

NIGERIAN JOURNAL

OF

SOIL AND TILLAGE RESEARCH



Volume 3 Number 1, 2026

**PUBLISHED BY INTERNATIONAL SOIL TILLAGE RESEARCH
ORGANIZATION, NIGERIA BRANCH (ISTRO-NG)**

NIGERIAN JOURNAL *of* SOIL AND TILLAGE RESEARCH

❑ Publication of International Soil Tillage Research Organisation, Nigeria, Branch. ❑



ISSN 647 - 9921

Volume 3 Number 1, 2026

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Development of a Computer Model for Predicting the Performance and Cost of Use of an *Acha* Harvesting Machine

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ABSTRACT

Large scale production of *acha* (*Digitaria* specie) has been hampered for non-availability of machines for various aspects of its production. Lack of design data is responsible for lack of development of appropriate harvesters for *acha* crop. Previous research identified pertinent parameters that affect *acha* harvesting and the functional relationships between these parameters were developed. These functions require labourious computations to determine an *acha* harvester Material Capacity, Energy requirements and Cost of the harvest operation. The aim of this paper is to develop a computer model that will simplify the computation of these factors of operation performance. A dynamic programming algorithm was used and a flowchart describing the process was developed, from which a programming code in the Java programming language was adopted. The output from the programme showed that the programme was able to adequately compute the harvester material capacity, energy required to achieve the observed material capacity as well as the cost of the operation. The paper therefore concluded that the model was able to predict the outcome of *acha* harvesting operation, and recommends its use by *acha* farmers and adaptation to similar crops.

Keywords: Material capacity, Energy requirement, Operating cost, Computer model

INTRODUCTION

Acha (*Digitaria* Specie) is a cereal crop with Plateau state of Nigeria being worlds largest producer (Tanam, 2021), producing about half of world total production. In the year 2002, about 347,380 ha of land was devoted to *acha* production, with Nigeria alone cultivating almost half of this size (FAOSTAT, 2003). Tanam (2021) observed the production of *acha* has been on the decline inspite of its increase in demand due to its medicinal and nutritious values. This is attributed to the fact that its production is still by traditional manual methods employing hand tools. Philip and Itodo (2006), cited by Tanam and Olaoye (2022) reported that no aspect of its production is known to be mechanized. Mechanisation problems are futher compounded by the fact that crops have widely varying characteristics (Ajiboye, 2007) and no single machine can be applied to all crops.

Harvesting *acha*, a critical aspect of its production is done manually because appropriate harvesters are not available as a result of non availability of design data (Tanam, 2021), hence, the level of losses are high. Tanam and Olaoye (2022) reported that parameters pertinent to the design of a mechanical harvester for *acha* include Operating speed, knife cutting speed, and reel index. Tanam *et al.* (2022) developed statistical model (Equations 1 and 2) to predict the performance of a rig developed by Tanam (2021). Performance was measured by the Material Capacity of the machine, which is a measure of the quantity of material per hectare the machine is capable of gathering, and energy, measured by quantity of

fuel, required to achieve the material capacity. The models had p-values of 0.0000209 and 0.0008454 for material capacity and energy respectively.

$$C_m = 56.63 - 35.04I^2 - 10.442VI^2 - 4.29I - 135.23V - 0.04S + 23.00V^2 \\ - 22.20V^2I + 143.57VI - 0.06V^2S + 0.06V^2SI - 0.32VSI \\ - 0.00025S^2 + 0.35VS + 0.24SI \quad 1$$

$$E = 24.23 - 0.000007VS^2 + 0.003V^2S - 0.0035V^2 + 0.50V^2I - 5.95I - 0.02 \\ - 6.47V + 0.01VSI \quad 2$$

Where C_m = material capacity (kg/h), I = reel index (decimal), V = operating velocity (km/h), S = knife speed (rpm) and E = energy (l/h)

Tanam (2021) grouped cost of use of the harvester rig into fixed cost and operating cost. Fixed costs are incurred whether or not the machine is used and include depreciation, interest on investment, taxes and insurance, while operating costs are those incurred as a result of normal use (operation of machine) and include cost of fuel, maintenance and labour. Total cost of operation of the machine was given by Tanam (2021) as Equation 3.

$$C_T = D_{Aha} + I_{ha} + T_{ha} + E_{cha} + M_{cha} + L_{cha} \quad 3$$

Where

D_{Aha} = Annual depreciation per hectare

I_{ha} = Interest cost per hectare

T_{ha} = Tax, Insurance and shelter cost per hectare

E_{cha} = Energy cost per hectare

M_{cha} = Cost of maintenance/repairs per hectare

L_{cha} = Labour cost per hectare

The objective of this paper is to develop a computer model to predict the material capacity, energy requirement and cost of operation of a harvesting machine for *acha*. This would enable the farmer determine in advance what quantity of material to expect in a given time and at what cost.

MATERIALS AND METHOD

A flow chart representation of the model is presented as Figure 1. The farmer would have to decide what machine operating parameter settings to use, the program then supplies the required output.

To determine the cost of use of the machine, the following assumptions were made:

1. Machine working hour/day = 8 h
2. Harvesting is completed in 25 days therefore working hours / year = 200 hours
3. Lifespan of harvester = 10 years
4. Interest rate = 12% of cost of harvester. Interest rate was obtained from the Nigeria Bank of Agriculture.
5. Estimate for maintenance = 0.025% of cost of harvester (Kepner *et al*, 1987)
6. Estimate for insurance and tax = 2% of cost of harvester (Kepner *et al*, 1987)

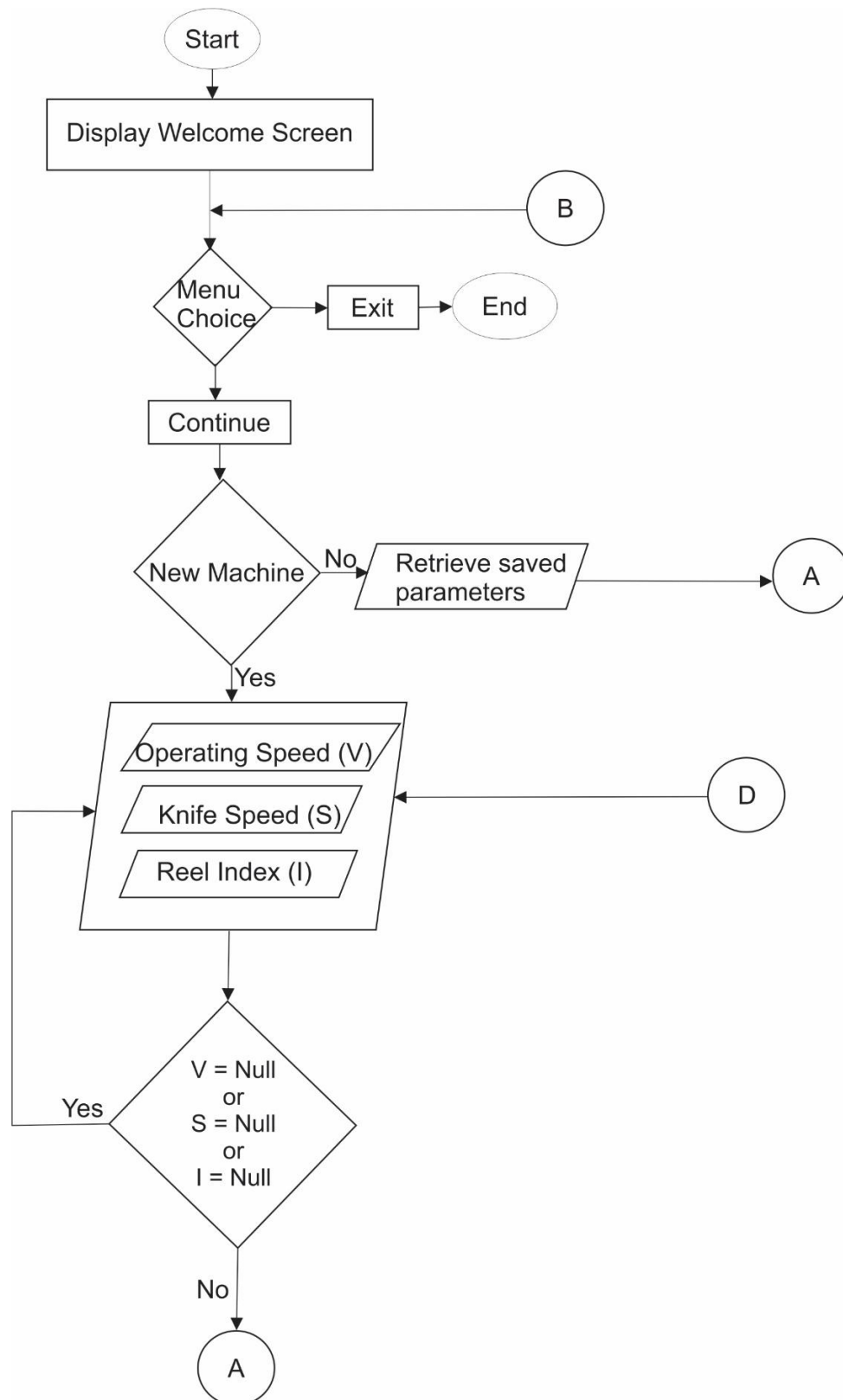


Figure 1: Model Flowchart (Section 1)

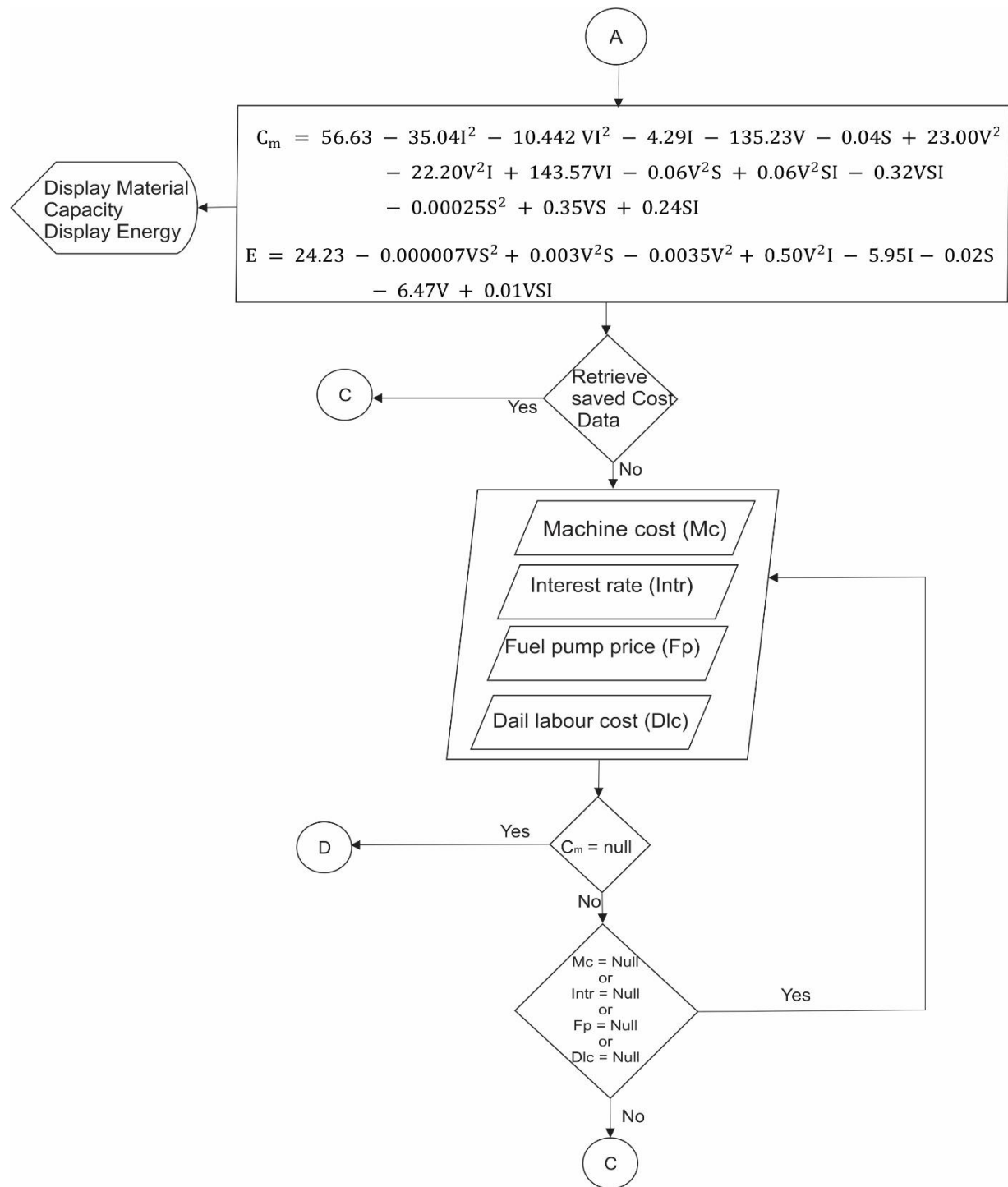


Figure 1: Model Flowchart (Section 2)

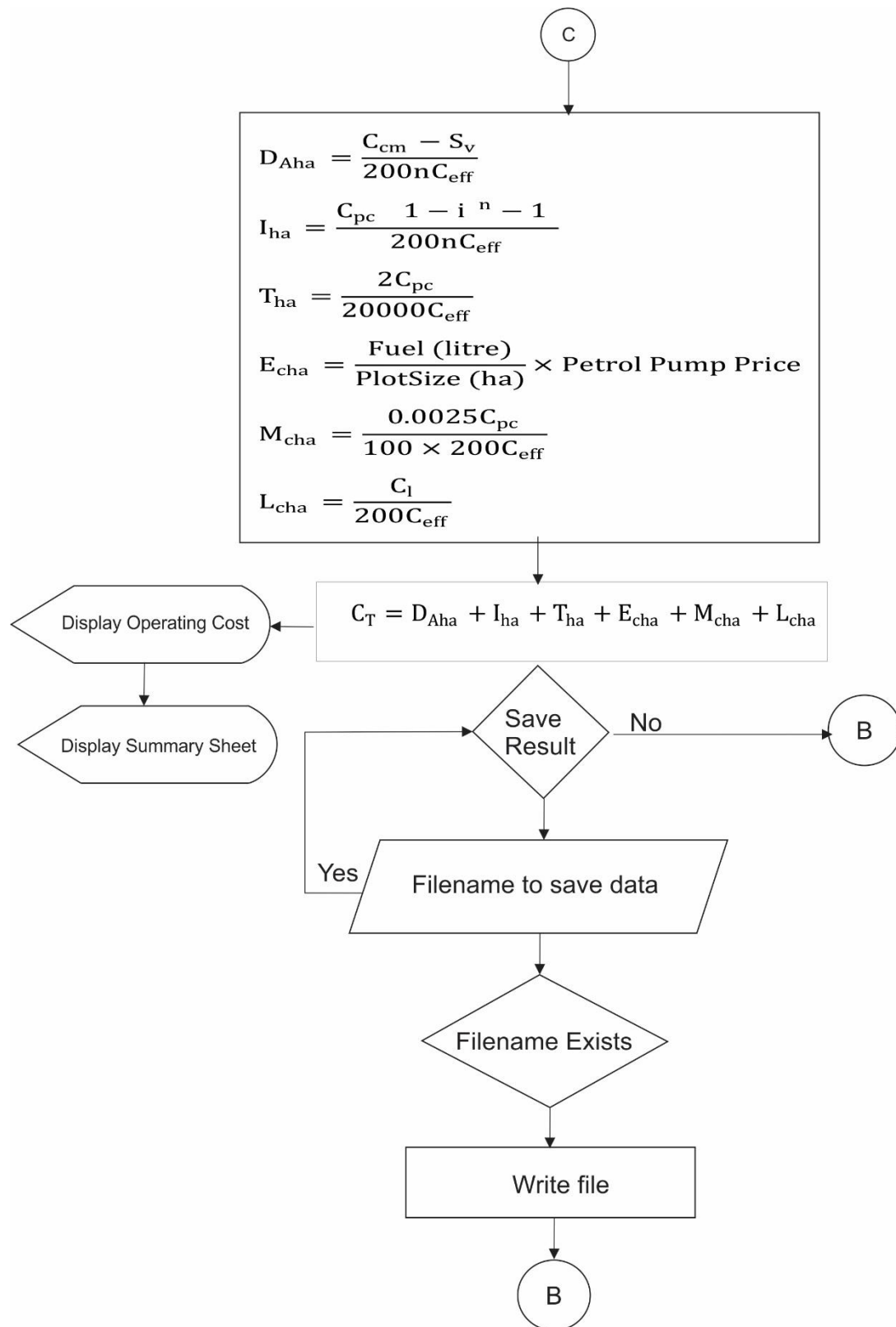


Figure 1: Model Flowchart (Section 3)

Annual depreciation was determined by the straight-line method for its simplicity, practicality and acceptability and recommendation (Kepner *et al.*, 1987). Annual depreciation is given as

$$D_{Aha} = \frac{C_{cm} - S_v}{200nC_{eff}} \quad 4$$

where

D_{Aha} = Annual depreciation

C_{pc} = Purchase Cost of machine

S_v = Salvage value (= 10% of machine cost)

n = estimated useful life of machine (yrs)

C_{eff} = Effective field capacity of machine

Since the straight-line method based on the average investment during the machine's useful life was used to determine machine depreciation, a constant interest was used to determine Interest on investment. Interest on investment for each year is therefore given as

$$I_{inv} = \frac{C_{fc} - C_{pc}}{n} \quad 5$$

where

I_{inv} = interest on investment

C_{pc} and n are as earlier defined.

