampled off-season in 2022.

2.3 Laboratory and Data analysis

Soil samples were air-driedand sieved to remove materials larger than 2 mm. The less than 2 mm portions were used to determine the physico-chemical properties of the soils. Soil pH was determined in 1:2.5 soil/water suspensions while organic carbon was determined by the wet combustion method of Walkley-Black (Nelson and Summers, 1982). The particle-size distribution was determined by the hydrometer method of Gee and Bauder (Gee and Bauder, 1986). Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) were extracted using 1N ammonium acetate (NH_4OAc) solution at pH 7 (International Institute of Tropical Agriculture (IITA), 1979). Calcium and Mg^{2+} concentrations were read on aBUCK Scientific ACCUSYS 230 Atomic Absorption Spectrophotometer and K^{+} and Na^{+} by a PFP-7 Industrial Flame Photometer. Effective cation exchange capacity (ECEC) was calculated asthe sum of the basic cations and the exchange activity.

Available phosphorus was extracted using the Bray 1 method of Bray and Kurtz (1945). Total nitrogen (TN) was determined by the macro-Kjehdal method (Bremner and Mulvaney, 1982). Available micronutrients (Zn, Cu, Mn, Fe) were determined using the DTPA method of Lindsay and Norwell (1978). The values were then read on an atomic adsorption spectrophotometer. Boron (B) was determined by Morgan’s solution and concentration read using a Spectronic 20. Data collected were subjected to summary exploratory statistical analysis in R. Geostatistical interpolation was done in ArcGISPro to create continuous surface (raster) layers of soil properties employing the Ordinary Kriging technique and using the spherical semi-variogram model and a variable search radius of 12 points. Hierarchical clustering (implemented in Scikit-learn Python library) and correlation analysis (using "corrplot" R package) were performed to establish patterns and explore relationships between measured parameters and experimental factors.

3. Results and Discussion

3.1 Status of soil physical properties, nutrients and geochemical elements

The soils of Kwara State exhibited a predominantly acidic reaction, with pH values ranging from 4.4 to 7.6 (Table 1). The widespread occurrence of acidic soils is consistent with previous studies in Nigerian savanna regions, where leaching and prolonged weathering contribute to soil acidification (Adepetu *et al.*, 1996; Akinrinde and Obigbesan, 2000). Acidic soils influence nutrient availability by reducing cation exchange capacity and increasing the solubility of toxic elements such as aluminum and manganese, which can negatively impact plant growth (Hartz, 2007). The low pH observed in many of the sampled soils suggests a potential need for liming to enhance soil fertility, particularly in cultivated areas where nutrient depletion is more pronounced due to intensive farming practices (Brady and Weil, 2016).

Soil OM content varied widely across the study area, with approximately 65% of the soils exhibiting relatively moderate organic carbon (OC) concentrations (~20 g kg^{-1}). About 31% of the soils had OC levels between 10 and 20 g kg^{-1}, while 4% had concentrations below 10 g kg^{-1}. The moderate OC levels in some regions in the study area aligns with findings by Raji *et al.* (1999), suggesting preservation of C over time possibly related to C addition-promoting land-use practices, such as organic amendment and forestry. However, in areas with low OC content, practices such as intensive tillage and residue removal may have contributed to organic matter depletion, leading to reduced soil fertility and soil water-holding capacity (Lal, 2004). Given the critical role of soil organic matter in enhancing microbial activity, nutrient retention, and

Table 1: Descriptive statistics of soil properties across the study area (0 - 30 cm; N=266)

	Sand (%)	Silt (%)	Clay (%)	B (mg kg^{-1})	S (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
Mean	87.7	5.64	6.60	1.64	1.84	1.21	0.35
Median	88.2	6.00	5.76	1.64	1.46	0.79	0.27
Minimum	54.2	1.00	5.76	0.69	0.88	0.08	0.02
Maximum	94.4	30.0	25.8	2.62	11.7	3.50	2.49
Standard deviation	5.88	4.73	2.15	0.36	1.87	0.89	0.28

	OM (%)	OC (%)	pH H_2O	pH KCl	AP (mg kg^{-1})	TP (mg kg^{-1})	TN (%)	K^+ (cmol$_c$ kg^{-1})	Ca^{2+} (cmol$_c$ kg^{-1})	Mg^{2+} (cmol$_c$ kg^{-1})	Na^+ (cmol$_c$ kg^{-1})
Mean	3.80	2.20	6.68	5.32	5.74	138	0.420	0.04	0.12	0.20	0.30
Median	3.84	2.23	6.80	5.40	5.79	141	0.195	0.04	0.10	0.20	0.04
Minimum	0.34	0.20	4.40	3.40	0.02	104	0.01	0.02	0.01	0.12	0.02
Maximum	5.43	3.15	7.60	6.60	16.6	184	15.7	0.07	0.26	0.22	34.9
Standard deviation	1.00	0.58	0.45	0.67	3.72	14.4	1.14	0.01	0.07	0.01	2.98

Note: AP – Available Phosphorus, TP – Total Phosphorus, TN – Total Nitrogen structural stability, maintaining adequate OM levels through conservation agriculture, cover cropping, and organic amendments is essential for sustainable soil management (Paustian *et al.*, 2016).