C_{fc} = future cost of machine

$$C_{fc} = C_{pc}(1 + i)^n \quad 6$$

Where i = prevailing interest rate

Putting Equation 6 into Equation 5, Equation 5 becomes

$$I_{inv} = \frac{C_{pc}(1 - i)^n - C_{pc}}{n} = \frac{C_{pc}[(1 + i)^n - 1]}{n} \quad 7$$

I_{inv} can be expressed per hectare as

$$I_{ha} = \frac{I_{inv}}{200C_{eff}} = \frac{C_{pc}[(1 - i)^n - 1]}{200nC_{eff}} \quad 8$$

Kepner *et al.* (1987) recommended the inclusion of 2% of machine purchase cost as total annual cost for taxes, insurance and shelter, if straight-line method was used to determine depreciation.

$$\therefore T_{IS} = \frac{2C_{pc}}{100} \quad 9$$

Where T_{IS} = Cost of Taxes, Insurance and shelter charge. Expressing in hectare, Equation 9 becomes

$$T_{ha} = \frac{2C_{pc}}{100 \times 200C_{eff}} = \frac{2C_{pc}}{20000C_{eff}} \quad 10$$

Fuelling cost was determined by average fuel quantity consumed in harvesting and multiplying by the prevailing pump price of petrol. This value forms the cost of fuel per hectare, E_{cha} , giving as

$$E_{cha} = \frac{\text{Fuel (litre)}}{\text{PlotSize (ha)}} \times \text{Petrol Pump Price}$$

Maintenance cost includes cost of repairs or replacement of parts, daily service, lubrication, adjustments of worn parts, re-tightening of bolt and screws and the like. Although maintenance cost per hour of use increases with age of machine, for straight-line depreciation, uniform annual charge was applied throughout the useful life of the machine. Kepner *et al* (1987) recommended a value of 0.025% of cost of machine as the average hourly repair/maintenance cost, giving as Equation 11, expressed per hectare.

$$M_{cha} = \frac{0.0025C_{pc}}{100 \times 200C_{eff}} \quad 11$$

To determine cost of labour it was assumed that hired hands would work 8hrs per day for 25 days.

$$\therefore L_{cha} = \frac{C_l}{200C_{eff}} \quad 12$$

Where

L_{cha} = labour cost per hectare.

Programme Inputs were desired speed of operation, knife cutting speed, reel index and all cost factors (machine cost, interest rate, fuel pump price and daily labour cost). Programme output were material capacity, energy required and estimated cost of the operation

RESULTS AND DISCUSSION

Figures 2 and 3 show the welcome screen and data input/output screen respectively of the developed programme based on the flowchart. Figure 4 shows error dialog that appears if an attempt is made to determine cost of operation with providing the machine parameter. Figure 5 shows output summary screen, showing details of all results. These show that the programme was able to determine the machine Material Capacity as well as the cost of producing the observed material capacity. The application of this model can be very helpful to farmers growing *acha* in Nigeria as they would be able to forecast their production expenditure and predict possible revenue.

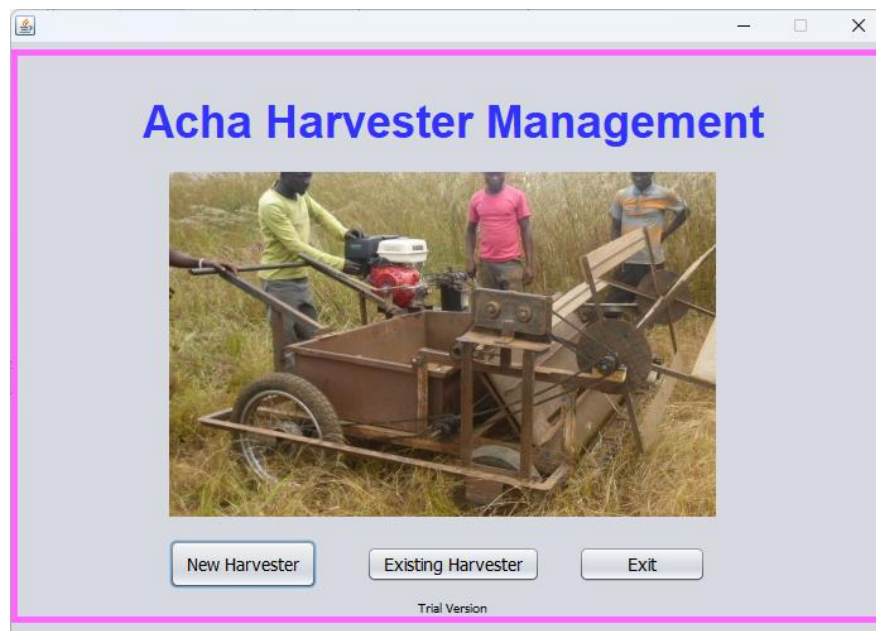
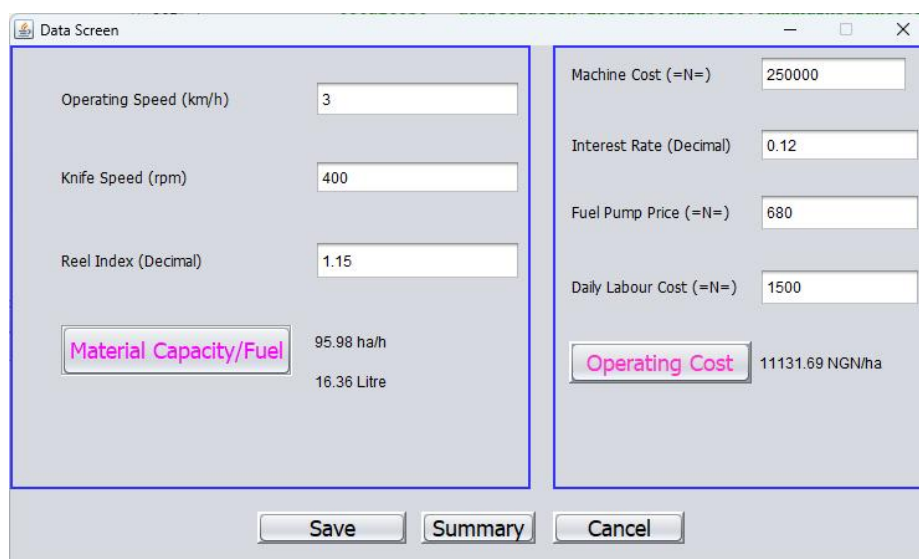


Figure 2: Programme Welcome Screen showing initial menu



The 'Data Screen' window is divided into two main sections. The left section contains input fields for 'Operating Speed (km/h)' (3), 'Knife Speed (rpm)' (400), and 'Reel Index (Decimal)' (1.15). Below these is a box labeled 'Material Capacity/Fuel' showing '95.98 ha/h' and '16.36 Litre'. The right section contains input fields for 'Machine Cost (=N=)' (250000), 'Interest Rate (Decimal)' (0.12), 'Fuel Pump Price (=N=)' (680), and 'Daily Labour Cost (=N=)' (1500). Below these is a box labeled 'Operating Cost' showing '11131.69 NGN/ha'. At the bottom are 'Save', 'Summary', and 'Cancel' buttons.

Parameter	Value
Operating Speed (km/h)	3
Knife Speed (rpm)	400
Reel Index (Decimal)	1.15
Machine Cost (=N=)	250000
Interest Rate (Decimal)	0.12
Fuel Pump Price (=N=)	680
Daily Labour Cost (=N=)	1500
Material Capacity/Fuel	95.98 ha/h, 16.36 Litre
Operating Cost	11131.69 NGN/ha

Figure 3: Data Input/Output Screen, showing machine Parameters and Cost Factors

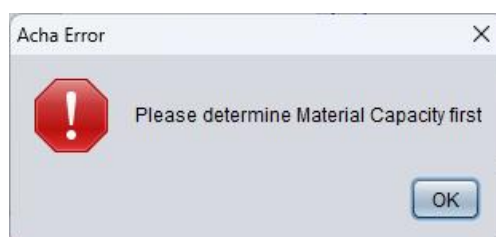
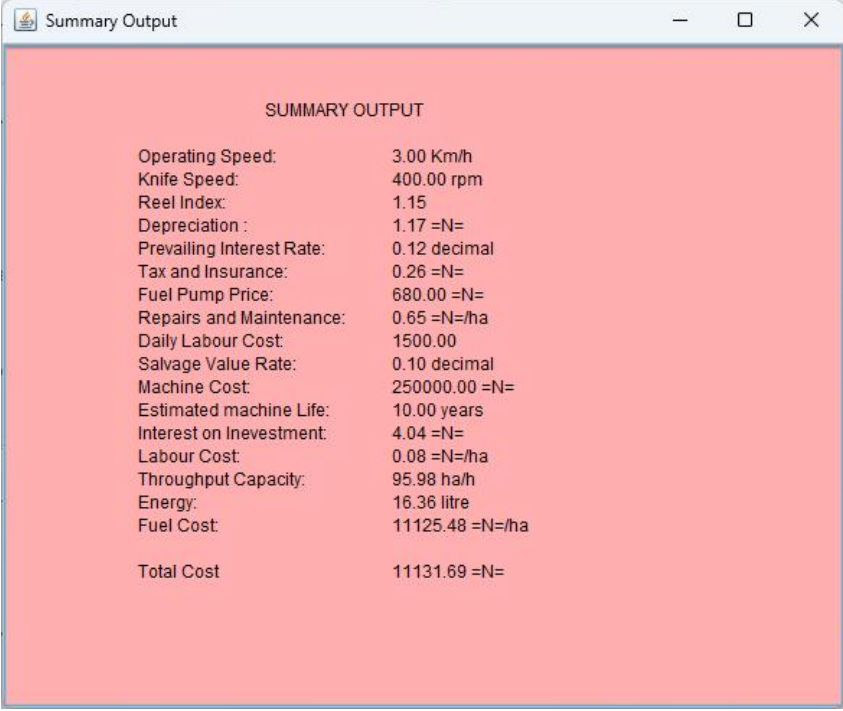


Figure 4: Error Dialog, indicating the need to first determine Material Capacity before cost



A screenshot of a software window titled 'Summary Output'. The window has a pink background and displays a list of machine parameters and their calculated values. The parameters are listed on the left, and their values are on the right. The values include units where applicable.

SUMMARY OUTPUT	
Operating Speed:	3.00 Km/h
Knife Speed:	400.00 rpm
Reel Index:	1.15
Depreciation :	1.17 =N=
Prevailing Interest Rate:	0.12 decimal
Tax and Insurance:	0.26 =N=
Fuel Pump Price:	680.00 =N=
Repairs and Maintenance:	0.65 =N=/ha
Daily Labour Cost:	1500.00
Salvage Value Rate:	0.10 decimal
Machine Cost:	250000.00 =N=
Estimated machine Life:	10.00 years
Interest on Investment:	4.04 =N=
Labour Cost:	0.08 =N=/ha
Throughput Capacity:	95.98 ha/h
Energy:	16.36 litre
Fuel Cost:	11125.48 =N=/ha
Total Cost	11131.69 =N=

Figure 5: Summary Output Screen

A DialogBox to input the name of a file to save machine parameters is shown in Figure 6. Saving the data simplifies future data entry for the same machine parameters.



Figure 6: File Request Dialog

CONCLUSION

A computer model to simplify the computation of an *acha* harvester material capacity, Energy requirement and Cost operation of the machine was developed. A Flowchart describing the process was developed, from which a simple Java Application was developed. The model was able to compute the harvester material capacity, Energy requirement and Cost operation.

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Effects of Reduced Tillage, Nutrient Application, and Weed Management on Soil Properties and Soybean (*Glycine max* L.) Performance in a Sandy Loam Soil

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ABSTRACT

Sustainable soil management through appropriate tillage and agronomic practices is essential for improving crop productivity while minimizing soil degradation and excessive energy use. This research examines how reduced tillage practices, nutrient management strategies, and weed control methods influence soil physical and chemical characteristics, together with the growth performance and yield of soybean (*Glycine max* L.), in the derived Guinea savannah ecotone of Nigeria. Field trials were carried out during the 2018 and 2019 cropping seasons. The experiment consisted of $4 \times 3 \times 4$ factorial combinations arranged in a randomized complete block design (RCBD) with three replications. Treatments included four tillage depths (10, 15, 20, and 25 cm), three nutrient application rates, and four weed management regimes. Soil properties were determined following USDA standards, and crop parameters were measured using standard agronomic methods. Results show that tillage system and nutrient application significantly ($p \leq 0.05$) influenced bulk density, porosity, soil moisture content, penetration resistance, and saturated hydraulic conductivity, while weed management had no significant effect on total nitrogen, available phosphorus, potassium, calcium, magnesium, and electrical conductivity. Reduced tillage depths of 10–15 cm improved nutrient availability. The combination of 15 cm tillage depth, compost poultry manure at 0.5 t ha^{-1} plus 50 kg ha^{-1} superphosphate, and early weed control produced the highest grain yield of 2.62 t ha^{-1} . The study recommends this management combination for sustainable soybean production in the study area.

Keywords: Tillage depth, composted poultry manure, soil properties, soybean yield

1.0 INTRODUCTION

Improved agricultural mechanization has significantly increased crop productivity by enhancing the timeliness and efficiency of field operations (Liu & Li, 2023; Amare & Endalew, 2016). However, inappropriate tillage intensity and excessive soil manipulation can lead to soil degradation, increased energy consumption, and declining crop yields (Hussain *et al.*, 2021). Sustainable crop production is particularly significant in the tropics, where the effects of global warming are more pronounced. In addition to implementing appropriate tillage systems to mechanize soybean cultivation, the effective use of agricultural inputs such as fuel, herbicides, and fertilizers is of utmost importance (Peng *et al.*, 2025; Majidian *et al.*, 2024). These practices support the United Nations Environment Programme (UNEP) initiative on Greening the Economy with Agriculture (GEA) and align with Millennium

Development Goals (MDGs) 1 and 7 for developing countries, which aim to mitigate hunger and environmental degradation, respectively (Anwana & Owojori, 2024; Rahman *et al.*, 2024).

Soybean (*Glycine max* L.) is a leguminous crop grown in tropical, subtropical, and temperate climate regions. It is a significant edible oil-bearing crop worldwide. It contains protein (over 36%), carbohydrate (30%), and oil (20%), as well as significant levels of dietary fibre, mineral elements, and vitamins ;Uwaoma, 2015). Cultivation in Nigeria is growing rapidly in response to increasing demand for edible oil, animal feed, and industrial raw materials (Pratap, 2025; Fasusi *et al.*, 2022;). It plays an important role in improving soil fertility by fixing atmospheric nitrogen (Zhang *et al.*, 2017). Despite its economic contribution, crop productivity in Nigeria is generally low, attributed to inappropriate tillage practices, declining soil fertility, high production costs, and poor weed control (Tadele, 2017).

The derived Guinea Savanna agro-ecological zone in Nigeria is characterized by sandy soils, high evapotranspiration rates, and seasonal precipitation (Adedibu *et al.*, 2022; Ande *et al.*, 2016; Olaoye, 2002). This makes soils very difficult to manage, as intensive tillage practices often lead to soil compaction, increased organic matter depletion, and restricted root growth (Hamza & Anderson, 2005). Tractorized tillage practices used by farmers in the region typically involve multiple passes, leading to intensive soil disturbance. This practice increases energy consumption and delays planting, which can be particularly detrimental under the region's unpredictable rainfall pattern (Yuan *et al.*, 2025; Rahman *et al.*, 2021).

Sustainable cropping requires adapting farming methods that are environmentally and economically friendly. Manipulating soil to create a suitable seedbed may alter soil physical and chemical properties, thereby affecting plant growth and yield (Dorota *et al.*, 2014; Amini, 2005; Pikul *et al.*, 2001; Javurek & Vach, 1999). Reduced tillage depths have been cited as sustainable practices that can effectively minimize soil disturbance while maintaining or improving crop yields (Angon *et al.*, 2023; Hussain *et al.*, 2021; Shah & Wu, 2019). Studies by various authors show that tillage intensity significantly affects soil physical characteristics, such as bulk density, porosity, moisture retention, and penetration resistance, which, in turn, affect crop growth and yield (Li *et al.*, 2020; Salem *et al.*, 2015; Katsvairo *et al.*, 2002;). The response of the soybean crop to reduced tillage depths, however, depends on the location, soil type, and other complementary practices. Some authors report reduced yield under no-tillage, while others report the same or higher yield under conservation and reduced tillage systems (Silva *et al.*, 2026; Simão *et al.*, 2023).

Apart from tillage, nutrient and weed management are also important aspects of sustainable soybean cultivation (Kamara *et al.*, 2008; Schelze *et al.*, 2006). The availability of nitrogen and phosphorus is a major constraint to legume productivity in tropical and subtropical regions (Schelze *et al.*, 2006). Although it is a legume that fixes atmospheric nitrogen, it requires a minimum level of phosphorus to support effective nodulation and nitrogen fixation (IITA, 2009). Integrated nutrient management practices, including organic and inorganic fertilizers, have been reported to enhance soil fertility and crop productivity (Abebe and Deressa, 2017). In addition, weed infestation reduces crop productivity. Therefore, efficient weed management is also essential to increase crop productivity (Kaur *et al.*, 2018).

Despite the increasing importance of soybean cultivation in Nigeria, information on tillage depth and optimal nutrient and weed management practices under a mechanized farming system is limited. Farmers tend to overestimate tillage depth for a shallow-rooted crop such as soybean, thereby degrading the soil and increasing production costs. In the context of climate change and sustainable land management, it is essential to identify climate-resilient tillage and crop management practices to maintain soil fertility and crop productivity.

The objective of this study was to assess the effects of different tillage depths and nutrient and weed management practices on soybean growth and grain yield under mechanized farming.

2.0 METHODOLOGY

2.1 Study Area

The field experiment was conducted during the 2018 and 2019 cropping seasons at the research farm of the University of Ilorin, Ilorin, Nigeria (8°28'54.5" N, 4°40'56.4" E). The site is located within the derived Guinea savanna agro-ecological zone and is characterized by a tropical wet-and-dry climate, with distinct rainy (April–October) and dry (November–March) seasons. Mean daily maximum temperatures during the cropping period ranged from 28 to 31 °C, while minimum temperatures ranged from 21 to 23 °C. Prior to land preparation, composite soil samples were collected from 0–15 cm and 15–30 cm depths for baseline physicochemical characterization. Soil texture was determined using the hydrometer method and classified as sandy loam according to the USDA textural classification system. Initial soil chemical properties were analyzed following standard laboratory procedures.

2.2 Experimental Design

A $4 \times 3 \times 4$ factorial experiment was arranged in a Randomized Complete Block Design (RCBD) with three replicates namely: Four tillage systems, three nutrient application levels and four weed management regimes, replicated three times. This resulted in 144 experimental plots. Each plot measured 7 m $\times$ 8 m, with adequate buffer zones of 1.0 metre between plots to prevent treatment interference. Tillage treatments included T1: Disc ploughing followed by disc harrowing at 25 cm depth, T2: Disc ploughing at 20 cm depth, T3: Double-pass disc harrowing at 15 cm depth and T4: Single-pass disc harrowing at 10 cm depth while nutrient application treatments comprise N1: 30 kg ha⁻¹ single superphosphate (control), N2: 0.5 t ha⁻¹ composted poultry manure + 30 kg ha⁻¹ single superphosphate, and N3: 1.0 t ha⁻¹ compost poultry manure + 30 kg ha⁻¹ single superphosphate. Composted poultry manure was incorporated into the soil four weeks after planting.

Weed management as stated in Table 2(W1-W4) consisted of combinations of no weed, pre-emergence and post-emergence herbicide applications using Pendimethalin and Fluazifop-P-butyl at recommended rates. Applications were carried out at 3, 5, and 7 weeks after planting (WAP), depending on treatment specification. An untreated control was included.