The surface soil texture across the study area was generally sandy, with sand content ranging from 54 to 94% and silt content between 1 and 30%. Approximately one-third of the samples were classified as loamy sand, while sandy loam soils with heavier surface textures were found primarily in levee areas, swampy terrains, and gently undulating plains. The prevalence of sandy soils indicates rapid drainage, which may exacerbate nutrient leaching and reduce soil moisture retention, particularly in upland areas (Brady and Weil, 2016). This poses a challenge for crop production, especially under climate change which precipitates erratic rainfall patterns. Under these conditions, the incorporation of OM and mulching could help improve water retention and mitigate nutrient losses (Bationo *et al.*, 2007).

Despite the moderate to high N content in Kwara State's soils, available phosphorus (AP) levels were generally low, with approximately 95% of soils containing less than 10 mg P kg^{-1}. Only 5% of the samples exhibited higher AP concentrations (>10 mg P kg^{-1}), primarily concentrated in Baruten LGA, a key agricultural region in the northwestern part of the State (Fig. 3). This aligns

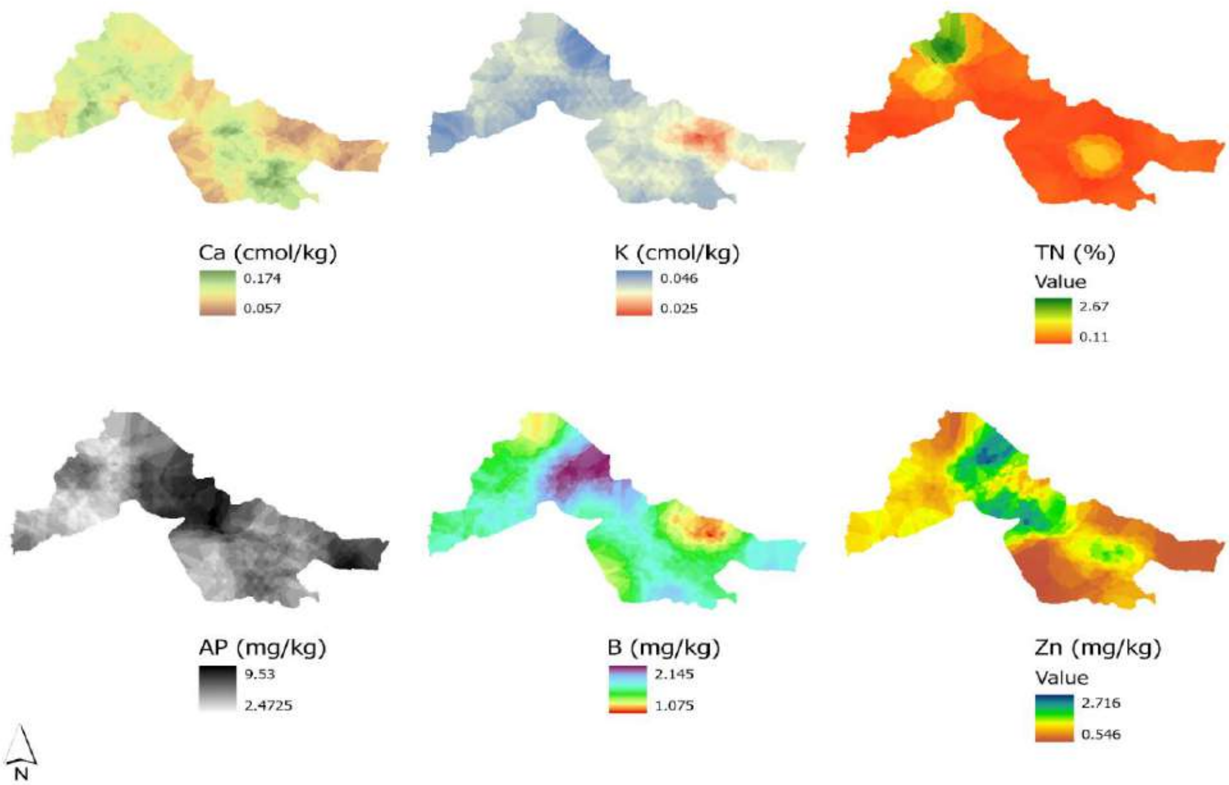

Fig. 3: Spatial distribution of geochemical elements

with previous studies highlighting phosphorus deficiency as a major constraint to crop production in sub-Saharan Africa (Buresh *et al*., 1997; Sanchez, 2002). Phosphorus is an essential nutrient for root development and energy transfer in plants, and its low availability may significantly limit agricultural productivity. The low AP levels suggest that phosphorus fertilization or the application of rock phosphate amendments may be necessary to improve soil fertility (Kolawole *et al*., 2024). Additionally, some urban areas exhibited relatively high AP levels, likely due to organic waste accumulation and fertilizer application, supporting findings by previous researchers that human activities significantly influence phosphorus distribution in soils (Yoon *et al*., 2024).

Soil exchangeable Ca values ranged from 0.01 to 0.26 $cmol_c\ kg^{-1}$ with a mean value of 0.11 $cmol_c\ kg^{-1}$. Exchangeable Mg, K and Na were all rated as very low with mean values of 0.20, 0.04 and 0.30 $cmol_c\ kg^{-1}$ (Table 1, Fig. 3). The very low percentage of variance (<1%) points to the uniformity of these bases however, there are relatively lower K contents within the schist belts in the southeastern part of the State (Fig. 3). Schists are generally known to weather slowly and low in bases. The CEC of the studied soils was predominantly low, with values mostly falling below 10 $cmol_c\ kg^{-1}$. However, soils derived from basaltic parent materials exhibited moderate CEC values, ranging from 10 to 20 $cmol_c\ kg^{-1}$. The low CEC values are indicative of limited nutrient-holding capacity, which can lead to rapid nutrient depletion under intensive cropping systems (Havlin *et al*., 2013). In contrast, moderate CEC values in basalt-derived soils suggest a better ability to retain essential cations such as calcium, magnesium, and potassium, which are critical for plant growth (Brady and Weil, 2016). To mitigate the challenges posed by low CEC, soil management practices such as organic matter incorporation, biochar application, and the use of cover crops can be implemented to enhance nutrient retention and improve soil fertility (Lehmann and Joseph, 2015).