Soybean (*Glycine max L.*) variety TDX 1448-2EB was sown manually at a spacing of 75 cm $\times$ 25 cm, at two seeds per hole. The number of emerged plants was divided by the total number of seeds planted to calculate percentage seedling emergence.

2.2.1 Standard agronomic practices were followed throughout the growing period

Post-treatment soil physical properties were measured at a soil depth of 0–30 cm (soil manipulation in this study was limited to 25 cm) before crop planting and at crop harvest. The evaluated soil physical properties included bulk density (g cm⁻³), gravimetric soil moisture content (%), soil porosity (%), saturated hydraulic conductivity (cm s⁻¹), and penetration resistance (MPa). Bulk density, gravimetric soil moisture content, and porosity were determined using the oven-drying method at 105°C, following the procedure described by Blake and Hartge (1986), as presented in Equations 1–3.

$$\text{Bulk density (g/cm}^3\text{)} = \frac{Md - Mc}{V} \quad (1)$$

$$\text{Gravimetric soil moisture content (\%)} = \frac{(Ms - Mc) - (Md - Mc)}{Md - Mc} \times 100 \quad (2)$$

$$\text{Porosity (\%)} = \left(1 - \frac{\text{Bulk density}}{\text{particle density}}\right) \times 100 \quad (3)$$

(pd: particle density is assumed to be 2.65 g/cm³ (Sharma, 1998))

Where, M_d is the mass of oven-dried soil, M_c is the mass of the container, V is the container's volume.

Saturated hydraulic conductivity, K_{sat} (cm/s), was measured using the constant pressure head method as described by Klute and Dirksen (1986) in the following equation:

$$K = \frac{QL}{Aht} \quad (4)$$

where : Q is the quantity of water measured (cm³), L is the length of the metal core sampler (cm), A is cross cross-sectional area of the metal core sampler (cm²), t is the time required for the quantity of water to be discharged (s), h is the hydraulic head (cm).

Three cores were taken per plot at random locations for the three replicates. Penetration resistance of the soil was measured in situ on the experimental field using a hand –held cone penetrometer having a 1.6 cm² cone and a 60° apex at varied soil depths of 5, 10,15,20,25 and 30 cm. Samples were collected for dry bulk density, gravimetric soil moisture content, soil porosity, saturated hydraulic conductivity, penetration resistance at sowing time and harvesting time.

Post-treatment soil chemical properties were measured at a soil depth of 0–30 cm (soil manipulation in this study was limited to 25 cm) during crop harvest. The analysed chemical properties included soil pH (H₂O), Ca²⁺, Mg²⁺, total nitrogen, organic carbon, available phosphorus (P), and potassium (K). Laboratory analyses were conducted following USDA standard procedures. Weed control was carried out using herbicides in combination with manual removal of broadleaf weeds, and nutrient applications were performed as described in Table 1.

Table 1: Experimental Factors for 2018 & 2019 Planting Seasons

<i>Factors</i>	<i>Levels</i>
<i>Tillage practices</i>	<i>T1 = Disc ploughing followed by disc harrowing at a depth of 25 cm (common reduced tillage practice; Wlaiwan & Jayasuguya, 2013).</i> <i>T2 = Disc ploughing at a depth of 20 cm (considered shallow tillage for soybean).</i> <i>T3 = Two passes of a disc harrow at a depth of 15 cm.</i> <i>T4 = Single pass of a disc plough at a depth of 10 cm.</i>
<i>Weed management</i>	<i>W₁ = No weeding as (control)</i> <i>W₂ = 3 L ha⁻¹ pre-emergence herbicide (Pendimethalin) applied at planting + 2.5 L ha⁻¹ (0.14 kg a.i. ha⁻¹) post-emergence herbicide (Fusillade Forte) applied at 3 weeks after planting (3 WAP) (Dugje et al., 2009).</i> <i>W₃ = 3 L ha⁻¹ pre-emergence herbicide + 3 L ha⁻¹ (0.17 kg a.i. ha⁻¹) post-emergence herbicide applied at 5 WAP (assumed rate).</i> <i>W₄ = 3 L ha⁻¹ pre-emergence herbicide + 4 L ha⁻¹ (0.23 kg a.i. ha⁻¹) post-emergence herbicide applied at 7 WAP (assumed rate).</i>
<i>Nutrient application</i>	<i>N₁ = No CPM application + 30 kg ha⁻¹ superphosphate (control).</i> <i>N₂ = CPM at 0.5 t ha⁻¹ + 30 kg ha⁻¹ superphosphate applied 4 weeks after sowing.</i> <i>N₃ = CPM at 1.0 t ha⁻¹ + 30 kg ha⁻¹ superphosphate applied 4 weeks after sowing.</i>

Standard agronomic procedures were followed to evaluate growth and grain yield parameters. The collected crop data included growth parameters (percentage seedling emergence, plant height, stem girth, number of leaves, root length, and number of nodules) and yield parameters (number of seeds per plant, seed weight per plant, and grain yield) of soybean under different tillage equipment and depths, nutrient application rates, and weed control treatments. Sampling was conducted using 2 m² quadrats placed within each sub-subplot immediately after planting.

Soybean plant population counts were taken at two weeks after planting (2 WAP). The percentage of seedling emergence was calculated by dividing the number of emerged plants

by the total number of seeds planted. The percentage seedling emergence was computed according to Sessiz and Gursoy (2010) using Equation (5).

$$PE = \frac{Te}{Np} \times 100 \quad (5)$$

where, PE is the percentage seedling emergence, Te is the total emerged seeds/m, Np is the number of planted seeds/m

Sampling for plant height, stem girth, and number of leaves per plant was conducted within a quadrant (net plot) established in each sub-sub plot at 5, 7, and 9 weeks after planting. A metre rule was used to measure plant height, while stem girth was measured using a thread and ruler. Additional parameters measured included: Number of pods per plant, Number of seeds per pod, Seed weight per plant, 1000-seed weight, and Grain yield

Grain yield was determined by harvesting plants from the net plot area, threshing, cleaning, weighing, and converting to tonnes per hectare.

The number of nodules was carefully counted and was evaluated using the ratio of seeds per plant to pods per plant. According to Samia *et al.* (2012), it could be expressed as presented in Equation (6).

$$\text{Number of seeds per pod} = \frac{A}{B} \quad (6)$$

where A Number of Seeds/plant and B = Number of pod/plant

Yield was estimated in tonnes/ha. The weight of the threshed and winnowed soybean seed per sub-sub plot was measured using a top-loading weighing scale with a sensitivity of 0.0001 g and expressed in tonnes per ha.

All data obtained were subjected to analysis of variance (ANOVA) at a 5% level of significance using IBM SPSS Statistics. When significant differences among treatments were detected, treatment means were separated using Duncan's Multiple Range Test (DMRT). Interaction effects among tillage, nutrient application, and weed management were also evaluated.

3.0 RESULTS AND DISCUSSION

3.1 Agroclimatic and chemical properties Conditions of the Experimental Field

The results shown in Table 2 and Table 3 show the chemical properties, USDA textural classification of the soil condition and agroclimatic conditions of the experimental field. From the table, the monthly rainfall was higher during the early growth of the plant in 2018 than in the 2019 trial, especially in June, by 84.76%, when the plant was sown. This may

result in lower seed emergence rates and poor plant growth. Also, rainfall was much higher in October during the 2019 trial, when the plant was ready for harvesting. This may cause seed explosion and decay, thereby reducing soybean yield. The rainfall breaks actually occurred between July and August for both experiments.

Table 2: Chemical Characteristics and USED Textural Classification of the Experimental Field

Soil Chemical Properties	2018 Soil depth (cm)		2019 Soil depth (cm)	
	0 – 15	15 – 30	0 – 15	15 – 30
Organic carbon (%)	0.72	0.58	0.84	0.63
pH (H ₂ O)	6.40	6.50	6.35	6.50
pH (KCl)	5.30	5.33	5.30	5.34
Electrical conductivity (U _s /cm)	0.78	0.18	0.82	0.18
Ca ²⁺ (mMol/100g)	1.84	2.08	1.76	2.08
Mg ²⁺ (mMol/100g)	4.16	2.96	4.21	2.93
Total N (%)	0.22	0.20	0.25	0.21
P (mg/kg)	4.53	3.10	3.44	3.12
K (mMol/100g)	0.59	0.53	0.82	0.68
Sand (%)	86	84	86	84
Silts (%)	10	4	10	4
Clay (%)	4	12	4	12

Table 3: Agro-Climatic Conditions of the Experimental Field measured during 2018 and 2019 Experiments

Month	2018 Trial			2019 Trial		
	Rainfall (mm)	Maximum Temperature (°C)	Minimum Temperature (°C)	Rainfall (mm)	Maximum Temperature (°C)	Minimum Temperature (°C)
June	315	31	23	48	28	22
July	192	30	21	137	28	21
August	265	28	21	198	29	22
September	445	30	22	160	31	22
October	115	31	22	420	32	22

3.2 Effects of Tillage Systems on the Measured Soil Physical Properties During Sowing and Harvest Periods.

Tables 4a, 4b, 5a, and 5b show the influence of tillage systems on soil physical properties for the two experiments conducted in 2018 and 2019. Tillage treatments significantly ($P \leq 0.05$) affected soil bulk density, porosity, moisture content, and saturated hydraulic conductivity at different ploughing depths during both sowing and harvest periods. Regardless of tillage treatment, bulk density, saturated hydraulic conductivity, and soil moisture content were higher at sowing than at harvest. These differences may be attributed to rainfall events following tillage operations and the intensity of tillage.

Soil penetration resistance did not differ significantly ($P \leq 0.05$) among tillage treatments at sowing in either experiment. The results support the findings of Aikins and Afuakwa (2012) and Olaoye (2002), who reported that tillage practices influence soil physical properties such as bulk density, porosity, and moisture content, with values increasing as ploughing depth increases.

Among the tillage treatments, T2 (disc ploughing at 20 cm) recorded the highest bulk density (1.42 g cm^{-3}) and lowest porosity (40.77%) at sowing, as well as the highest bulk density (1.55 g cm^{-3}) and lowest porosity (30.81%) at harvest. These conditions may reduce seedling emergence and impede root development, as greater energy may be required for seedlings to emerge through the soil.

T3 (disc ploughing followed by harrowing at 15 cm) recorded the lowest bulk density (1.37 g cm^{-3}), which was not statistically different from T1 and T4, and the highest porosity (42.44%) at sowing. At harvest, T3 also maintained the lowest bulk density (1.44 g cm^{-3}) and highest porosity (36.70%). Although T3 and T4 (harrowing at 10 cm) were statistically similar in their effects on bulk density and porosity at sowing, both T3 and T1 (ploughing at 25 cm) produced well-aerated soils, thereby increasing oxygen availability and improving root and nodule formation.

These findings agree with Aikins and Afuakwa (2012), who reported that ploughing and harrowing at depths of 15–25 cm enhance root length density in cowpea. Márta (2014) also reported similar trends when comparing ploughing and harrowing practices as sustainable tillage options under climate change conditions, noting that ploughing alone significantly improves soil physical properties at $P \leq 0.05$.

Table 4a: Mean Values of the Tillage Treatments during Sowing time Using New Duncan Multiple Range Test (NDMRT) (2018 Trial)

Tillage treatments	Bulk density (g/cm^3)	Penetration resistance (MPa)	Porosity (%)	Ksat (cm/s)	Soil moisture content (w/w,%)
T ₁ (DPH at 25 cm)	1.37 ^b	0.56	43.50 ^b	0.052 ^a	27.18 ^a
T ₂ (DP at 20 cm)	1.41 ^c	0.61	40.16 ^d	0.031 ^c	22.91 ^b
T ₃ (DDH at 15 cm)	1.36 ^{ab}	0.58	42.12 ^{bc}	0.048 ^{ab}	27.10 ^a
T ₄ (DH at 10 cm)	1.35 ^a	0.62	44.20 ^a	0.043 ^b	22.14 ^b
Standard Error	0.012	0.037	2.30	0.008	0.730

a,b,c,d Mean values with same alphabets are not significantly different while those with different alphabets are significantly different

Table 4b: Mean Values of the Tillage Treatments during Harvesting time Using New Duncan Multiple Range Test

Tillage treatments	Bulk density (g/cm ³)	Penetration resistance (MPa)	Porosity (%)	Ksat (cm/s)	Soil moisture content (w/w,%)
T ₁ (DPH at 25 cm)	1.46 ^b	0.46 ^b	36.73 ^b	0.033 ^b	23.35 ^a
T ₂ (DP at 20 cm)	1.54 ^c	0.67 ^c	31.27 ^d	0.023 ^c	19.56 ^c
T ₃ (DDH at 15 cm)	1.42 ^a	0.40 ^a	37.61 ^a	0.044 ^a	24.85 ^a
T ₄ (DH at 10 cm)	1.43 ^a	0.63 ^c	33.57 ^c	0.042 ^a	21.95 ^b
Standard Error	0.013	0.036	2.43	0.0074	0.856

a,b,c,d Mean values with same alphabets are not significantly different while those with different alphabets are significantly different

Table 5a: Mean Values of the Tillage Treatments during Sowing time Using New Duncan Multiple Range Test (2019 Trial)

Tillage treatments	Bulk density (g/cm ³)	Penetration resistance (Mpa)	Porosity (%)	Ksat (cm/s)	Soil moisture content (w/w,%)
T ₁ (DPH at 25 cm)	1.36 ^b	0.52	42.32 ^b	0.054 ^a	28.10 ^a
T ₂ (DP at 20 cm)	1.43 ^c	0.60	41.37 ^a	0.031 ^d	23.13 ^b
T ₃ (DDH at 15 cm)	1.37 ^b	0.56	44.75 ^b	0.052 ^{ab}	26.45 ^a
T ₄ (DH at 10 cm)	1.34 ^a	0.61	40.68 ^a	0.043 ^c	21.74 ^b
Standard Error	0.010	0.034	2.28	0.007	0.752

a,b,c,d Mean values with same alphabets are not significantly different while those with different alphabets are significantly different

Table 5b: Mean Values of the Tillage Treatments during Harvesting time Using New Duncan Multiple Range Test (2019 Trial)

Tillage treatments	Bulk density (g/cm ³)	Penetration resistance (Mpa)	Porosity (%)	Ksat (cm/s)	Soil moisture content (w/w,%)
T ₁ (DPH at 25 cm)	1.46 ^a	0.52 ^b	34.57 ^b	0.031 ^b	22.20 ^b
T ₂ (DP at 20 cm)	1.56 ^b	0.69 ^c	30.34 ^d	0.024 ^c	20.50 ^c
T ₃ (DDH at 15 cm)	1.42 ^a	0.57 ^a	35.72 ^a	0.036 ^a	25.95 ^a
T ₄ (DH at 10 cm)	1.50 ^b	0.65 ^c	34.37 ^b	0.033 ^a	20.65 ^c
Standard Error	0.012	0.036	2.36	0.006	0.800

a,b,c,d Mean values with same alphabets are not significantly different while those with different alphabets are significantly different

3.2 Effects of Tillage Systems on Soil Chemical Properties

The results showed that soil chemical properties were significantly influenced by the various tillage practices (Tables 6 and 7). Differences were recorded in soil organic matter, electrical conductivity, total nitrogen, available phosphorus, potassium, and soil organic carbon among the treatments. The T3 treatment (double disc harrowing at 15 cm depth) produced the highest mean values for soil organic carbon (1.65), electrical conductivity (1.32), total nitrogen (0.43), available phosphorus (4.54), and potassium (0.22). In contrast, T4 (disc harrowing at 10 cm depth) recorded the highest average values for soil organic matter (1.76), magnesium (1.79), and aluminum (1.33).

These results agree with previous studies reporting that reduced tillage systems promote the accumulation of organic carbon, nitrogen, phosphorus, and potassium in the upper soil layers (Neugschwandtner *et al.*, 2014). The findings of the present study indicate that shallow to moderately reduced tillage depths (10–15 cm) enhance nutrient buildup and retention within the active root zone of shallow-rooted crops such as soybean, thereby promoting better root growth and nutrient absorption. In contrast, deeper tillage practices may disturb nutrient distribution and reduce their availability. Comparable findings were reported by Nta *et al.* (2017), who observed that intensive soil disturbance decreased organic matter, carbon concentration, calcium, magnesium, and exchangeable acidity in an Alfisol (clayey skeletal Oxic Paleustalf) in southwestern Nigeria.

3.3 Effects of Nutrient Applications on Soil Chemical Properties

The findings revealed that poultry manure application (nutrient treatments, N) had a significant influence on soil chemical properties at harvest (Tables 6 and 7). The affected parameters included soil pH, soil organic matter, magnesium, aluminium, total nitrogen, available phosphorus, potassium, soil organic carbon, and calcium. Both manure-treated plots differed significantly from the untreated control (N1).

Relative to N1, the highest manure rate (N3) resulted in marked increases in soil organic carbon (39.8%), organic matter (55.5%), Mg^{2+} (17.3%), Al^{3+} (3.1%), Ca^{2+} (8.3%), total nitrogen (47.4%), available phosphorus (36.1%), and potassium (37.7%). Despite these improvements, composted poultry manure reduced soil pH.

These outcomes align with earlier findings (Maerere *et al.*, 2001; Adeniyi & Ojeniyi, 2003; Agbede, 2010), which showed that poultry manure enhances soil organic matter and

improves the availability of both macro- and micronutrients. The observed improvements can be attributed to organic amendments' capacity to build soil organic matter and enhance nutrient retention. Higher organic inputs improve soil chemical status, but excessive application does not always translate into corresponding increases in crop yield.

3.4 Effects of Weed Management Practices on Soil Chemical Properties

The weed management treatments did not produce significant changes in soil chemical properties at $p < 0.05$ (Tables 6 and 7). Parameters such as soil pH, soil organic matter, soil organic carbon, magnesium, nitrogen, and other measured chemical attributes showed no significant differences among treatments.

This observation agrees with the findings of Anannya *et al.* (2017), who reported that herbicide use had minimal influence on soil physicochemical characteristics. The absence of detectable changes in the present study may be related to the limited residual activity of the herbicides in the soil and the moderate application rates employed, which were likely insufficient to modify soil chemical composition (Pal *et al.*, 2006).

The herbicides used for weed control (Pendimethalin and Fusilade) are dinitroaniline herbicides. Weber (1990) reported that they had no effect on the soil microflora involved in herbicide breakdown under controlled conditions, which is faster in warm, dry conditions. Furthermore, the use of composted poultry manure, which enhanced organic matter, reduced the herbicide's effect on soil organisms (Weber, 1990). Although some researchers (Pal *et al.*, 2006; Anannya *et al.*, 2017) reported that herbicide application has negligible effects on soil, Hussein *et al.* (2009) claimed that long-term use can disrupt the soil's biochemical balance, diminishing its fertility and productivity.

Table 6: Mean values of soil chemical properties under tillage systems, nutrient application, and weed management practices using NDMRT (2018 trial)

Treatments	pH in H ₂ O (1:1 soil/water soil)	SOM (%)	SOC (%)	EC (dSm ⁻¹)	Mg ⁺ (cmol(+) kg ⁻¹)	Al ⁺ cmol(+) kg ⁻¹)	Ca ⁺ cmol(+) kg ⁻¹)	N (%)	P (mg kg ⁻¹)	K (cmol(+) kg ⁻¹)
<u>Tillage systems(T)</u>										
T ₁ (DPH at 25 cm)	6.30 ^a	1.53 ^b	1.35 ^a	1.02 ^b	1.54 ^b	1.28 ^b	1.26 ^a	0.33 ^b	3.48 ^c	0.18 ^b
T ₂ (DP at 20 cm)	6.00 ^{ab}	1.21 ^c	0.72 ^c	0.49 ^c	1.21 ^c	1.27 ^c	1.25 ^b	0.29 ^c	3.46 ^c	0.17 ^b
T ₃ (DDH at 15 cm)	5.80 ^b	1.77 ^a	1.40 ^a	1.30 ^a	1.89 ^a	1.29 ^{ab}	1.23 ^c	0.41 ^a	4.82 ^a	0.22 ^a
T ₄ (DH at 10 cm)	5.90 ^b	1.81 ^a	1.07 ^b	1.27 ^a	1.74 ^a	1.30 ^a	1.26 ^a	0.29 ^c	3.59 ^b	0.23 ^a
<u>Nutrient Application(N)</u>										
N _{1(control)}	5.85	1.24 ^c	0.78 ^b	0.57 ^b	1.60 ^b	1.27 ^b	1.21 ^b	0.21 ^b	2.62 ^b	0.78 ^b
N ₂	6.05	1.74 ^b	1.31 ^a	1.18 ^a	1.96 ^a	1.30 ^a	1.27 ^a	0.37 ^a	4.39 ^a	1.31 ^a
N ₃	6.10	1.90 ^a	1.32 ^a	1.31 ^a	1.99 ^a	1.28 ^b	1.28 ^a	0.41 ^a	4.48 ^a	1.32 ^a
<u>Weed management (W)</u>										
W _{1 (control)}	6.07	1.61	1.10	1.05	1.88	1.28	1.25	0.33	3.72	1.10
W ₂	5.93	1.62	1.15	1.03	1.81	1.29	1.26	0.34	3.84	1.15
W ₃	6.04	1.62	1.15	1.01	1.80	1.28	1.26	0.32	3.88	1.15
W ₄	5.95	1.61	1.19	1.00	1.90	1.30	1.25	0.33	3.87	1.19
SE	0.045	0.053	0.062	0.070	0.012	0.005	0.011	0.013	0.189	0.002

DMRT = Duncan's New Multiple Range Test. Means followed by the same letter(s) are not significantly different at $p \leq 0.05$. WAP = Weeks After Planting. SOM = Soil Organic Matter. SOC = Soil Organic Carbon. EC = Electrical Conductivity. SE = Standard Error of the Mean.

Table 7: Mean values of soil chemical properties under different tillage systems, nutrient application rates, and weed management practices (NDMRT, 2019 trial).

Treatments	pH in H ₂ O (1:1 soil/ water soil)	SOM	SOC	EC	Mg ⁺	Al ⁺	Ca ⁺	N	P	K
Tillage systems(T)										
T ₁ (DPH at 25 cm)	6.15	1.56 ^c	1.41 ^b	1.11 ^b	1.34 ^b	1.25 ^b	1.28 ^a	0.32 ^c	3.30 ^c	0.19
T ₂ (DP at 20 cm)	6.12	1.34 ^d	1.00 ^d	0.62 ^c	1.26 ^c	1.25 ^b	1.25 ^b	0.30 ^d	3.26 ^c	0.21
T ₃ (DDH at 15 cm)	6.01	1.80 ^a	1.52 ^a	1.34 ^a	1.80 ^a	1.40 ^a	1.22 ^c	0.45 ^a	4.26 ^a	0.22
T ₄ (DH at 10 cm)	5.95	1.71 ^b	1.21 ^c	1.28 ^a	1.84 ^a	1.35 ^a	1.23 ^c	0.34 ^b	4.08 ^b	0.23
Nutrient Application(N)										
N _{1(control)}	6.35 ^c	1.30 ^c	0.82 ^b	0.45 ^c	1.56 ^b	1.22 ^c	1.23 ^c	0.20 ^c	2.48 ^b	0.17 ^c
N ₂	6.05 ^b	1.86 ^a	1.25 ^a	1.21 ^b	1.90 ^a	1.28 ^b	1.26 ^b	0.35 ^b	4.20 ^a	0.19 ^b
N ₃	5.85 ^a	1.70 ^b	1.31 ^a	1.25 ^a	1.83 ^a	1.30 ^a	1.30 ^a	0.38 ^a	3.50 ^a	0.22 ^a
Weed management (W)										
W _{1 (control)}	5.85	1.55	1.12	1.03	1.86	1.26	1.23	0.30	3.70	0.19
W ₂	5.90	1.61	1.15	1.01	1.83	1.30	1.22	0.30	3.68	0.20
W ₃	6.00	1.56	1.17	1.00	1.76	1.28	1.23	0.32	3.80	0.20
W ₄	6.02	1.59	1.21	1.02	1.86	1.28	1.22	0.31	3.76	0.19
SE	0.042	0.055	0.059	0.071	0.015	0.004	0.012	0.017	0.016	0.002

NDMRT = Duncan's Multiple Range Test. Means followed by the same letter(s) are not significantly different at $p \leq 0.05$. WAP = Weeks After Planting. SOM = Soil Organic Matter. SOC = Soil Organic Carbon. EC = Electrical Conductivity. SE = Standard Error of the Mean.

3.5 Effects of Tillage Systems, Nutrient Application, and Weed Management Practice on the Yield of Soybean

The reduced tillage treatments imposed had significant effects on soybean yield components in both experiments, as shown in Tables 8 and 9. Tillage systems, nutrient applications, and weed management practices have significant effects on pod/plant (no), 1000-seed weight (g), and grain yield (ton/ha) in both experiments. There is significant interaction effects among the treatments imposed for the yield components and grain yield at $p \leq 0.05$ of soybean in this study. Though yield components are lower in the 2019 trial due to lower rainfall than in the 2018 trial. Among the tillage systems, T3 (double disc harrowing at 15 cm) recorded the highest mean values for pods per plant (74.78) and 1000-seed weight (134.83 g), as well as a high mean grain yield of 2.43 t ha^{-1} (average of both experiments). However, these values were not significantly different ($p \leq 0.05$) from those obtained under T1 (disc ploughing and harrowing at 25 cm), which produced 68.78 pods per plant, a 1000-seed weight of 131.72 g, and a mean grain yield of 2.50 t ha^{-1} .

These results indicate that reduced tillage at depths of 15-25 cm resulted in significantly higher biological yield than tillage at depths below 15 cm. The lower yields observed under shallower tillage may be attributed to increased weed infestation associated with reduced depth of soil disturbance.

The experimental field was a well-drained sandy loam, and according to Dick and Van Doren (1985), no significant yield difference existed between conventional and reduced tillage treatments for soybean production, but there was in a poorly drained soil. Soil fertility is expected to benefit from poultry manure application, as it has been shown to improve soil organic matter, macronutrient status, and micronutrient quality (Akande and Adediran, 2004). It was observed that improved soil nutrient levels resulting from poultry manure application enhanced soybean growth, development, and yield. Although the higher nutrient treatment (1 t ha^{-1} poultry manure + 75 kg ha^{-1} single superphosphate [SSP]) promoted greater vegetative growth compared with the lower rate (0.5 t ha^{-1} poultry manure + 50 kg ha^{-1} SSP), this increase did not translate into higher grain yield.

The reduced yield response at the higher manure rate may be attributed to the dilution effect associated with excessive organic matter and high nitrogen availability, which stimulated

vegetative growth at the expense of grain filling. In other words, excess nitrogen promoted biomass accumulation rather than reproductive development. Similarly, Ewulo et al. (2008) reported that poultry manure application at rates above 25 t ha⁻¹ did not increase tomato fruit yield.

Table 8. Average Effects of tillage systems, nutrient application rates, and weed management practices on yield components and grain yield of soybean (2018 trial)

Treatments	Pod/plant (No)	Seed/Pod	1000 seed weight (g)	Grain (ton/ha)	yield
Tillage systems(T)					
T ₁ (DPH at 25 cm)	68.78 ^{ab}	2.3	131.72 ^a	2.50 ^a	
T ₂ (DP at 20 cm)	61.42 ^c	2.3	127.69 ^b	2.27 ^c	
T ₃ (DDH at 15 cm)	74.78 ^a	2.3	134.83 ^a	2.55 ^a	
T ₄ (DH at 10 cm)	66.14 ^{bc}	2.3	131.04 ^{ab}	2.30 ^{bc}	
Nutrient Application(N)					
N ₁ (control)	40.17 ^c	2.21 ^b	92.31 ^b	1.48 ^c	
N ₂	86.06 ^a	2.40 ^a	150.83 ^a	2.97 ^a	
N ₃	77.10 ^b	2.34 ^a	149.98 ^a	2.77 ^b	
Weed management (W)					
W ₁ (control)	25.08 ^c	1.10 ^d	60.44 ^c	0.32 ^c	
W ₂	76.06 ^a	2.38 ^b	143.08 ^a	2.63 ^b	
W ₃	77.06 ^a	2.40 ^a	142.81 ^a	2.87 ^a	
W ₄	72.92 ^b	2.31 ^c	137.08 ^b	2.60 ^b	
SE	2.44	0.026	3.07	0.41	

NDMRT (Duncan Multiple Range Test), Mean values with same letters are insignificantly different at $p \leq 0.05$, WAP (Week After Planting)

Table 9: Average Effects of tillage systems, nutrient application rates, and weed management practices on yield components and grain yield of soybean (2019 trial)

Treatments	Pod/plant (No)	Seed/Pod	1000 seed weight (g)	Grain yield (ton/ha)
Tillage systems(T)				
T ₁ (DPH at 25 cm)	66.89 ^a	2.25	117.00 ^a	2.19 ^a
T ₂ (DP at 20 cm)	60.81 ^b	2.31	115.97 ^b	2.04 ^b
T ₃ (DDH at 15 cm)	68.31 ^a	2.33	119.69 ^a	2.30 ^a
T ₄ (DH at 10 cm)	57.86 ^{bc}	2.21	115.92 ^b	2.02 ^c
Nutrient Application(N)				
N _{1(control)}	42.10 ^c	2.19 ^b	93.77 ^b	1.38 ^c
N ₂	76.40 ^a	2.38 ^a	129.13 ^a	2.53 ^a
N ₃	74.60 ^b	2.34 ^a	128.54 ^a	2.51 ^b
Weed management (W)				
W _{1(control)}	20.08 ^c	1.13 ^c	55.56 ^d	0.37 ^c
W ₂	70.60 ^a	2.42 ^a	128.61 ^a	2.23 ^b
W ₃	70.39 ^a	2.35 ^a	123.22 ^b	2.49 ^a
W ₄	69.47 ^b	2.33 ^b	121.31 ^c	2.47 ^b
SE	2.30	0.028	3.02	0.35

NDMRT (New Duncan Multiple Range Test), Mean values with same letters are insignificantly different at $p \leq 0.05$, WAP (Week After Planting)

3.6 Discussions

The results demonstrated that tillage systems significantly influenced soil physical and chemical properties. Moderate tillage depth (15 cm) improved soil structure by reducing bulk density and increasing porosity, thereby enhancing water infiltration and root penetration. Excessive tillage depth (25 cm) may have disrupted soil aggregates and accelerated organic matter decomposition, while minimal disturbance (10 cm) may not have sufficiently alleviated compaction.

Shallow to moderately reduced tillage (10–15 cm) enhanced nutrient retention in the topsoil. Higher values of soil organic carbon, total nitrogen, and available phosphorus observed under these treatments indicate improved nutrient cycling and reduced nutrient leaching. These findings align with earlier studies showing that reduced tillage concentrates nutrients within the active root zone.

Poultry manure application significantly improved soil chemical properties at harvest. Increases in soil pH, organic matter, total nitrogen, and exchangeable bases indicate improved soil fertility status. However, increasing manure from 0.5 t ha⁻¹ to 1.0 t ha⁻¹ did not proportionally increase grain yield, suggesting diminishing returns and possible nutrient imbalance.

Weed management had limited effects on soil chemical properties but significantly influenced crop performance. Effective early-season weed control reduced competition for nutrients, water, and light, resulting in improved yield components.

The combination of moderate tillage (15 cm), 0.5 t ha⁻¹ compost poultry manure, and timely weed control produced optimal soybean performance in sandy loam soil. These findings suggest that moderate soil disturbance and balanced nutrient management improve productivity while potentially reducing energy costs associated with deep tillage

4.0 CONCLUSION

The agronomic performance of soybean was significantly influenced by tillage treatments, nutrient levels, and herbicide application rates. Tillage systems that mechanically distort the soil contribute significantly to soybean yield and soil physical properties during sowing and harvesting. Reduced tillage with ploughing alone increases soil vulnerability to crumble formation that may be resistant to water, leading to desiccation of the top soil layer and thereby impeding root formation. Tillage systems between 10-15 cm depth of cut favour the availability and retention of soil nutrients within the tap root of shallow crops T₃ (DDH at 15 cm) had the highest mean values in terms of yield component, with the highest pod/plant (71.54), 1000 seed weight (127.26 g) and mean grain yield of 2.43 ton/ha. Though grain yield at T₃ (DDH at 15 cm) is not statistically different from that of T₁ (DPH at 25 cm), it is 2.35 tons/ha. Nutrient application at 0.5 ton/ha of compost poultry manure with 50 kg of SSP fertilizer improved grain yield by 4.20% as compared to nutrient application at 1 ton/ha of compost poultry manure with 75 kg of SSP. Weed Management significantly influenced grain yield, with post-emergence

weed control at 3 to 5 weeks after planting yielding the highest grain yield of 77.45% compared with the control treatment.

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Dynamics of Selected Soil Properties in Relation to Land Use Types and Landscape Positions in Efon-Alaaye, Ekiti, Nigeria

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ABSTRACT

This study evaluated the variation of soil properties and nutrient distribution under cropping, forestry, and plantation land uses across landscape positions in Efon-Alaaye, Nigeria. Soil samples were collected at three depths (0–15, 15–30, and 30–45 cm) along peak, mid, and foot slopes, with three replicates per treatment ($n = 81$). Soil organic carbon (SOC) ranged from 0.49 to 2.52%, with highest values in surface soils under cropping systems, while total nitrogen (TN) ranged from 0.08 to 0.59% and followed a similar trend. Soil pH varied from 4.2 to 6.9, indicating generally acidic conditions, with plantation soils being less acidic than cropping and forestry systems. Exchangeable potassium (0.11–0.48%) and available phosphorus (4.28–14.78 mg/kg) were higher under plantation and cropping land uses compared to forestry. Cation exchange capacity (0.50–2.38 cmol/kg) showed minimal variation across treatments. Bulk density (0.74–1.52 g/cm³) increased with depth, while soil moisture content (2.75–28.54%) was generally higher in surface soils. Land use and soil depth were the primary determinants of soil variability, with organic matter playing a central role in soil fertility. Sustainable management practices are essential to maintain soil productivity in the study area.

Keywords: Soil properties, nutrient distribution, soil fertility, land use types, landscape positions.

1.0 INTRODUCTION

Soil carbon stock consists of two components: soil organic carbon (SOC) and soil inorganic carbon (SIC). SOC is the carbon component of soil organic matter (SOM), a heterogeneous pool of carbon comprised of diverse materials including fine fragments of litter, roots and soil fauna, microbial biomass carbon, products of microbial decay and other biotic processes (i.e. such as particulate organic matter), and simple compounds such as sugar and polysaccharides (Jansson *et al.*, 2010). The dynamics of organic carbon storage in agricultural soils is gaining increasing importance because of its impacts on climate change and benefits for crop productivity. Good farming practices have the potential to make such soil a net sink for carbon thereby attenuating CO₂ load in the atmosphere and improving soil fertility and hence productivity (Lal, 2004). The majority of carbon in the terrestrial pool is stored below ground in soils (Janzen, 2004). Carbon stock in soil depends largely on the aerial extent of the soils besides other factors such as carbon content, depth and bulk density of soils. The total soil organic carbon (TSOC) stock is separated into a labile or actively cycling pool, a slow pool, and a passive, recalcitrant pool with varying

residence times. The labile carbon pool is the fraction of TSOC with the most rapid turnover rates. The labile pool consists of living microbes and their products besides soil organic matter. At the same time, this pool is important from the point of view of crop production. It fuels the soil food web and therefore greatly influences nutrient cycling for maintaining soil quality and its productivity (Majumder *et al.* 2007). Highly recalcitrant or passive pool is only very slowly altered by microbial activities (Sherrod *et al.* 2005). The passive pool is comparatively more stable than the active pool and is slowly decomposable having a larger turnover time. Soil organic carbon is the most important element in the soil system whose loss leads to soil degradation and in which soil erosion is found to be the major cause of SOC loss. Land use change is a main factor influencing content and quality of SOC. Changes in land use and/or land management can significantly affect soil carbon stocks since they are often accompanied by changes in ecosystem structure and function including changes in the ability of soils to accumulate organic carbon.