Soil micronutrients in Kwara State ranged from low to moderate concentrations. Copper (Cu) levels varied from 0.024 to 2.49 mg kg^{-1}, with a mean of 0.35 mg kg^{-1}. Extractable zinc (Zn) concentrations were rated as moderate to high, with a mean of 1.21 mg kg^{-1} (Fig. 3). Boron (B) and sulphur (S) contents ranged from 0.69 to 2.62 mg kg^{-1} and 0.88 to 11.74 mg kg^{-1}, respectively, classifying them as moderate to high. These micronutrients were not significantly influenced by topography or land use; however, parent material exhibited a significant correlation with B and Zn. The highest concentrations of these micronutrients were recorded in soils derived from granite gneiss and hornblende biotite gneiss in the northern part of the state. Conversely, relatively lower micronutrient contents were found in soils overlying amphibolite and medium to coarse biotite and hornblende granite formations in the south eastern and southern regions.

The coefficient of variation (CV) for soil properties ranged from 0.2 to 207%, with total phosphorus exhibiting the highest variability, highlighting the strong influence of parent material, land use and human activities on soil nutrient distribution. Conversely, pH and organic matter showed the lowest variability (CV <1%), indicating relatively stable conditions across the study area. The stability of pH and OM levels is particularly important, as drastic fluctuations in soil acidity and OM content can have significant implications for nutrient cycling and crop productivity (Loska *et al.*, 2004). These findings underscore the importance of site-specific soil fertility management in Kwara State. Given the heterogeneity in soil properties, tailored soil amendment strategies - such as targeted liming for acid soils, phosphorus supplementation for deficient areas, and OM management to improve nutrient retention - will be essential for optimizing agricultural productivity while maintaining long-term soil health.

3.2 Influence of parent materials on soil properties

Hierarchical clustering analysis provided critical insights into the classification of parent materials based on soil properties (Fig. 4). The results show two primary clusters that distinguish granite-related parent materials from metamorphic and sedimentary-derived materials, although the linear discriminant analysis (LDA) validation of the clusters had a relatively low accuracy of 30.1%. Previous studies suggest that the association of these elements may be interpreted in terms of anthropogenic or geogenic influences (Romic and Romic, 2003; Powlson *et al.*, 2011; Lv *et al.*, 2014; Lorenz and Lal, 2018; Rashid *et al.*, 2023). Available phosphorus, K^+ (cmol$_c$ kg^{-1}), silt %, sand % and pH were the top variables that influenced the separation of classes. The highest AP and K^+ levels were recorded under biotite and hornblende parent materials, with mean values reaching 9.12 mg kg^{-1} and 0.04 cmol$_c$ kg^{-1} respectively. This differentiation is supported by well-established research indicating that soil genesis is strongly influenced by the mineralogical and geochemical characteristics of parent material (Jenny, 1941; Brady and Weil, 2016).

The first major cluster comprised granite-derived parent materials, including granite gneiss, porphyritic granite (porphyroblastic), and porphyroblastic gneiss. These materials exhibit close relationships due to their similar mineral compositions, which typically include quartz, feldspars, and mica. Granite-derived soils are generally coarse-textured, well-drained, and tend to have low fertility due to their slow weathering rates and nutrient-poor composition (Birkland, 1999). The close clustering of porphyritic granite and porphyroblastic gneiss suggests similar weathering patterns and resultant soil properties, reinforcing prior findings on granite-related pedogenesis (Tucker, 2010). Conversely, the second major cluster consists of metamorphic and sedimentary parent materials such as flaggy quartzite with biotite gneiss, fine-grained flaggy quartzite, banded gneiss, marble, migmatite, and undifferentiated schist. The close association of flaggy quartzite variants suggests a strong influence of quartz content, which is known to contribute to well-drained, low-nutrient soils with high sand fractions (Duchaufour, 1982). Additionally, marble-derived soils, which typically have higher calcium content and improved fertility, exhibit distinct clustering, aligning with research on carbonate-rich parent materials (Schroeder, 2013).

The substantial clustering distance between granite-related and metamorphic/sedimentary parent materials highlights significant differences in soil properties, likely driven by variations in mineral weathering rates, base cation release, and textural composition. This finding is consistent with studies demonstrating the role of lithology in dictating soil fertility, structure, and hydrology (Buol *et al.*, 2011; Amundson *et al.*, 2015). Furthermore, the positioning of other parent