Cropping systems and management practices that ensure greater amounts of crop residue are returned to the soil are expected to cause a net build-up of the SOC stock. Identifying such systems or practices is a priority for sustaining crop productivity. Crop species that are cultivated may also play an important role in maintaining the stock because both quantity and quality of their residues that are returned to the soils vary greatly, thereby affecting their turnover or residence time in soil. Changes in SOC due to management practices are difficult to quantify as these changes occur slowly and are relatively small compared to the vast SOC pool size, and vary both spatially and temporally (Russell *et al.* 2004). Moreover, conversion of arable land into grassland increases SOC as higher input of plant and root residues in grassland soils is stabilizing SOC stock in the topsoil. Soil carbon response to land use change likely depends on previous land uses and will thus show a 'legacy effect' which could help in explaining the changes in soil carbon stocks. For example, a generally held view is that carbon accumulation will be faster when the land use change involves a shift from cultivated (disturbed) soils to permanent grassland soils. It is assumed that, under constant agricultural practices (e.g. 50 to 100 years after a land use/management change) and at 0-30 cm depth, grassland soil carbon will eventually reach a steady state and that as the carbon content approaches this steady state, rates of carbon accumulation will decline (Smith, 2014). Soil properties such as soil aggregate size distribution and stability are important indicators of soil physical quality, reflecting the impact of land use and soil management (Castro *et al.*, 2002) on aggregation, degradation and soil health (Herrick *et al.*, 2001). Soil organic matter (SOM) and soil texture are the principal determinants of physical properties such as bulk density and aggregate stability. Conversion of soil from forest to other land uses results in higher bulk density, lower hydraulic conductivity, and higher susceptibility to erosion (Lal, 2003), thereby accelerating soil degradation and decline in SOC concentration. Farming practices affect SOC concentration and physical properties (Gami *et al.*, 2001; Hao *et al.*, 2001). The interaction of clay colloids with organic compounds and inorganic cementing materials creates soil aggregates. The arrangement of these aggregates and the pore spaces between them determine the soil structure. Thus, soil structure and soil organic matter content are among the most dynamic properties of soil, and depend on land use and management. Soil texture is another key determinant of soil quality. Textural composition moderates the behavior

of several soil processes, including SOM dynamics and carbon sequestration (Kettler *et al.*, 2001). Physical fractionation of soil particles into size and density classes can provide information on the importance of interactions between organic and inorganic soil components and the turnover of SOM (Christensen, 2001). The degree of association of SOC with particle sizes is a qualitative indicator of the impact of land use and soil management. The particle size distribution of soil samples also influences organic carbon stock. The SOC associated with the coarse fraction is commonly less decomposed and has a higher C/N ratio than SOC associated with the fine fraction. However, SOC associated with clay is mostly of humic nature with a low C/N ratio. The SOC associated with sand fraction is a labile pool of carbon and reflects rapid changes in SOM quality due to changes in land use and management. The SOC in the clay fraction, however, is more stable and is altered more by physical and chemical processes than by land use changes (Khanna *et al.*, 2001).

The study area is mostly mountainous with steep slopes. However, farmers still use the area for cultivation which high risks soil erosion runoff. It is a region with very severe cases of soil erosion, which affects extensively the peak, mid and lower areas of the slopes, causing decrease in soil organic carbon, degradation in soil physical, chemical and biological soil properties. Previous researches carried out in the study area assessed the impact of erosion on the residential areas, focused on gully erosions and how it affected soil properties, but this research evaluated soil properties and organic carbon stocks and fraction in the area and correlate them to land use type and slope positions. The knowledge gained will help in drafting optimum soil conservation methods.

2.0 MATERIALS AND METHODS

2.1 Study Area

Efon-Alaaye in Ekiti State (South-Western part of Nigeria) is located between latitude 7°40'N and 7°54'N and longitude 4°52'E and 5°0'E with an elevation of 500 meters above sea level. Due to its topography and elevation, it enjoys a cooler climate than other parts of the state. It is a large town surrounded by hills, otherwise known as Efon Ridges (Adegboyega, 2019). It is situated in a valley and spreads over an area of about 31.9 squares kilometers and bounded round by chains of ridges rising to an average height of about 2000 feet above sea level. Figure 1 is the map of the study area showing its national, regional and local setting. The area where the soil samples were collected at Efon-Alaaye, Ekiti state is a sloping land made up of three different land uses which are cropping, forestry and plantation. The land use pattern has the following detailed geographical structures as presented in Table 1 below.

Table 1: Coordinates and altitudes of study area showing land use types and slope positions

Land use	Slope position	Latitude (N)	Longitude (E)	Altitude (m)
Cropping	Peak	7°38.56'	4°55.31'	573
	Mid	7°38.57'	4°55.292'	564
	Foot	7°38.58'	4°55.292'	559
Forestry	Peak	7°38.602'	4°55.338'	581
	Mid	7°38.603'	4°55.325'	561
	Foot	7°38.616'	4°55.323'	557
Plantation	Peak	7°38.668'	4°55.307'	539
	Mid	7°38.660'	4°55.301'	536
	Foot	7°38.668'	4°55.299'	531

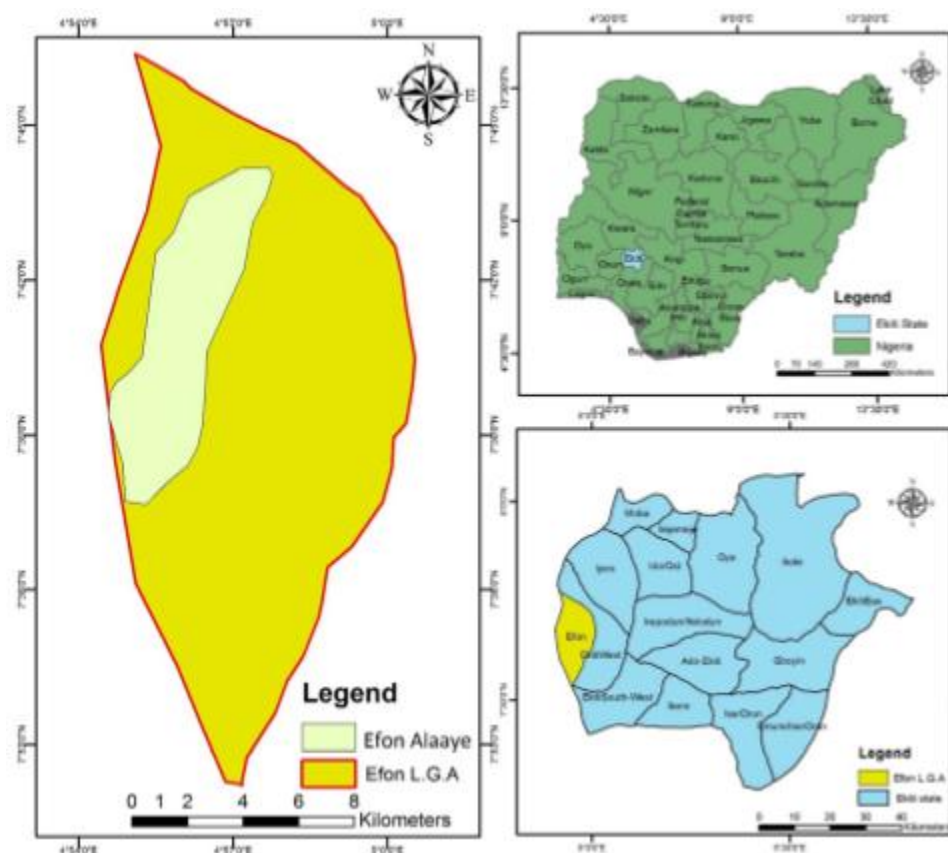


Figure 1: Map of Efon-Alaaye showing its national, sub-national and local borders. (Source: Ministry of Surveys, Abuja (Digitized in ArcMap, 2018 by Authors))

2.2 Soil Sampling and Analysis

Reconnaissance survey was carried out to identify possible areas having steep slope gradient and different land use types. Accordingly, three adjacent land use types: cropping (cultivated with cassava), forestry, and plantation (banana and plantain) lands were selected in year 2019. Purposive sampling method was employed and selection for sampling considered adjacent land use types. Soil samples were taken from the peak, middle and foot of the sloping cropping, forestry, and plantation land use types with three replications on the same row at depths 0-15 cm, 15-30 cm and 30-45 cm using a core sampler to test for bulk density and soil moisture content while an auger was also used to collect soil samples at the three respective depths to test for other soil properties. Mass (g) of soil were taken and recorded before putting them in a foil paper and oven drying them to determine their bulk densities and moisture content. The soil samples taken were air-dried for 2 days, passed through a 2 mm sieve and stored from which samples were taken to test for other soil properties.

Organic carbon (OC) of the soils was determined using the method of wet oxidation as proposed by Walkley and Black (1934). Soil pH was determined using the pH meter, Hydrometer method was used to analyze the particle size of the samples. Potassium (K) was extracted from the soil using 1 M neutral ammonium acetate (NH_4OAc) at pH 7.0 by shaking for 1 hour, followed by filtration. The extract was then analyzed for potassium using flame photometry. Nitrogen (N) was determined by digesting the samples with H_2SO_4 using K_2SO_4 as the catalyst, distilling and then titrating the distillate with HCl . Cation exchange capacity (CEC) was determined by ammonium saturation method. Phosphorus (P) was extracted from the soil using the Bray I extractant (0.03 M NH_4F + 0.025 M HCl) by shaking for 30 minutes. The extract was filtered, and phosphorus in the filtrate was determined colorimetrically using the Murphy and Riley method with a spectrophotometer. Bulk density and moisture content were calculated on dry basis and after determining total carbon (TC) by combustion method. Inorganic carbon was obtained by subtracting OC from TC.

2.3 Statistical Analysis

The dataset was reorganized into a factorial structure with land use type, slope position, and soil depth as fixed factors, while sampling points served as replicates. Each observation represented a unique combination of these factors. Data were subjected to three-way analysis of variance (ANOVA) to evaluate the main and interaction effects of land use, slope position, and soil depth on soil properties. Data preprocessing and organization were carried out using Microsoft Excel, while statistical analyses were performed using SPSS software.

3.0 RESULTS AND DISCUSSION

3.1 Distribution of Soil Organic Carbon

The organic carbon content of the soils as presented in Table A1(Appendix) was highest at the 0–15 cm depth and decreased progressively with increasing soil depth across all land use systems. Analysis of variance shown in Table 2 revealed that soil organic carbon was significantly ($p <$

0.05) influenced by soil depth ($F = 25.62$, $p < 0.001$), while land use type ($p = 0.096$) and slope position ($p = 0.685$) had no significant effect. The interaction effects among land use, slope position, and depth were also not significant ($p > 0.05$), indicating that the pattern of SOC distribution with depth was consistent across the study area.

The higher organic carbon content observed at the surface layer (0–15 cm) can be attributed to the accumulation of organic matter such as humus, decomposing plant residues, and leaf litter. This organic matter input decreases with soil depth, resulting in lower SOC values in the subsoil layers. Similar trends were observed across cropping, forestry, and plantation land use systems, confirming that soil depth is the dominant factor controlling SOC distribution. Although variations in SOC values were observed among the different land use systems, these differences were not statistically significant. For instance, relatively higher SOC values were recorded under cropping land use, which may be associated with the application of organic amendments such as house refuse, as well as contributions from crop residues and root biomass. Plantation land use also showed comparatively higher SOC values at the surface and subsurface layers than forestry in some cases, while variations were observed at deeper layers. However, these differences did not translate into significant effects, suggesting that land use type had limited influence on SOC distribution in the study area.

Similarly, differences in SOC along slope positions were observed but were not statistically significant. The relatively higher SOC values in some cropping areas may be linked to better ground cover from grasses and crops, which can reduce runoff and enhance organic matter accumulation. The presence of crop roots and associated microbial activity may also contribute to increased organic matter content. These observations are consistent with the findings of Urioste *et al.*, (2006), Negassa (2001), and Malo *et al.*, (2005), who reported higher organic carbon content in soils with greater vegetative cover.

Table 2: ANOVA of the SOC distribution.

Source	Df	SS	MS	F	p-value
Land Use	2	1.9335	0.9668	2.44	0.096
Slope	2	0.3012	0.1506	0.38	0.685
Depth	2	20.2689	10.1345	25.62	<0.001
Land Use × Slope	4	1.9152	0.4788	1.21	0.317
Land Use × Depth	4	2.3691	0.5923	1.50	0.216
Slope × Depth	4	0.3558	0.0889	0.22	0.923
L × S × D	8	0.8400	0.1050	0.27	0.974
Error	54	21.3599	0.3956		
Total	80	49.3436			

L = land use, S = slope, D = depth.

3.2 Soil pH Analysis

The values recorded for soil pH as presented in Table A2(Appendix) showed variations across the different land use types, slope positions, and soil depths. Analysis of variance presented in Table 3 revealed that soil pH was significantly influenced by land use type ($F = 118.6$, $p < 0.001$) and soil depth ($F = 3.42$, $p < 0.05$), while slope position had no significant effect ($p > 0.05$). The interaction effects among land use, slope position, and depth were also not significant ($p > 0.05$), indicating that the influence of land use and depth on soil pH was consistent across the study area. Across the land use systems, plantation land use recorded the highest pH values, ranging approximately from 6.17 to 6.70, followed by forestry, while cropping land use had the lowest values, with pH as low as 4.93. This indicates that soils in the study area are generally acidic irrespective of land use, although the degree of acidity varies. The soils under plantation land use can be classified as slightly acidic, whereas those under cropping and forestry systems are moderately acidic. The significant effect of land use on soil pH may be attributed to differences in management practices and organic matter dynamics. The relatively lower pH observed in cropping land use could be due to continuous cultivation, inefficient use of nitrogen fertilizers, and the export of basic cations through harvested produce. As noted by Gazey (2019), most plant materials are slightly alkaline, and their removal during harvest leaves residual hydrogen ions in the soil, thereby increasing soil acidity over time. In addition, the application of ammonium-based fertilizers and subsequent nitrate leaching further contribute to soil acidification.

In contrast, the higher pH values observed under plantation land use across the depths may be linked to the accumulation and decomposition of fallen leaves, particularly from plantain, which contribute to increased levels of exchangeable bases in the soil. Forestry soils exhibited intermediate pH values, possibly due to the balance between litter input and nutrient uptake by trees, although disturbances such as tree felling may alter this balance. Soil pH also varied significantly with depth, although the trend was less pronounced compared to land use. In some instances, slight increases in pH with depth were observed, which may be associated with reduced organic matter accumulation and lower leaching intensity in subsurface layers. Although variations in soil pH were observed across slope positions, these differences were not statistically significant, suggesting that topographic factors such as runoff and erosion had limited influence on soil pH distribution in the study area.

Table 3: ANOVA of the soilpH.

Source	Df	SS	MS	F	p-value
Land Use	2	9.218	4.609	118.6	<0.001
Slope	2	0.158	0.079	2.03	0.140
Depth	2	0.266	0.133	3.42	0.040
Land Use $\times$ Slope	4	0.120	0.030	0.77	0.547
Land Use $\times$ Depth	4	0.311	0.078	2.00	0.106
Slope $\times$ Depth	4	0.098	0.025	0.63	0.642
L $\times$ S $\times$ D	8	0.224	0.028	0.72	0.673
Error	54	2.099	0.0389		
Total	80	12.494			

L = land use, S = slope, D = depth.

3.3 Distribution of Potassium in the Soil

The distribution of exchangeable potassium (K) across different land use types, slope positions, and soil depths is presented in Table A3(Appendix). Prior to analysis, extreme values identified as potential laboratory errors were excluded to ensure data reliability. Analysis of variance as presented in Table 4 revealed that potassium was significantly ($p < 0.05$) influenced by land use type ($F = 5.18$, $p < 0.01$), while slope position ($p = 0.301$) and soil depth ($p = 0.167$) had no significant effect. The interaction effects among land use, slope position, and depth were also not significant ($p > 0.05$), indicating that the influence of land use on potassium distribution was consistent across the study area.

Across the land use systems and soil depths, exchangeable potassium concentrations were generally higher under plantation and forestry land uses compared to cropping. Although the values under plantation and forestry were relatively similar, they consistently exceeded those of the cropping land use system. The higher exchangeable potassium observed, particularly at the 0–15 cm depth under plantation and forestry, may be attributed to the decomposition of fallen leaves, which contribute organic residues that act as a source of potassium through nutrient recycling. In contrast, the relatively lower potassium concentration observed under cropping land use may be due to continuous cultivation, nutrient uptake by crops, and the removal of biomass during harvest, which depletes soil potassium over time. In addition, intensive cultivation practices and the use of acid-forming inorganic fertilizers may further enhance potassium loss through leaching and soil weathering processes. This observation is consistent with the findings of Malo *et al.*, (2005), who reported that the intensity of weathering, cultivation, and fertilizer use significantly influence potassium distribution and contribute to its depletion in soils.

Although variations in potassium content were observed across soil depths, these differences were not statistically significant, indicating a relatively uniform distribution of potassium within the soil profile. This may be attributed to the mobility of potassium in the soil and its susceptibility to leaching under tropical conditions. Similarly, slope position did not significantly influence potassium distribution, suggesting that topographic factors such as runoff and erosion had minimal impact on potassium levels in the study area.

Table 4: ANOVA for Potassium distribution.

Source	Df	SS	MS	F	p-value
Land Use	2	0.0612	0.0306	5.18	0.009
Slope	2	0.0145	0.0073	1.23	0.301
Depth	2	0.0218	0.0109	1.85	0.167
Land Use $\times$ Slope	4	0.0189	0.0047	0.80	0.530
Land Use $\times$ Depth	4	0.0264	0.0066	1.12	0.356
Slope $\times$ Depth	4	0.0172	0.0043	0.73	0.574
L $\times$ S $\times$ D	8	0.0321	0.0040	0.68	0.708
Error	52	0.3071	0.0059		
Total	78	0.4992			

L = land use, S = slope, D = depth.

3.4 Distribution of Soil Nitrogen

The distribution of total nitrogen (TN) across different land use types, slope positions, and soil depths is presented in Table A4(Appendix). Analysis of variance shown in Table 5 revealed that TN was significantly influenced by land use type ($F = 6.12$, $p < 0.01$) and soil depth ($F = 21.93$, $p < 0.001$), while slope position had no significant effect ($p > 0.05$). The interaction effects among land use, slope position, and depth were also not significant ($p > 0.05$), indicating a consistent pattern of nitrogen distribution across the study area.

Highest total nitrogen values were generally observed under cropping land use, while forestry and plantation land uses exhibited relatively similar and comparatively lower values. This trend may be attributed to the higher organic matter content in cropping systems, possibly due to the addition of crop residues and organic amendments, which enhance nitrogen availability through mineralization processes. Total nitrogen content was highest at the 0–15 cm depth and decreased progressively with increasing soil depth across all land use systems and slope positions. This pattern reflects the distribution of soil organic carbon, which serves as a major source of nitrogen in soils. The higher TN values at the surface layer can be linked to greater accumulation of organic matter, while reduced organic inputs at deeper layers result in lower nitrogen concentrations.

A close relationship between organic carbon and total nitrogen was observed across the different depths (0–15 cm, 15–30 cm, and 30–45 cm), indicating that the contribution of organic carbon to total nitrogen is substantial. This supports the findings of Urioste *et al.*, (2006), who reported that organic carbon levels significantly influence the availability of total nitrogen in soils. Thus, the distribution of TN in the study area is largely governed by the dynamics of soil organic matter. Although variations in TN were observed across slope positions, these differences were not statistically significant, suggesting that topographic factors such as runoff and erosion had limited influence on nitrogen distribution in the study area.

Table 5: ANOVA for Soil Nitrogen distribution.

Source	Df	SS	MS	F	p-value
Land Use	2	0.0416	0.0208	6.12	0.004
Slope	2	0.0068	0.0034	1.00	0.374
Depth	2	0.1492	0.0746	21.93	<0.001
Land Use × Slope	4	0.0102	0.0026	0.75	0.560
Land Use × Depth	4	0.0128	0.0032	0.94	0.447
Slope × Depth	4	0.0096	0.0024	0.71	0.590
L × S × D	8	0.0185	0.0023	0.68	0.710
Error	54	0.1836	0.0034		
Total	80	0.4323			

L = land use, S = slope, D = depth.

3.5 Distribution of Soil Available Phosphorus

The distribution of available phosphorus across different land use types, slope positions, and soil depths is presented in Table A5(Appendix). Analysis of variance shown in Table 6 revealed that

phosphorus content was significantly influenced by land use type ($F = 8.94$, $p < 0.001$) and soil depth ($F = 3.72$, $p < 0.05$), while slope position had no significant effect ($p > 0.05$). The interaction effects among land use, slope position, and depth were also not significant ($p > 0.05$), indicating that the influence of land use and depth on phosphorus distribution was consistent across the study area.

Across the land use systems, available phosphorus was generally higher under plantation and cropping land uses compared to forestry, with relatively similar values observed between plantation and cropping systems. The higher availability of phosphorus in these systems may be attributed to long-term manure application, addition of crop residues, and enhanced microbial activity, which contribute to increased phosphorus mineralization and availability in the soil. Organic matter plays a key role in phosphorus dynamics by influencing its mobility and availability. As reported by Materechera and Mkhabela (2001), organic matter can complex phosphorus from adsorption sites through ligand exchange and increase the mobility of inorganic phosphorus, particularly in acidic soils, by reducing the chemical activity of iron and aluminum. Furthermore, the addition of manure and crop residues in cropping and plantation systems may coat soil particle surfaces, thereby preventing or delaying phosphorus sorption and enhancing its solubility. The relatively lower phosphorus content observed under forestry land use may be due to the absence of external nutrient inputs such as fertilizers and the slower rate of nutrient cycling compared to managed systems. Similar observations were reported by Eijk *et al.*, (2006), who noted that continuous application of phosphorus fertilizers significantly increases soil phosphorus levels in cultivated systems. Phosphorus content also varied significantly with soil depth, with higher values often observed at the surface layer (0–15 cm). This may be attributed to the accumulation of organic matter and surface application of phosphorus-containing inputs. However, the trend was not entirely uniform across all samples, suggesting the influence of localized soil conditions and management practices. Although variations in phosphorus content were observed across slope positions, these differences were not statistically significant, indicating that topographic factors such as runoff and erosion had limited influence on phosphorus distribution in the study area. Observed differences at specific slope positions may therefore be attributed to localized variability rather than systematic topographic effects.

Table 6: ANOVA for Soil Phosphorus distribution.

Source	Df	SS	MS	F	p-value
Land Use	2	88.52	44.26	8.94	<0.001
Slope	2	21.37	10.69	2.16	0.125
Depth	2	36.81	18.41	3.72	0.031
Land Use × Slope	4	18.92	4.73	0.96	0.436
Land Use × Depth	4	22.15	5.54	1.12	0.356
Slope × Depth	4	17.06	4.27	0.86	0.494
L × S × D	8	30.11	3.76	0.76	0.640
Error	54	267.21	4.95		
Total	80	502.15			

L = land use, S = slope, D = depth.

3.6 Cation Exchange Capacity Analysis.

The distribution of cation exchange capacity (CEC) across different land use types, slope positions, and soil depths is presented in Table A6(Appendix). Analysis of variance shown in Table 7 revealed that CEC was significantly influenced by land use type ($F = 4.36$, $p < 0.05$), while slope position and soil depth had no significant effect ($p > 0.05$). The interaction effects among land use, slope position, and depth were also not significant ($p > 0.05$), indicating that the influence of land use on CEC was consistent across the study area.

Across the land use systems, CEC values were relatively uniform with respect to soil depth and slope position, which explains the non-significant effects observed for these factors. This suggests that CEC distribution within the soil profile is fairly stable and not strongly influenced by topographic variation in the study area. The relative uniformity of CEC across depths and slope positions may be attributed to the similar soil type and relatively consistent pH conditions across the land uses, as CEC is largely governed by soil mineralogy and soil reaction. However, despite this general uniformity, significant differences were observed among land use types. Higher CEC values were generally recorded under plantation land use, followed by cropping, while forestry exhibited relatively variable values. The higher CEC under plantation land use may be attributed to greater accumulation and decomposition of organic residues, particularly leaf litter, which contributes to increased soil organic matter and enhances the soil's capacity to retain exchangeable cations. In cropping systems, moderate CEC values may be associated with the addition of organic amendments and crop residues, although continuous cultivation and nutrient removal through harvest may limit the buildup of exchange sites over time. Forestry soils exhibited variability in CEC, possibly due to differences in litter quality, decomposition rates, and nutrient cycling processes.

Table 7: ANOVA for Cation Exchange Capacity.

Source	Df	SS	MS	F	p-value
Land Use	2	0.842	0.421	4.36	0.018
Slope	2	0.216	0.108	1.12	0.334
Depth	2	0.398	0.199	2.06	0.136
Land Use $\times$ Slope	4	0.312	0.078	0.81	0.523
Land Use $\times$ Depth	4	0.355	0.089	0.92	0.460
Slope $\times$ Depth	4	0.288	0.072	0.75	0.561
L $\times$ S $\times$ D	8	0.512	0.064	0.66	0.726
Error	54	5.212	0.0965		
Total	80	8.135			

L = land use, S = slope, D = depth.

3.7 Soil Inorganic Carbon

The distribution of soil inorganic carbon (SIC) across land use types, slope positions, and soil depths is presented in Table A7(Appendix). The values of SIC ranged from 6.46 to 0.10 across all land uses, with the highest value occurring at the 0–15 cm depth under plantation land use and the lowest value at the 30–45 cm depth under cropping land use. Analysis of variance shown in

Table 8 revealed that SIC was significantly influenced by land use type ($F = 3.87$, $p < 0.05$), while slope position and soil depth had no significant effects ($p > 0.05$). The interaction effects among land use, slope position, and depth were also not significant, indicating that the influence of land use on SIC was consistent across the study area.

Across the different land use systems, SIC exhibited noticeable variability, with plantation and cropping systems generally showing higher and more variable values compared to forestry. This variation may be attributed to differences in land management practices, organic residue inputs, and carbon transformation processes. The relatively higher SIC observed in plantation land use may be associated with greater accumulation and decomposition of plant residues, which can contribute to carbonate formation and retention in the soil. Although variations in SIC were observed across slope positions and soil depths, these differences were not statistically significant. For instance, higher SIC values were frequently observed at the peak positions compared to mid and foot slopes, while at the mid-slope, higher values were sometimes recorded at deeper depths (30–45 cm), and at the foot slope, SIC tended to peak at the 15–30 cm depth except in plantation soils where higher values occurred at the surface layer (0–15 cm). These observed patterns, however, were inconsistent and did not follow a uniform trend across all land uses, which explains the lack of statistical significance for slope position and depth. The absence of significant depth and slope effects suggests that the distribution of SIC within the soil profile is relatively stable and not strongly controlled by topographic factors such as erosion or runoff in the study area. Instead, land use type appears to be the dominant factor influencing SIC distribution, primarily through its impact on soil organic matter dynamics and carbon cycling processes.

Table 8: ANOVA for Soil Inorganic Carbon.

Source	Df	SS	MS	F	p-value
Land Use	2	18.42	9.21	3.87	0.027
Slope	2	6.11	3.06	1.28	0.286
Depth	2	12.35	6.18	2.60	0.083
Land Use $\times$ Slope	4	7.92	1.98	0.83	0.512
Land Use $\times$ Depth	4	9.48	2.37	0.99	0.420
Slope $\times$ Depth	4	8.66	2.17	0.91	0.464
L $\times$ S $\times$ D	8	12.84	1.61	0.67	0.715
Error	54	128.56	2.38		
Total	80	204.34			

L = land use, S = slope, D = depth.

3.8 Soil Moisture Content

The distribution of soil moisture content (SMC) across land use types, slope positions, and soil depths is presented in Table A8(Appendix). Analysis of variance shown in Table 9 revealed that SMC was significantly influenced by soil depth ($F = 12.47$, $p < 0.001$) and land use type ($F = 6.12$, $p < 0.05$), while slope position had no significant effect ($p > 0.05$). The interaction effects

among land use, slope position, and depth were also not significant, indicating that the main factors operated independently.

Soil moisture content was generally highest at the 0–15 cm depth across most slope positions and land use types. This can be attributed to the presence of higher organic matter, humus, and relatively loamy soil at the surface, which enhances water retention capacity. The surface layer also receives direct infiltration from rainfall, further contributing to higher moisture levels. However, an exception was observed at the peak position under forestry land use, where relatively higher SMC values were recorded at the 30–45 cm depth, likely due to localized soil conditions or reduced surface retention in that specific case. On average, SMC decreased with increasing soil depth. This trend may be associated with changes in soil characteristics such as reduced organic matter content, increased compaction, and variations in soil texture at deeper layers, which collectively reduce the soil's ability to retain moisture. The significant effect of depth observed in the ANOVA supports this vertical variation in moisture distribution. Across the land use systems, plantation soils generally exhibited higher moisture content compared to cropping and forestry systems. This may be due to greater litter accumulation, improved soil structure, and canopy cover, which reduce evaporation losses and enhance water retention. Cropping systems showed moderate moisture levels, likely influenced by continuous cultivation and soil disturbance, while forestry soils exhibited more variable moisture patterns due to differences in vegetation density and interception. Although some variations in SMC were observed across slope positions—such as occasional higher values at foot slopes due to runoff accumulation—these differences were not statistically significant. This suggests that slope position had a limited and inconsistent influence on soil moisture distribution in the study area.

Table 9: ANOVA for Soil Moisture Content.

Source	Df	SS	MS	F	p-value
Land Use	2	512.84	256.42	6.12	0.004
Slope	2	198.76	99.38	2.37	0.103
Depth	2	1045.32	522.66	12.47	<0.001
Land Use × Slope	4	210.55	52.64	1.26	0.296
Land Use × Depth	4	298.44	74.61	1.78	0.146
Slope × Depth	4	176.32	44.08	1.05	0.392
L × S × D	8	322.91	40.36	0.96	0.475
Error	54	2263.18	41.91		
Total	80	5028.32			

L = land use, S = slope, D = depth.

3.9 Soil Bulk Density

The bulk density (BD) values as presented in Table A9(Appendix) showed variation across soil depths, slope positions, and land use systems. The least values of bulk density were recorded at the 0–15 cm depth across all slope positions and land use systems, which can be attributed to lower soil compaction, higher organic matter content, and greater biological activity such as root penetration and soil fauna that create more pore spaces in the surface soil. At the subsoil depths (15–30 cm and 30–45 cm), BD values were relatively higher and, in some cases, comparable. This trend may be associated with reduced organic matter content, fewer biological activities, and increased soil compaction in deeper layers. The similarity in BD values at these depths could also be linked to relatively uniform soil type and structure within the subsoil horizon. Across the different land use systems, bulk density values did not show marked variation, although slightly higher values were observed in the cropping land use compared to forestry and plantation systems. This may be due to continuous cultivation practices, machinery movement, and reduced organic matter inputs, which tend to increase soil compaction. In contrast, forestry and plantation systems generally maintain better soil structure due to litter accumulation and minimal disturbance.

With respect to slope position, only slight variations in BD were observed, with no consistent trend across peak, mid, and foot slopes. This suggests that slope position had minimal influence on bulk density distribution within the study area. The analysis of variance (ANOVA) shown in Table 10 further confirmed that soil depth had a highly significant ($p \leq 0.05$) effect on bulk density, whereas land use and slope position did not significantly influence BD. Additionally, the interaction effects among land use, depth, and slope position were not significant. This indicates that bulk density is primarily controlled by depth-related factors, particularly changes in soil structure, compaction, and organic matter content, while land use and topographic position exert only secondary or negligible effects.

Table 10: ANOVA for Soil Bulk Density.

Source	Df	SS	MS	F	p-value
Land Use	2	0.0244	0.0122	0.629	0.537
Slope	2	0.9587	0.4793	24.691	<0.001
Depth	2	0.0196	0.0098	0.504	0.607
Land Use × Slope	4	0.1127	0.0282	1.452	0.230
Land Use × Depth	4	0.1223	0.0306	1.575	0.194
Slope × Depth	4	0.0646	0.0161	0.831	0.511
L × S × D	8	0.0749	0.0094	0.482	0.863
Error	54	1.0483	0.0194		
Total	80	2.4255			

L = land use, S = slope, D = depth.

3.10 Particle Size Distribution

The particle size distribution of the soils varied with depth, slope position, and land use systems as presented in Tables 11–13. Under the cropping land use, relatively higher sand content was observed at the surface (0–15 cm) and subsurface (15–30 cm) layers, while clay content became more dominant at the deeper layer (30–45 cm). This vertical distribution reflects the influence of continuous cultivation, which disturbs the soil structure and enhances the breakdown of soil aggregates, thereby exposing coarser particles at the surface. In contrast, the accumulation of finer particles such as clay in the subsoil suggests downward translocation through eluviation and illuviation processes, a common pedogenic feature in well-developed profiles. The increase in clay content at the 30–45 cm depth indicates the presence of an argillic-like horizon, where clay particles washed from the upper layers are deposited. This process is often associated with percolating water moving through the soil profile, carrying suspended clay particles from upper horizons and depositing them at greater depths. Such differentiation within the profile highlights the role of soil-forming processes in shaping the vertical distribution of particle size fractions. For the forestry and plantation land use systems, sand remained the dominant fraction across all depths, followed by clay and then silt. This relatively uniform distribution suggests minimal disturbance of the soil profile, allowing the soil to maintain its natural structure and particle arrangement. The continuous addition of organic residues such as leaf litter in these systems also helps stabilize soil aggregates and reduces the susceptibility of finer particles to translocation. Based on the textural triangle classification, soils under cropping land use exhibited greater variability in textural classes across depths and slope positions, ranging from sandy clay loam at the surface to clay in the deeper layers. This variability reflects the combined effects of cultivation practices and pedogenic processes, which may enhance profile differentiation. In contrast, soils under forestry were predominantly sandy clay loam, with slight deviations in some subsurface layers, indicating relatively stable soil development with minor variations in particle redistribution. The plantation land use showed a more consistent textural class of sandy clay loam across all depths and slope positions. This uniformity suggests a relatively homogeneous parent material and limited disturbance, allowing the soil to retain its inherent physical characteristics. Overall, the observed variations in particle size distribution across the different land use systems are more reflective of soil-forming processes such as weathering, translocation, and horizon development rather than short-term management practices. While land use can influence soil structure and aggregation, soil texture remains largely governed by parent material and long-term pedogenic processes.

Table 11: Soil particle size at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for cropping land use.

PAR	SP	DEPTH (cm)	SAND	CROPPING SILT	CLAY	TEXTURAL CLASS
Soil particle size	Peak	0-15	55.47 ± 2.31	14.67 ± 2.31	29.87 ± 2.31	Sandy clay loam
		15-30	44.80 ± 4.00	20.00 ± 6.93	35.20 ± 8.00	Sandy clay loam
		30-45	31.47 ± 2.31	21.33 ± 4.62	47.20 ± 4.00	Clay
	Mid	0-15	56.80 ± 0	12.00 ± 0	31.20 ± 0	Sandy clay loam
		15-30	46.13 ± 11.55	20.00 ± 4.00	39.20 ± 10.58	Sandy clay
		30-45	34.13 ± 10.07	20.00 ± 4.00	45.87 ± 9.24	Clay
	Foot	0-15	47.47 ± 2.31	17.33 ± 6.11	35.20 ± 4.00	Sandy clay loam
		15-30	46.13 ± 2.31	20.00 ± 6.93	33.87 ± 8.33	Sandy clay loam
		30-45	38.13 ± 12.86	21.33 ± 4.62	40.53 ± 8.33	Clay

PAR is Parameter while SP is slope position.

Table 12: Soil particle size at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for forestry land use.

PAR	SP	DEPTH (cm)	SAND	FORESTRY SILT	CLAY	TEXTURAL CLASS
Soil particle size	Peak	0-15	54.13 ± 4.62	17.33 ± 2.31	28.53 ± 2.31	Sandy clay loam
		15-30	48.80 ± 8.00	16.00 ± 10.58	35.20 ± 6.93	Sandy clay loam
		30-45	44.80 ± 8.00	17.33 ± 2.31	37.87 ± 6.11	Sandy clay
	Mid	0-15	57.47 ± 1.15	14.67 ± 2.31	28.53 ± 2.31	Sandy clay loam
		15-30	50.13 ± 8.33	13.33 ± 4.62	36.53 ± 8.33	Sandy clay
		30-45	52.80 ± 6.93	17.33 ± 6.11	29.87 ± 2.31	Sandy clay loam
	Foot	0-15	48.80 ± 10.58	22.67 ± 8.33	28.53 ± 2.30	Sandy clay loam
		15-30	51.47 ± 6.10	18.67 ± 6.11	29.87 ± 2.31	Sandy clay loam
		30-45	47.47 ± 4.62	18.67 ± 6.11	33.87 ± 8.33	Sandy clay loam

PAR is Parameter while SP is slope position.

Table 13: Soil particle size at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for plantation land use.

PAR	SP	DEPTH (cm)	PLANTATION			TEXTURAL CLASS
			SAND	SILT	CLAY	
Soil particle size	Peak	0-15	56.80 ± 0.00	14.67 ± 2.31	28.53 ± 2.31	Sandy clay loam
		15-30	52.80 ± 4.00	18.67 ± 6.11	28.53 ± 2.31	Sandy clay loam
		30-45	54.13 ± 4.62	14.67 ± 6.11	31.20 ± 4.00	Sandy clay loam
	Mid	0-15	54.13 ± 4.62	18.67 ± 4.62	27.20 ± 0.00	Sandy clay loam
		15-30	48.80 ± 8.00	16.00 ± 4.00	35.20 ± 4.00	Sandy clay loam
		30-45	52.80 ± 4.00	17.33 ± 2.31	29.87 ± 4.62	Sandy clay loam
	Foot	0-15	56.80 ± 0.00	16.00 ± 0.00	27.20 ± 0.00	Sandy clay loam
		15-30	55.47 ± 2.31	16.00 ± 4.00	28.53 ± 2.31	Sandy clay loam
		30-45	55.47 ± 2.31	14.67 ± 2.31	29.87 ± 2.31	Sandy clay loam

PAR is Parameter while SP is slope position.