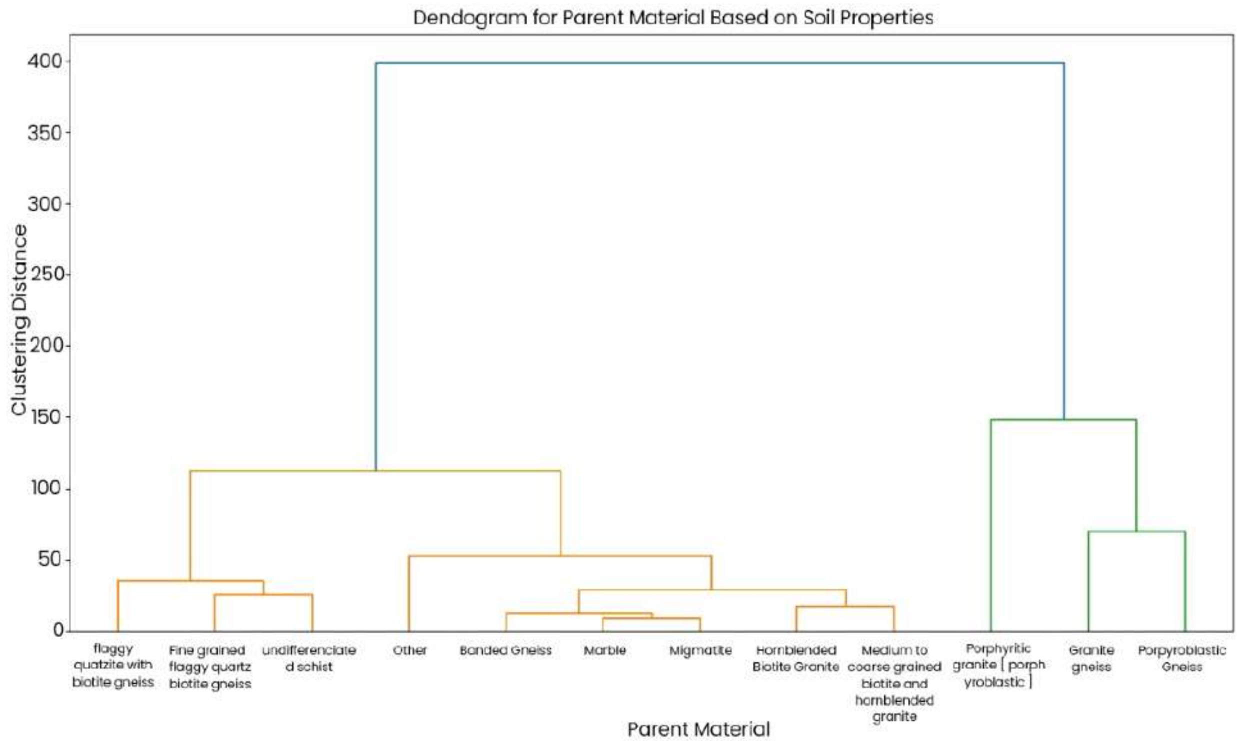

Fig. 4: Clustering of measured soil properties based on parent materials

materials and undifferentiated schist materials as more distinct entities suggests unique soil characteristics that warrant further investigation. The clustering of parent materials based on soil properties has practical implications for sustainable land management. Granite-derived soils, being inherently nutrient-poor, may require targeted soil fertility amendments, including OM additions and micronutrient supplementation, to support agricultural productivity. In contrast, soils derived from metamorphic parent materials, particularly those associated with schist and carbonate rocks, may offer higher fertility potential but variable drainage properties that necessitate site-specific management strategies (Brady and Weil, 2016). These findings underscore the necessity of incorporating parent material classification into digital soil mapping and precision agriculture frameworks. By integrating this knowledge with geospatial analysis, land managers and policymakers can optimize soil use strategies, enhance crop productivity, and improve ecosystem sustainability in diverse geological settings.

3.3 Land use based clustering and agricultural implications

The cluster analysis based on land use classification provides crucial insights into how different management practices impact soil properties. Three major clusters were shown: Agricultural Land, Forest Land, Urban/Disturbed Land (Fig. 5). The LDA validation of the identified clusters had a relatively low accuracy of 61%, with soil K^+ ($cmol_c$ kg^{-1}), AP (mg kg^{-1}), sand%, silt%, and pH, in that order, being the top influencing variables of the separation of classes.