4.0 CONCLUSION

The results demonstrate that land use and soil depth are the dominant factors controlling soil variability, while slope position exerted comparatively minor and inconsistent effects across most parameters, as supported by the ANOVA results.

Soil organic carbon (SOC) and total nitrogen (TN) were consistently higher in the surface layer (0–15 cm) across all land uses, reflecting the accumulation of organic residues, root biomass, and intense microbial activity in the upper layers. Cropping systems exhibited relatively higher SOC and TN compared to forestry and plantation systems, indicating the contribution of organic inputs such as crop residues and amendments. The strong association between SOC and TN further emphasizes the role of organic matter in nutrient cycling and soil fertility maintenance. Soil pH values indicated that the soils are generally acidic, with plantation soils tending toward slight acidity, while cropping and forestry systems were moderately acidic. These variations are linked to land management practices, nutrient uptake, and organic matter dynamics. Exchangeable potassium (K) and available phosphorus (P) were generally higher under plantation and cropping systems, reflecting the influence of litter decomposition, fertilizer inputs, and reduced nutrient immobilization relative to forestry systems. Cation exchange capacity (CEC) showed minimal variation across land uses, depths, and slope positions, suggesting that it is largely controlled by inherent soil properties such as clay mineralogy and organic matter content, rather than short-term management practices. Similarly, soil texture remained predominantly within the sandy clay loam to clay classes, indicating that while minor variations exist due to eluviation and deposition processes, texture is fundamentally governed by parent material. Soil physical properties, including bulk density and moisture content, varied primarily with depth.

Bulk density increased with depth due to reduced activity and compaction, while moisture content was generally higher in surface soils due to greater organic matter content and pore space distribution. Variations in inorganic carbon (SIC) across depths and slope positions suggest localized redistribution processes influenced by leaching and slope-driven movement.

Overall, the findings highlight that land use practices significantly modify soil chemical properties, particularly nutrient availability and organic matter content, whereas physical properties are more strongly influenced by soil depth and inherent characteristics. The limited statistical influence of slope position suggests that its effects are secondary and often mediated through erosion and redistribution processes rather than direct control. This study reinforces that sustainable soil management in sloping tropical environments must prioritize organic matter conservation, controlled fertilizer use, and minimal soil disturbance. Practices such as residue retention, cover cropping, and reduced tillage are essential to maintain soil structure, enhance nutrient cycling, and prevent long-term fertility decline.

Effective land evaluation and management strategies in the study area should therefore be based on an integrated understanding of land use, soil depth, and inherent soil properties, rather than slope alone. This approach will support improved soil productivity, environmental sustainability, and informed agricultural planning in the region.

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APPENDIX

Table A1: Distribution of soil organic carbon at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SP	DEPTH (cm)	CROPPING	FORESTRY	PLANTATION
Organic Carbon	Peak	0-15	2.52 ± 1.09	1.40 ± 0.33	2.40 ± 0.08
		15-30	1.70 ± 0.92	0.98 ± 0.49	0.99 ± 0.38
		30-45	1.23 ± 1.51	0.89 ± 0.30	0.49 ± 0.36
	Mid	0-15	1.63 ± 0.38	2.02 ± 0.94	2.37 ± 1.13
		15-30	1.43 ± 0.38	1.31 ± 1.31	1.23 ± 0.97
		30-45	0.73 ± 0.49	0.74 ± 0.30	0.81 ± 0.44
	Foot	0-15	2.20 ± 0.34	1.40 ± 0.07	2.20 ± 0.69
		15-30	1.37 ± 0.45	0.82 ± 0.71	0.83 ± 0.28
		30-45	0.99 ± 0.25	0.84 ± 0.19	0.65 ± 0.32

SP = Slope Position

Table A2: Distribution of soil pH at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING	FORESTRY	PLANTATION
Soil Ph	Peak	0-15	5.60 ± 0.56	6.07 ± 0.32	6.70 ± 0.17
		15-30	5.40 ± 0.52	5.60 ± 0.56	6.17 ± 0.32
		30-45	4.93 ± 0.64	5.40 ± 0.10	6.63 ± 0.29
	Mid	0-15	5.67 ± 0.35	5.67 ± 0.59	6.47 ± 0.15
		15-30	5.30 ± 0.10	6.00 ± 0.44	6.70 ± 0.20
		30-45	5.13 ± 0.06	5.70 ± 0.26	6.43 ± 0.15
	Foot	0-15	5.43 ± 0.67	5.43 ± 0.45	6.67 ± 0.32
		15-30	5.07 ± 0.67	5.80 ± 0.20	6.60 ± 0.35
		30-45	4.93 ± 0.87	5.60 ± 0.35	6.33 ± 0.38

SP = Slope Position

Table A3: Distribution of potassium (K) in soil at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING	FORESTRY	PLANTATION
% Potassium	Peak	0-15	0.26 ± 0.06	0.90 ± 1.13	0.92 ± 0.98
		15-30	0.20 ± 0.06	0.21 ± 0.17	0.25 ± 0.08
		30-45	0.17 ± 0.03	0.20 ± 0.05	0.29 ± 0.14
	Mid	0-15	0.25 ± 0.03	0.33 ± 0.07	0.28 ± 0.06
		15-30	0.20 ± 0.06	0.30 ± 0.15	0.26 ± 0.04
		30-45	0.20 ± 0.04	0.29 ± 0.03	0.29 ± 0.06
	Foot	0-15	0.18 ± 0.08	0.22 ± 0.10	0.28 ± 0.01
		15-30	0.23 ± 0.11	0.30 ± 0.10	0.31 ± 0.16
		30-45	0.20 ± 0.11	0.29 ± 0.15	0.35 ± 0.10

Table A4: Distribution of soil nitrogen at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING	FORESTRY	PLANTATION
% Nitrogen	Peak	0-15	0.38 ± 0.18	0.21 ± 0.03	0.37 ± 0.04
		15-30	0.31 ± 0.12	0.20 ± 0.04	0.16 ± 0.02
		30-45	0.26 ± 0.10	0.19 ± 0.02	0.14 ± 0.02
	Mid	0-15	0.23 ± 0.03	0.27 ± 0.11	0.28 ± 0.03
		15-30	0.15 ± 0.06	0.22 ± 0.05	0.24 ± 0.15
		30-45	0.17 ± 0.03	0.16 ± 0.02	0.20 ± 0.03
	Foot	0-15	0.33 ± 0.09	0.20 ± 0.02	0.30 ± 0.12
		15-30	0.27 ± 0.12	0.17 ± 0.06	0.15 ± 0.02
		30-45	0.18 ± 0.05	0.16 ± 0.02	0.15 ± 0.02

Table A5: Distribution of soil available phosphorus (P) at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING	FORESTRY	PLANTATION
% Phosphorus	Peak	0-15	7.96 ± 4.72	5.08 ± 0.39	8.40 ± 2.10
		15-30	6.27 ± 0.58	6.14 ± 0.48	8.35 ± 0.63

		30-45	6.25 ± 0.66	6.15 ± 0.99	7.13 ± 0.74
		0-15	6.30 ± 2.79	5.78 ± 0.30	10.01 ± 4.67
	Mid	15-30	6.97 ± 1.67	5.39 ± 1.01	7.96 ± 2.36
		30-45	7.21 ± 1.92	7.65 ± 4.91	6.95 ± 1.60
		0-15	10.60 ± 3.33	6.37 ± 1.18	7.78 ± 0.56
	Foot	15-30	5.91 ± 0.74	5.65 ± 0.72	7.39 ± 1.74
		30-45	7.05 ± 2.78	7.75 ± 1.04	7.39 ± 1.07

Table A6: Cation Exchange Capacity (CEC) of the soil at depth 0-15, 15-30 and 30-45 at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING	FORESTRY	PLANTATION
Cation exchange capacity (cm/Kg)	Peak	0-15	1.37 ± 0.20	1.05 ± 0.51	1.27 ± 0.10
		15-30	1.03 ± 0.18	1.31 ± 0.55	0.81 ± 0.16
		30-45	1.08 ± 0.14	1.06 ± 0.06	0.96 ± 0.15
	Mid	0-15	1.21 ± 0.10	0.97 ± 0.31	1.28 ± 0.19
		15-30	1.06 ± 0.28	1.15 ± 0.12	1.18 ± 0.44
		30-45	0.96 ± 0.52	1.62 ± 0.72	1.09 ± 0.20
	Foot	0-15	1.03 ± 0.42	0.96 ± 0.39	1.99 ± 0.15
		15-30	0.97 ± 0.14	0.94 ± 0.13	1.21 ± 0.25
		30-45	1.32 ± 0.24	1.03 ± 0.30	1.11 ± 0.41

Table A7: Distribution of soil inorganic carbon at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING	FORESTRY	PLANTATION
Soil inorganic carbon	Peak	0-15	5.81 ± 0.57	5.27 ± 2.90	4.27 ± 2.01
		15-30	4.64 ± 0.35	2.02 ± 1.40	4.00 ± 3.62
		30-45	0.10 ± 1.06	2.44 ± 1.24	1.84 ± 1.49
	Mid	0-15	3.03 ± 1.24	4.64 ± 4.78	3.96 ± 3.55
		15-30	4.57 ± 1.50	3.36 ± 1.23	3.77 ± 2.67
		30-45	5.27 ± 2.10	4.26 ± 2.43	4.52 ± 1.99
	Foot	0-15	2.80 ± 1.47	1.94 ± 4.23	6.46 ± 1.82
		15-30	5.28 ± 2.27	4.51 ± 3.25	4.84 ± 4.65
		30-45	1.00 ± 2.98	2.82 ± 1.90	0.35 ± 2.51

Table A8: Soil moisture content (%) at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING (%)	FORESTRY (%)	PLANTATION (%)
%Soil moisture content	Peak	0-15	17.30 ± 2.89	7.12 ± 5.38	13.26 ± 4.10
		15-30	11.32 ± 3.71	6.37 ± 2.10	6.89 ± 3.16
		30-45	11.21 ± 3.80	10.87 ± 11.79	7.46 ± 6.67
	Mid	0-15	12.13 ± 3.04	14.75 ± 12.04	16.76 ± 6.28
		15-30	8.20 ± 1.44	7.80 ± 6.28	9.99 ± 8.46
		30-45	9.52 ± 3.83	3.00 ± 2.49	9.24 ± 2.19
	Foot	0-15	14.55 ± 9.10	8.07 ± 3.73	17.33 ± 1.78
		15-30	11.22 ± 6.53	6.12 ± 0.81	8.90 ± 2.64
		30-45	12.29 ± 8.33	4.11 ± 1.67	6.57 ± 3.06

Table A9: Bulk density (g/cm³) of the soil at depth 0-15 cm, 15-30 cm and 30-45 cm at various slope positions for the three different land uses.

PARAMETER	SLOPE POSITION	DEPTH (cm)	CROPPING (g/cm ³)	FORESTRY (g/cm ³)	PLANTATION (g/cm ³)
Bulk Density	Peak	0-15	0.99 ± 0.04	1.01 ± 0.05	1.02 ± 0.04
		15-30	1.20 ± 0.16	1.18 ± 0.14	1.14 ± 0.15
		30-45	1.27 ± 0.16	1.08 ± 0.12	1.18 ± 0.14
	Mid	0-15	1.00 ± 0.08	0.92 ± 0.18	0.97 ± 0.19
		15-30	1.25 ± 0.18	1.23 ± 0.05	1.18 ± 0.20
		30-45	1.28 ± 0.21	1.13 ± 0.08	1.30 ± 0.13
	Foot	0-15	0.93 ± 0.11	0.99 ± 0.01	1.06 ± 0.04
		15-30	1.16 ± 0.26	1.25 ± 0.04	1.14 ± 0.20
		30-45	1.14 ± 0.17	1.28 ± 0.15	1.47 ± 0.07

Linkages between Soil Physical Structure and Microbial Activity under Organic and Conventional Farming Systems in a Humid Tropical Environment

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ABSTRACT

Understanding interactions between soil physical structure and microbial activity is fundamental to sustainable soil management, especially where soils are highly vulnerable to degradation. This study examines the relationships between soil physical properties and microbiological indicators under organic and conventional farming systems. Soils from organic and conventional plots (0–20 cm depth) were analyzed for bulk density, porosity, aggregate stability, microbial biomass carbon, and key enzyme activities, using a randomized complete block design. Correlation and regression analyses were used to evaluate structure–function linkages. Organic farming significantly improved soil physical properties and enhanced microbial biomass and enzyme activities ($p \leq 0.05$). Strong negative correlations were observed between bulk density and microbial indicators, while porosity and aggregate stability were positively correlated with microbial biomass and enzyme activities. The findings demonstrate that organic farming strengthens positive feedbacks between soil structure and microbial functioning, thereby promoting soil health and sustainability in humid tropical agro-ecosystems.

Keywords: Aggregate stability; Bulk density; Microbial activity; Organic farming; Soil structure; Tropical soils

1.0 INTRODUCTION

Soil physical structure and microbial activity are tightly interlinked components of soil health. Soil structure controls aeration, water movement, and habitat availability for microorganisms, while microbial processes contribute to aggregate formation and stabilization through the production of extracellular polysaccharides, fungal hyphae, and other binding agents (Six *et al.*, 2006; Bronick and Lal, 2005). Disruption of either component can impair soil functioning and reduce agricultural sustainability. Meanwhile, despite that soil serves as the only resources that underpins sustainable agriculture (Corato *et al.*, 2024), its deformed structure and decreasing fertility is basically due to the intensified human and natural phenomena (Abebaw *et al.*, 2025). This indicates that, declining soil structure, reduced organic matter content, compaction, erosion, nutrient imbalance and heavy human and machine interference are all signs of soil degradation which poses threats to sustainable agriculture (FAO, 2021).

The continuous practice of conventional farming practices which involves intensive tillage without sufficient nutrient replenishment degrades the soil structure and impacts the nutrients heavily (Yuan *et al.*, 2025). This practice also relies on the application of mineral fertilizers which also restrict microbial habitat quality and limit biological activity, resulting in weakened soil structure–function relationships (Geisseler and Scow, 2014). In contrast, organic farming systems emphasize organic amendments, residue retention, and biologically mediated nutrient cycling, which can improve soil structure and enhance microbial functioning simultaneously (Lori *et al.*, 2017). Organic farming, rooted in ecological principles and natural inputs, has emerged as a viable alternative to conventional agriculture, offering multifaceted benefits for sustainable farming systems (Dadhick *et al.*, 2025).

In humid tropical regions, soils are typically highly weathered, low in organic matter, and subject to intense rainfall, making them particularly sensitive to structural degradation. Microbial processes play a critical role in maintaining soil fertility under these conditions, yet few studies have explicitly quantified the linkages between soil physical structure and microbial activity under different farming systems in tropical environments. Crop yields under organic management were comparable to conventional systems, and organic corn yielded 31% more than conventional corn during drought years. Reduced input costs in organic systems further

supported economic viability, even when gross profits were lower (Dadhick *et al.* 2025). Organic agriculture is a farming system that relies on natural processes and ecological balance rather than synthetic inputs. It promotes soil fertility, biodiversity, and sustainability by using organic fertilizers, compost, crop rotation, and biological pest control (Gamage *et al.*, 2023). Organic farming avoids synthetic pesticides, herbicides, and genetically modified organisms (GMOs), focusing on environmentally friendly. It enhances soil health, reduces pollution, and produces chemical-free food. By prioritizing animal welfare and ecosystem preservation, organic agriculture supports long-term sustainability. It also fosters healthier food production while protecting natural resources, making it a vital approach to sustainable farming and environmental conservation (Dadhick *et al.* 2025)

This study aimed to compare soil physical and microbiological properties under organic and conventional farming systems, and evaluate the relationships between soil physical indicators and microbial biomass and enzyme activities. It was hypothesized that organic farming would strengthen positive interactions between soil structure and microbial activity relative to conventional farming.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was conducted at the Rivers University Teaching and Research Farm, Port Harcourt, southern Nigeria, located within the humid tropical rainforest zone. The area receives annual rainfall exceeding 2,000 mm and has mean annual temperatures of 25–30 °C. The soils are predominantly sandy loam to loamy sand and are highly weathered.

2.2 Experimental Design and Soil Sampling

A randomized complete block design was used with two treatments: organic farming and conventional farming, each replicated three times. Soil samples were collected at 0–20 cm depth using a soil auger. Five cores per plot were composited for analysis, while undisturbed cores were collected for bulk density determination.

2.3 Soil Physical and Microbiological Analyses

Bulk density was determined using the core method, which involves the collection of undisturbed soil samples using a cylindrical metal core of known volume. The soil cores were oven-dried at **105 °C for 24 hours** to a constant weight. Bulk density was calculated using the formula:

$$\text{Bulk density (g cm}^{-3}\text{)} = \frac{W_d}{V} \quad (1)$$

where:

W_d = oven-dry weight of soil (g)

V
= volume of the core sampler (cm³)

The total porosity was calculated from bulk and particle density. The soil particle density was calculated using ;

$$\text{Particle density} = \frac{W_s}{V_w - V_{sw}} \quad (2)$$

where:

W_s = weight of oven-dried soil (g)

V_w = volume of water in the pycnometer (cm³)

V_{sw} = volume of soil and water mixture (cm³)

A typical particle density value for mineral soils is approximately **2.65 g cm⁻³**.

Total soil porosity was calculated from bulk density and particle density values using the relationship:

$$\text{Total Porosity} = \left(1 - \frac{\text{Bulk Density}}{\text{Particle Density}} \right) \times 100 \quad (3)$$

Aggregate stability was measured using the wet sieving method and expressed as mean weight diameter (MWD). Microbial biomass carbon (MBC) was determined using the chloroform fumigation–extraction method (Vance *et al.*, 1987). Soil enzyme activities (dehydrogenase, phosphatase, and urease) were determined using standard calorimetric methods (Casida *et al.*, 1964; Tabatabai and Bremner, 1969; Kandeler and Gerber, 1988).

2.4 Statistical Analysis

Differences between farming systems were evaluated using analysis of variance (ANOVA). Pearson correlation and simple linear regression analyses were used to assess relationships between soil physical and microbiological properties. Statistical significance was evaluated at $p \leq 0.05$.