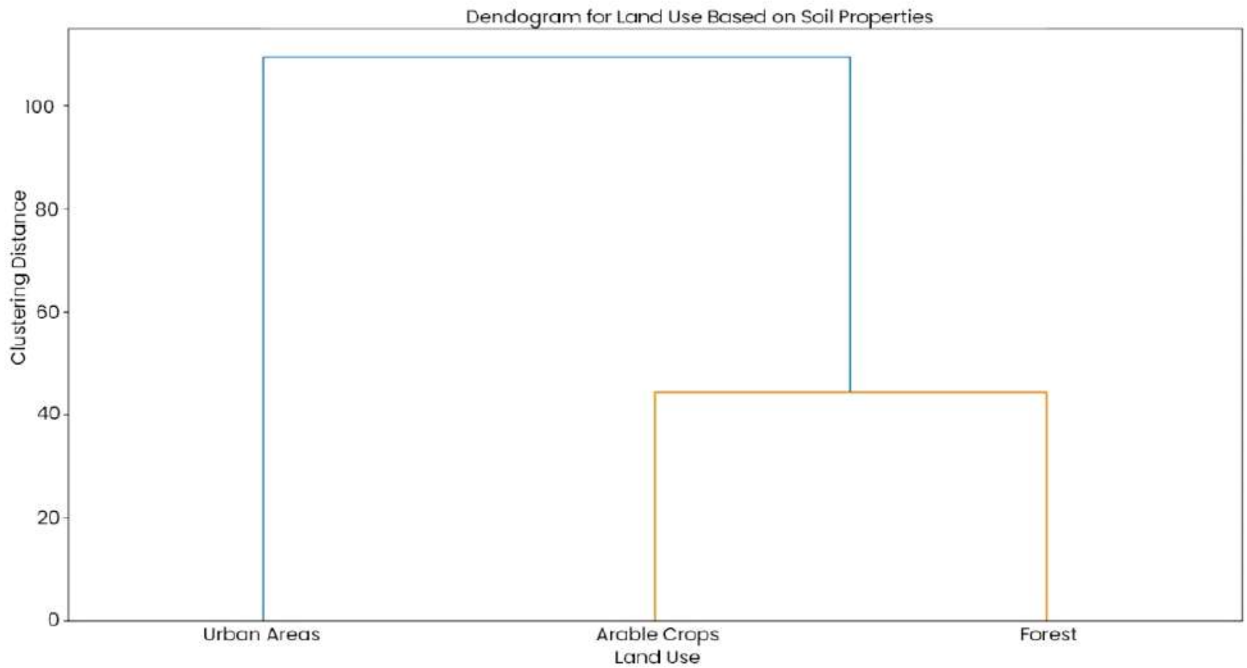

Fig. 5: Clustering of soil properties based on land use

Values for these soil quality indicators were consistently higher and comparable under forest and arable land use clusters with mean pH, AP and K^+ values ranging from 6.7 to 6.8 (SD: 0.3 – 0.6), 5.4 to 6.2 mg kg^{-1} (SD: 3.6 – 3.7), and 0.03 to 0.04 $cmol_c$ kg^{-1} (SD: ~0.008) respectively.

The clustering of these soils reflects the cumulative impact of cultivation, fertilizer application, and organic matter depletion due to continuous cropping (Brady and Weil, 2016). The variability within this cluster suggests that while some agricultural soils retain moderate fertility, others are significantly degraded due to overexploitation and soil nutrient mining. This finding aligns with studies on soil degradation in intensively farmed areas, where nutrient imbalances, acidification, and compaction reduce long-term soil productivity (McBratney *et al.*, 2003). Precision nutrient management, including balanced fertilization, crop rotation, and conservation tillage, is essential for restoring soil fertility and ensuring sustainable agricultural production.

Forest soils formed a distinct cluster, characterized by higher AP, K^+ and pH values. This clustering highlights the minimal disturbance in forested ecosystems, where continuous litter input and reduced erosion contribute to sustained soil fertility. Forest soils generally exhibit higher microbial activity and C sequestration potential, aligning with findings that undisturbed soils act as major carbon sinks (Six *et al.*, 2002). The separation of forest soils from agricultural soils in the clustering analysis indicates the significant impact of land conversion on soil properties. Deforestation and land clearing for agriculture often result in rapid declines in SOC, increased bulk density, and reduced infiltration capacity, leading to lower productivity and increased vulnerability to degradation (Lal, 2001). These results reinforce the need for agroforestry systems and sustainable land management practices that integrate trees into farmlands to enhance soil fertility and C storage.

Urban soils and those under human disturbances formed a separate cluster, indicative of altered physical and chemical properties possibly due to compaction, pollution, and reduced biological activity. The clustering of urban soils away from natural and agricultural soils suggests significant modifications, including lower AP and altered pH levels. These changes can negatively impact soil health, limiting its suitability for food production and ecosystem services. Restoring urban and degraded soils requires targeted interventions such as organic amendments, remediation techniques, and sustainable land-use planning (FAO, 2015). The use of biochar, compost, and phytoremediation strategies has been shown to improve soil quality in degraded urban landscapes, making them more productive for urban agriculture (McBratney *et al*., 2003).

The land use and topography-based clustering emphasize the need for differentiated soil management approaches tailored to specific landscape positions and land-use types. Sustainable intensification strategies, including conservation agriculture, site-specific nutrient management, and integrated land-use planning, can help mitigate soil degradation while enhancing productivity. Furthermore, integrating clustering analysis with digital soil mapping and remote sensing can improve the precision of soil fertility assessment, enabling policymakers and farmers to make informed decisions regarding soil conservation, fertilization, and land-use planning (McBratney *et al*., 2003). These findings support the ongoing transition towards precision agriculture, where soil variability is considered in decision-making to optimize resource use and sustainability.

3.4 Spatial variability of soil properties across LGAs in Kwara State

The hierarchical clustering of soil properties across Kwara State LGAs reveals distinct groupings based on soil characteristics (Fig. 6), likely influenced by regional variations in parent material, land use, and management practices. LDA validation of the resulting clusters had an accuracy of 78%, and AP, pH, K^+ (cmol$_c$ kg^{-1}), and sand%, in that order, were the top variables that influenced the separation of classes. LGAs with similar levels of these soil fertility indicators clustered together, highlighting geographical patterns in soil quality. The Baruten, Edu and Kaiama LGA cluster had the highest levels of AP with mean values ranging between 4.5 and 7.7 mg/kg. The trend was also the same for soil pH, with near neutral mean pH values of between 6.4 and 6.8. Soil mean K^+ values ranged between 0.03 and 0.04 cmol$_c$ kg^{-1}. This clustering can be attributed to differences in soil formation factors such as climate, topography, and human activity (Jenny, 1941). Understanding these regional soil similarities is essential for tailoring site-specific soil management practices to optimize crop productivity (Brady and Weil, 2016).

3.5 Topography based clustering of soil properties and its influence on soil fertility

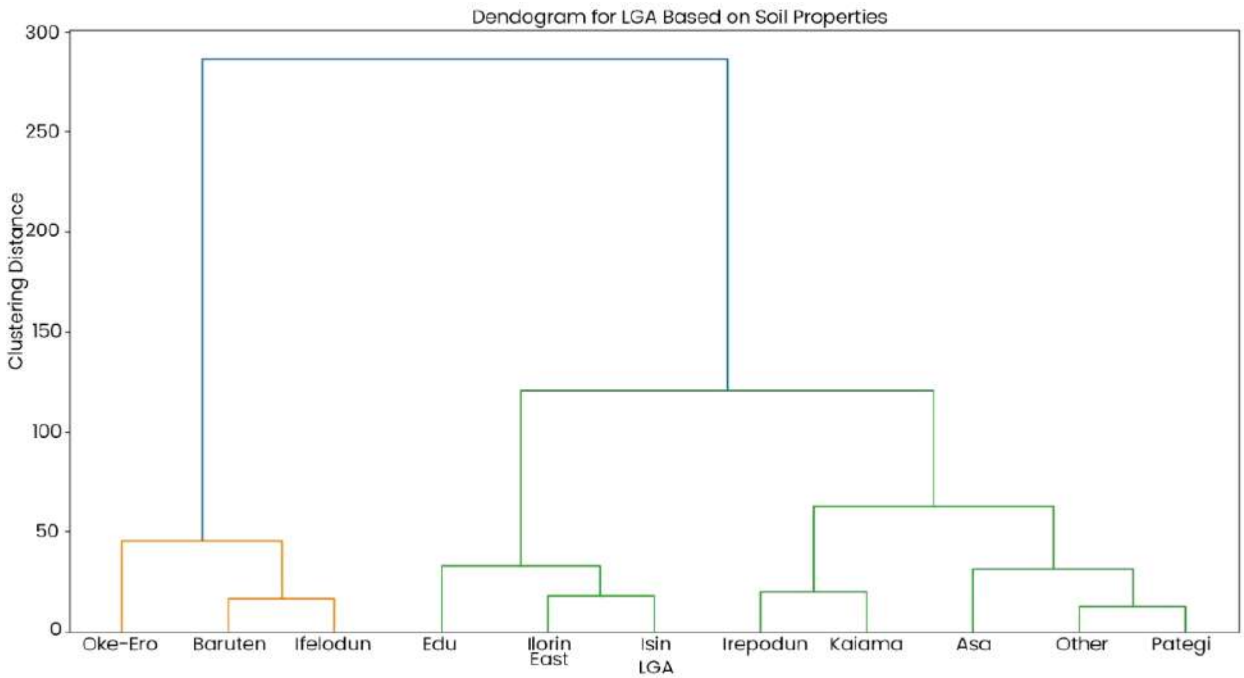

Fig. 6: Clustering of LGAs based on measured soil properties

The hierarchical clustering based on topography demonstrates a clear differentiation of soil properties across landscape positions (Fig. 7). LDA validation of the clusters had a less-than-average accuracy of 43%. Available phosphorus, K^+ ($cmol_c\ kg^{-1}$), sand%, silt%, and clay%, in that order, were the top variables with the most influence on class separation. Soils from lowland and gently undulating terrains formed a distinct cluster, having the highest levels of AP reaching up to 16.56 mg kg^{-1}. This trend indicates similarities in texture, OM content, and moisture retention, indicative of areas typical to accumulate fine-textured sediments, organic materials, and nutrients transported from upslope positions, resulting in higher soil fertility and productivity (Lal, 2001; Brady and Weil, 2016). Conversely, soils on steeper slopes and hilly landscapes clustered separately, reflecting increased susceptibility to erosion, leaching, and reduced OM accumulation.

In sloping terrains, the movement of water and soil particles due to runoff leads to the selective removal of finer particles and OC, often resulting in coarser, nutrient-poor topsoil with limited water-holding capacity (FAO, 2015). This clustering pattern is consistent with previous findings that erosion-prone soils in hilly regions require specific soil conservation strategies, such as contour plowing, mulching, and agroforestry, to enhance soil stability and fertility (Lal, 2001). The variation in soil properties with topography underscores the need for site-specific management, ensuring that erosion-prone areas receive adequate soil amendments and cover cropping to mitigate nutrient loss and improve soil structure. Moreover, soil moisture regimes differ significantly with topography, influencing plant-

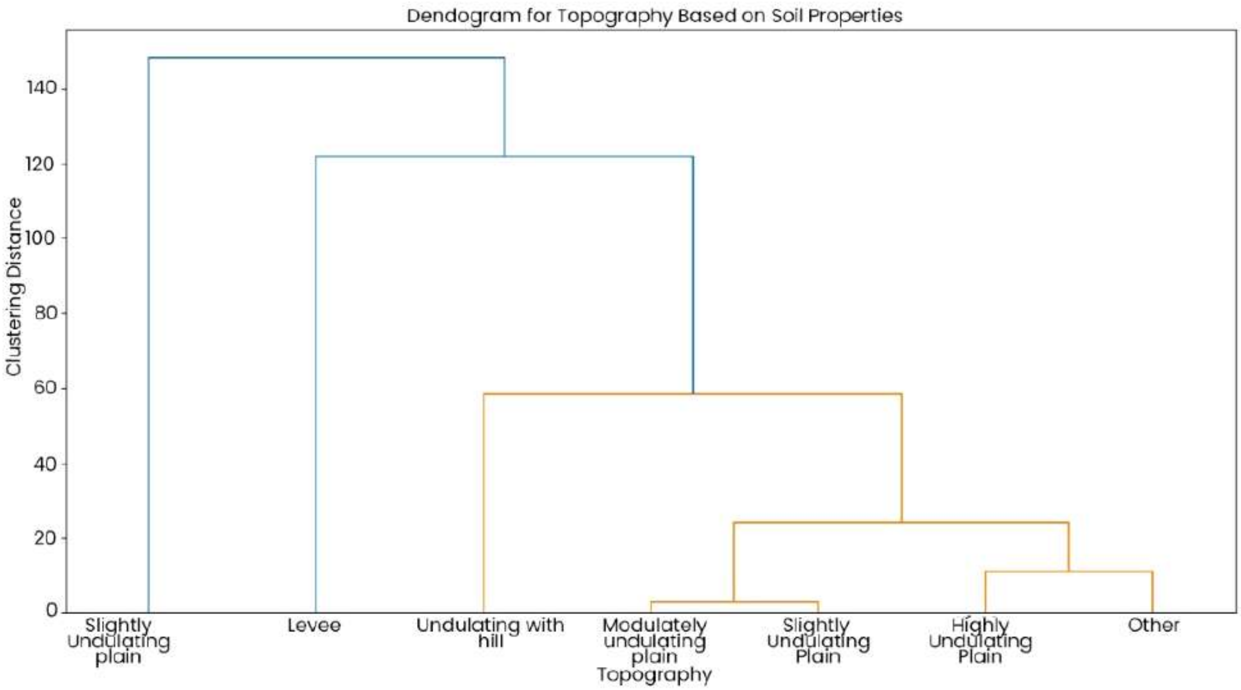

Fig. 7: Topography cluster classes based on soil properties

available water and microbial activity. Lowland soils, often classified within the same cluster, generally exhibit higher moisture retention due to limited drainage, making them more suitable for water-demanding crops. In contrast, well-drained, sloping soils tend to have lower moisture content, necessitating irrigation or drought-resistant cropping strategies. These findings align with studies indicating that topographically driven soil moisture variability affects nutrient cycling, root growth, and overall soil health (Six *et al*., 2002).

3.6 General relationships between soil physical and chemical properties in the study area

Correlation analysis of soil properties provides valuable insights into the relationships between soil properties, geochemical element availability and soil fertility under land uses and soil parent materials (Fig. 8). A strong positive correlation between sand content and soil pH (r = 0.64) suggests that sandy soils tend to have higher pH levels, likely due to their lower OM content and CEC, which reduces acid buffering capacity (Brady and Weil, 2016). In contrast, finer-textured soils with higher silt and clay content display weaker or negative correlations with pH, reflecting a tendency for these soils to retain more OM and acidic cations, which lower pH (Fageria *et al*., 2011). This highlights the significant role of soil texture in influencing pH, which in turn affects nutrient availability, a key consideration for land management practices such as lime application and crop selection.

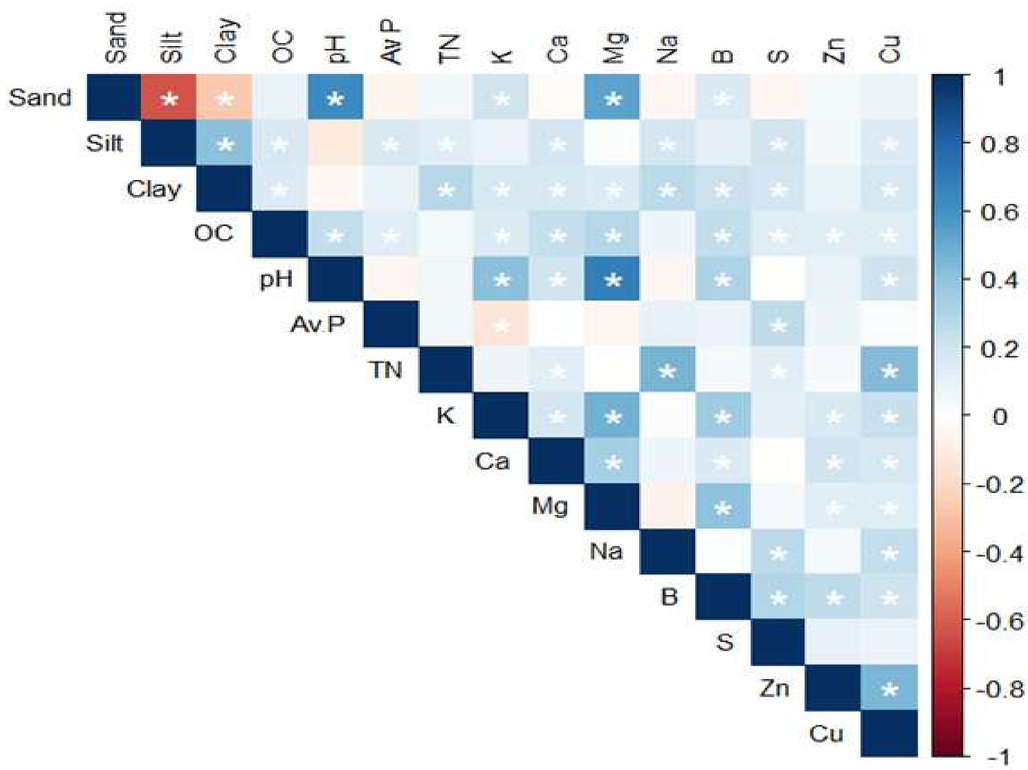

Fig. 8: General trends between analysed soil properties in Kwara State

The moderate positive correlation between OC and pH (r = 0.24; p= .001) supports the notion that soils with higher OM content can buffer pH changes through organic acid release and metal complexation (Lorenz and Lal, 2022). Additionally, OC shows positive correlations with key nutrients such as K, Ca, Mg, and B, indicating that OM enhances nutrient retention through improved CEC and nutrient mineralization (Pierzynski *et al*., 2005). Although the relationship between OC and available phosphorus is relatively weak (r = 0.12; p=.048), it nonetheless underscores the role of organic matter in maintaining phosphorus availability, which is influenced by other factors such as pH and clay content (Havlin *et al*., 2013).

These findings emphasize the importance of managing organic matter to improve soil fertility, particularly through practices like conservation tillage and organic amendments. Soil pH also plays a crucial role in determining nutrient availability, as evidenced by its positive correlations with K (r = 0.42; p = .001), Ca (r = 0.19; p = .001), and Mg (r = 0.68; p=.001). This suggests that higher pH levels promote the availability of these base cations, likely due to reduced leaching and increased solubility at neutral to slightly alkaline pH levels (Marschner, 2012). Conversely, micronutrients such as Zn and

Cu exhibit weaker positive correlations with pH, reflecting the complex interactions that govern micronutrient availability, which can decrease in highly alkaline soils (Schlesiger and Bernhardt, 2020). These correlations highlight the need for careful pH management to balance nutrient availability, particularly when applying lime to acidic soils, to ensure that macronutrient uptake is optimized without compromising micronutrient availability.

The positive relationship between clay content and TN (r = 0.28; p= .001) indicates that clay-rich soils tend to retain more N due to their higher CEC and water-holding capacity, which prevents N leaching and promotes OM accumulation (Schweizer *et al*., 2021).

This underscores the importance of clay content in maintaining soil fertility and highlights the need for land management practices that prevent nutrient depletion, particularly in clay-rich soils subjected to intensive agriculture. Furthermore, the correlations between macronutrients and micronutrients, such as the strong positive relationship between Cu and Zn (r = 0.45; p= .001), suggest that these elements share similar pathways of availability, possibly through parent material weathering or OM mineralization (Fageria *et al*., 2011). This interdependence implies that nutrient management strategies must consider the co-movement of nutrients to prevent imbalances and deficiencies.

The correlation analysis reveals that soil texture, OM, and pH are critical factors influencing nutrient availability in soils. Sandy soils are associated with higher pH levels, which improve the availability of base cations but may limit some micronutrients. Organic matter plays a central role in nutrient retention, while clay-rich soils show a greater capacity to retain N. These findings emphasize the need for tailored nutrient management strategies that account for the specific properties of soils under different land uses and parent materials. Sustainable practices that enhance organic matter and maintain optimal pH levels are essential for improving soil fertility and crop productivity (Brady and Weil, 2016; Lorenz and Lal, 2022).

4. Conclusion

Findings from this study indicate that the soils of Kwara State are inherently low in fertility, with both macronutrient and micronutrient deficiencies widespread across different parent materials, land use types, and topographical features. The hierarchical clustering analysis of soil properties based on parent materials, topography and land use reveals significant spatial and land-use-driven variations in soil fertility across Kwara State LGAs. Parent material influenced soil exchangeable cation, mainly potassium and pH levels. Topography-based clustering highlights the influence of landscape position on soil nutrient distribution, organic matter content, and erosion susceptibility. Soils in lowland areas exhibit higher fertility due to sediment and organic matter accumulation, while those on steep slopes are more prone to erosion and nutrient depletion, necessitating targeted soil conservation strategies such as contour farming and agroforestry.

Similarly, land-use-based clustering underscores the impact of human activities on soil quality. Agricultural soils, though productive, show varying degrees of degradation due to intensive cultivation and nutrient mining, reinforcing the need for sustainable soil management practices, including balanced fertilization and conservation tillage. In contrast, forest soils demonstrate higher soil OC content, emphasizing the ecological benefits of maintaining tree cover and implementing agroforestry systems. Urban and disturbed soils, which exhibit altered chemical and physical properties, require remediation interventions such as organic amendments and phytoremediation to restore fertility and functionality.

Given the significant correlation between soil pH and nutrient availability, soil acidity management should be prioritized to enhance nutrient retention and uptake in the State. For sustainable crop production, targeted soil fertility management strategies are essential. The application of balanced fertilizers, coupled with organic amendments, can help restore nutrient levels and improve soil productivity. Additionally, site-specific fertilizer recommendations based on parent material classification could enhance nutrient-use efficiency. Given the level of uniformity of soil mineralogy despite varying geological formations, future research should focus on detailed nutrient mapping and precision agriculture techniques to optimize soil management practices in the region.

These findings have critical implications for agricultural soil fertility assessment and management. By integrating clustering analysis with precision agriculture techniques, policymakers, researchers, and farmers can develop more effective site-specific soil fertility management strategies that optimize productivity while minimizing environmental degradation. Furthermore, digital soil mapping and remote sensing can enhance soil monitoring efforts, ensuring the long-term sustainability of agricultural systems. Ultimately, recognizing the complex interactions between landscape position, land use, and soil properties is essential for improving soil health, enhancing crop yields, and fostering resilient agroecosystems in the face of climate change and land degradation challenges.

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6. Competing interests

The authors declare that there are no known conflicts of interest.

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