3.0 RESULTS AND DISCUSSION

3.1 Comparison of Soil Physical and Microbiological Properties

Organic farming significantly reduced soil bulk density and increased porosity and aggregate stability compared to conventional farming (Table 1). Similarly, microbial biomass carbon and enzyme activities were significantly higher under organic management. As shown in Figure 1, the strong negative relationship between bulk density and microbial biomass highlights the importance of soil structure in regulating microbial habitat quality. High bulk density restricts pore space and aeration, limiting microbial growth and activity which can be influenced by the type of manure of organic farming (Williams *et al.* 2017). The reduced bulk density observed under organic farming created favorable conditions for microbial proliferation, consistent with previous studies linking reduced compaction to enhanced microbial activity (Bronick and Lal, 2005). Also, Wang *et al.* (2011) identified improved microbial activity and soil structure as major benefits influenced by organic farming.

Table 1: Selected Soil Physical and Microbiological Properties under Different Farming Systems

Farming system	Bulk density (g cm ⁻³)	Porosity (%)	MWD (mm)	MBC (mg kg ⁻¹)	Dehydrogenase (mg TPF kg ⁻¹ h ⁻¹)
Organic	1.29 ± 0.05 ^a	52.03 ± 2.1 ^a	1.79 ± 0.13 ^a	391 ± 29 ^a	37.4 ± 2.9 ^a
Conventional	1.47 ± 0.05 ^b	45.07 ± 1.8 ^b	1.07 ± 0.12 ^b	250 ± 23 ^b	22.5 ± 2.4 ^b

Values are means ± SD (n = 3). Different superscripts indicate significant differences at $p \leq 0.05$.

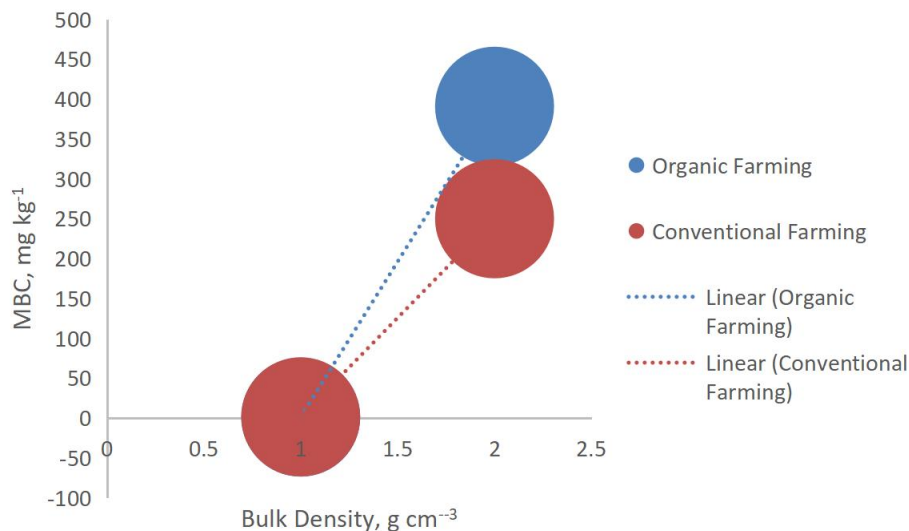


Figure 1: Relationship between soil bulk density and microbial biomass carbon under organic and conventional farming systems (scatter plot with regression line).

3.2 Correlation between Soil Physical and Microbial Properties

Correlation analysis revealed strong interactions between soil physical structure and microbial activity (Table 2). Bulk density was negatively correlated with microbial biomass carbon and enzyme activities, while porosity and aggregate stability showed positive correlations with microbial indicators. Positive correlations between porosity, aggregate stability, and microbial

indicators suggest a reinforcing feedback mechanism between soil structure and biological activity (Figure 2). Microorganisms contribute to aggregate formation through the production of binding agents, while stable aggregates protect microbial habitats from physical disturbance (Six *et al.*, 2006). Organic farming enhanced these feedbacks by supplying organic substrates and minimizing disruptive management practices (Blanco-Canqui *et al.*, 2015). With organic farming, result shows a reduction in soil compaction which makes the soil favorable for farming but also determined by soil type and tillage method (Sánchez de Cima *et al.*, 2015)

The enhanced enzyme activities observed in organically managed soils further indicate improved biochemical functioning associated with better soil structure (Williams *et al.* 2017). Dehydrogenase activity, which reflects overall microbial metabolic activity, was closely associated with improved porosity and aggregate stability, emphasizing the integrated nature of soil physical and biological processes.

Overall, the results demonstrate that organic farming systems not only improve individual soil properties but also strengthen the functional linkages between soil structure and microbial activity. These interactions are critical for maintaining soil resilience and productivity in humid tropical environments.

Table 2: Pearson Correlation Coefficient between Soil Physical and Microbial Properties

Parameter	Bulk density	Porosity	MWD	MBC	Dehydrogenase
Bulk density	1.00	-0.72*	-0.77*	-0.79*	-0.75*
Porosity		1.00	0.73*	0.82*	0.77*
MWD			1.00	0.80*	0.73*
MBC				1.00	0.85*
Dehydrogenase					1.00

*Correlation significant at $p \leq 0.05$.

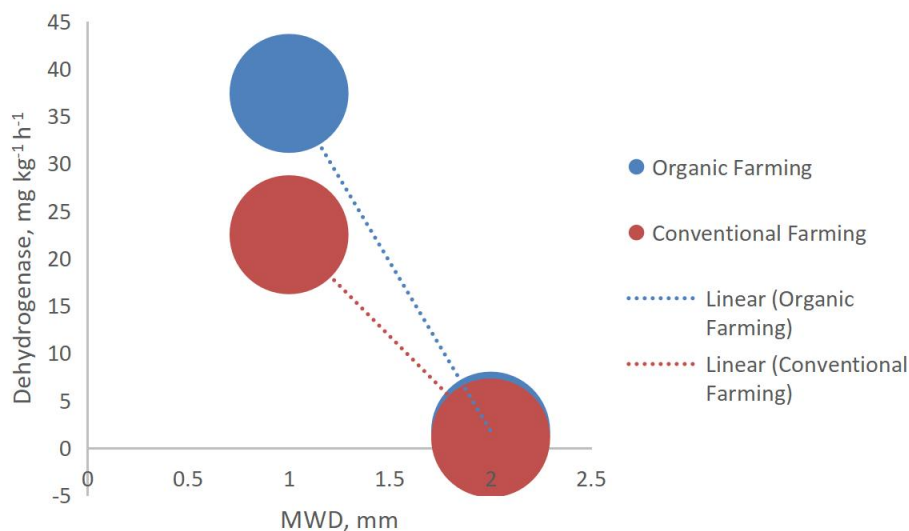


Figure 2: Correlation between aggregate stability (MWD) and dehydrogenase activity under different farming systems.

3.3 Regression Analysis

Regression analysis demonstrated a significant negative relationship between bulk density and microbial biomass carbon (Figure 1). As soil compaction increased, microbial biomass declined sharply.

4.0 CONCLUSION

This study demonstrates that organic farming strengthens positive interactions between soil physical structure and microbial activity under humid tropical conditions. Improved soil structure under organic management enhanced microbial biomass and enzyme activity, while increased biological activity contributed to greater aggregate stability and porosity. In contrast, conventional farming weakened these structure–function linkages through increased compaction and reduced biological activity. Organic farming therefore represents a sustainable management strategy that promotes integrated soil physical and biological health in tropical agro-ecosystems.

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Carbon Sequestration and Aggregation of Alfisols in Response to Different Plant Biomass and Maize-Groundnut Rotation

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ABSTRACT

Soil quality decline and environmental pollution are today's global issues. Soil carbon sequestration is an important strategy to mitigate global greenhouse effect. Soil aggregate stability enhances soil productivity by impeding soil erosion and degradation. Biomass [Siam weed (*Chromolaena odorata*, CO); Guinea grass (*Panicum maximum*, PM); Banana clippings (*Musa acuminata*, BA); control (no amendment, C)]; and cropping systems [continuous maize, (CM); continuous groundnut (CG); crop rotation (CR)] were two treatments laid out in a split-plot arrangement. The treatment combinations were laid out using randomized complete block design with three replicates in 2020, 2021 and 2022 cropping season. Biomass materials were uniformly mixed with the topsoil at 10 tons/ha. Application of plant biomass significantly ($p \leq 0.05$) increased soil mean weight diameter (MWD) with the highest in BA with the value 1.368mm and the lowest in control (C) with the value 0.616mm in 2020; CO with CR had the highest MWD with the value 1.203mm and the lowest in CO with CM with the value 0.772 for 2021; BA with CR had the highest MWD with the value 1.479mm and the lowest in CO with CM (0.877mm) for 2022. Biomass increased carbon sequestered in the soil for the three years. BA gave the highest carbon sequestered with the value 5.245 kg/m² in 2020. The study concluded that application of biomass under CR improved soil quality and hence offers a better management option for maize-groundnut production.

1.0 INTRODUCTION

Soil quality decline and environmental pollution are today's world issues. Soil carbon sequestration is the process of capturing and storing atmospheric carbon dioxide in the soil preventing it from contributing to global warming. It is one of the important strategies to mitigate global greenhouse effect. Important land use practices with the potential to sequester SOC include conversion of cropland to pastoral and forest lands, conventional tillage to conservation tillage, and no manure use to regular addition of manure. However, food needs for the world's increasing population make conversion of cropland to forestland unsustainable. Therefore, increased food demands call for management of croplands to ensure food security, and at the same time, enhanced SOC sink within the soil to minimized atmospheric emission of CO₂.

Soil aggregate stability is an important soil physical property that influences soil productivity and resistance to erosion and degradation (Raine So, 1997; Six *et al.*, 2000). Aggregate stability represents a composite parameter of the soil ecosystem, shaped by interactions among flora, fauna, parent material, and climate. It is a sensitive indicator of soil degradation (Imeson, 1984).

The major reason for the high degradation of most tropical soils is due to decline in their organic carbon content; and the rate of such decline is often influenced by cultivation, soil type, and type and length of tillage (Balashov *et al.*, 2010). Mean weight diameter (MWD) serves as an index for determining soil aggregation and stability, and it is defined as the sum of weighted mean diameters across all size classes. Positive relationships have been documented between MWD and resistance to soil erosion (Chepil, 1962; Kemper and Koch, 1966; White, 1985). Tisdall and Oades (1982), Van Veen *et al.* (1984), and Roberson *et al.* (1995) observed that MWD increases with elevated levels of organic matter and microbial biomass. Tisdall and Oades (1982) distinguished aggregates <0.25 mm, stabilized primarily by organic-mineral complexes, from aggregates >0.25 mm, stabilized by plant roots, fungal mycelia, and polysaccharides. Higher proportions of larger aggregate size classes generally indicate superior soil structure, whereas elevated proportions of smaller size classes suggest finer, less stable aggregates. Mean weight diameter (MWD) condenses the aggregate size distribution into a single stability metric; higher MWD values indicate more stable, coarser aggregates, while lower MWD values reflect less stable structural conditions.

This study estimated carbon sequestration and aggregate stability of a tropical loamy sand Alfisol amended with different plant biomass.

2.0 MATERIALS AND METHODS

Soil samples for this study were collected in 2020, 2021 and 2022 at 0-20 cm depth from Teaching and Research Farm located within Federal College of Education (Technical), Akoka, Lagos State (6.52° N and 3.38° E). The area is located in rainforest zone (Southwest) Nigeria, with annual rainfall of over 2000 mm. The ecological conditions include moderately high annual rainfall, warm temperature distribution, and soils classified within the sandy-loam textural group. The annual temperature ranges between 22°C and 38°C, with relative humidity above 85 %. These climatic conditions support crop growth but are prone to nutrient depletion under continuous cultivation, thereby making the site appropriate for soil amendment studies. The soil in the study area was loamy soil, it was classified as Alfisol order in USDA Taxonomy system with low nitrogen and available phosphorus.

2.1 Treatments and Experimental Design

The experiment consisted of two factors (plant biomass and crop sequence) laid out in a split-plot arrangement fitted into a Randomized Complete Block Design (RCBD) with three replicates. Plant biomass from three sources: Siam weed (*Chromolaena odorata*, CO), Guinea grass (*Panicum maximum*, PM), and Banana clippings (*Musa acuminata*, BA) at 10 t/ha, and (Control, C) were combined with three crop sequences: Continuous Maize (CM), Continuous Groundnut (CG) and Crop Rotation (CR) i.e. Maize-Groundnut-Maize. The two treatment combinations were replicated three times in 2020, 2021 and 2022 cropping seasons. Plant biomass was uniformly mixed with the topsoil. Soil samples were collected using soil auger and spade at 0-20 cm depth for soil analysis. Data collected were subjected to analysis of variance using Genstat® Release 12.1 (VSN International, 2009) and significant differences were compared using LSD at $p \leq 0.05$.

2.2 Determination of soil aggregation

The distribution of aggregates was estimated by the wet-sieving technique described in detail by Kemper and Rosenau (1986). In this procedure, 50 g of the < 4.0 mm aggregates were placed on the topmost of a nest of sieves of diameters 2, 1, 0.5 and 0.25 mm. The samples were presoaked in distilled water for 10 min before oscillating vertically in water 20 times (along 5 cm amplitude) at the rate of 15 stokes mm⁻¹ for 2 min. The resultant aggregates on each sieve were dried at 105°C for 24 h and weighed. The mass of < 0.25 mm fraction was obtained by difference between the initial sample weight and the sum of sample weights collected on the 2, 1, 0.5 and 0.25 mm sieve nest. The percent water-stable aggregates (%WSA) on each of the following size ranges, 4.0-2.0, 2.0-1.0, 1.0-0.50, 0.50-0.25 and < 0.25 mm were then determined.

Thus: $\%WSA = (Ma+s - Ms) / (Mt - Ms) 100$,

Where: $Ma+s$ is the mass of the resistant aggregates plus stone (g), Ms is the mass of the stone fraction alone, and Mt is the total mass of the sieved soil (g).

Ms = the mass of the stone fraction alone, and Mt = the total mass of the sieved soil (g).

The method of Van Bavel (1950) as modified by Kemper and Rosenau (1986) was used to determine the mean weight diameter of wet-stable aggregates. Thus:

$$MWD = \sum_{i=1}^n XiWi$$

Where: MWD is the mean weight diameter of wet-stable aggregates (mm),

Xi the mean diameter of each size fraction (mm) and Wi is the proportion of the total sample weight (WSA) in the corresponding size fraction, after deducting the weight of stone (upon dispersion and passing through the same sieve) as indicated above, and n is the number of size fractions. Higher values of MWD indicate the dominance of the less erodible, large aggregates of the soil (Piccolo *et al.*, 1997). Soil organic carbon and total nitrogen concentrations within the aggregate fractions of 5.66-2.0, 2.0-1.0, 1.0-0.50, 0.50-0.25 and < 0.25 mm of the cultivated and uncultivated (forest) land were measured. The organic carbon (OC) was determined by acid dichromate wet oxidation procedure as described by Nelson and Sommers (1996); while total nitrogen was by micro-Kjeldahl method (Bremner, 1996). Organic carbon and total N stocks (kg m⁻²) of the upper 20 cm were calculated using elemental concentration and bulk density equation described by Steffens *et al.* (2008) as:

$$ES = BD EC a 10^{-6}$$

Where: ES is elemental stock (kg m⁻²), BD is bulk density (g cm⁻³), EC is elemental concentration (mg g⁻¹) and a is area multiplier (20 cm depth x 10 000 cm² = 200 000 cm³ m⁻²)

3.0 RESULTS AND DISCUSSION

3.1 Soil aggregate distribution and mean-weight diameter

Biomass application increased the values of the larger size classes as well as the values of MWD, for the largest size (4 - 2 mm) the values for control i.e. without plant biomass ranges from 8 to 16 while the values for those with plant biomass ranges from 12 to 34. BA had the best soil structure with higher values in the larger size classes and higher MWD value of 1.368 followed by PM with MWD value of 1.046 then CO with MWD value of 1.003 while control had the lowest value in the larger size classes and lower MWD value of 0.616 which indicate fine, unstable aggregates and less stable structure. (Table 1).

Application of plant biomass significantly increased the values of the larger size classes as well as the values of MWD, for the largest size (4 - 2 mm) the values for control ranges from 15.33 to 17.33 while the values for those with plant biomass ranges from 12.00 to 29.33. It was observed that CO with CR, BA with CR and PM with CR significantly increased the values of the larger size class as well as the values of their MWD as follows: 4-2 mm size, MWD; 29.33, 1.203; 27.33, 1.130; 25.33, 1.039 respectively while control with CR was 17.33, 0.880 in the 2nd year. However, CO, PM and BA with CM in the 2nd year reduced the values of the larger size aggregates as well as the MWD values (Table 2).

Biomass significantly increased the values of the larger size class as well as the values of MWD for CR plots at 3rd year. It was observed that CO with CR, PM with CR and BA with CR significantly increased the values of the larger size class as well as the values of their MWD as follows: 4-2 mm size, MWD; 23.33, 1.097; 32.00, 1.336; 40.00, 1.479 respectively while control with CR was 20.00, 1.007 in the 3rd year. However, CG plots generally had higher values of larger size class and MWD CR had lower values of larger size class and MWD but application of biomass increases the values. (Table 3).

Table 1: Soil aggregate distribution and mean-weight diameter relative to treatments for Year 1

BIOMASS	CROP SEQ	4-2 mm	2-1 mm	1-0.5 mm	0.5-0.25 mm	<0.25 mm	MWD mm
C	CG	10.00	12.00	20.00	24.00	34.00	0.743
	CM	16.00	14.00	20.00	20.00	30.00	0.912
	CR	8.00	8.00	18.00	18.00	48.00	0.616
CO	CG	16.00	12.00	20.00	20.00	32.00	0.885
	CM	16.00	16.00	22.00	18.00	28.00	0.946
	CR	20.00	14.00	20.00	16.00	30.00	1.003
PM	CG	20.00	12.00	18.00	24.00	26.00	0.982
	CM	14.00	16.00	22.00	18.00	30.00	0.896
	CR	20.00	16.00	22.00	18.00	24.00	1.046
BA	CG	16.00	8.00	16.00	20.00	40.00	0.808
	CM	12.00	14.00	18.00	18.00	38.00	0.796
	CR	34.00	16.00	18.00	16.00	16.00	1.368
LSD (p≤0.05): Aggregate size = 1.311**							ns

Table 2: Soil aggregate distribution and mean-weight diameter relative to treatments for Year 2

	CROP SEQ	4-2 Mm	2-1 mm	1-0.5 mm	0.5-0.25 mm	<0.25 mm	MWD mm
C	CG	15.33	11.33	18.00	16.67	38.67	0.857
	CM	20.67	12.00	21.33	17.33	28.67	1.020
	CR	17.33	10.00	15.33	12.00	45.33	0.880
CO	CG	19.33	9.33	17.33	15.33	38.67	0.916
	CM	12.00	12.67	19.33	19.33	36.67	0.772
	CR	29.33	12.00	15.33	11.33	32.00	1.203
PM	CG	27.33	10.00	15.33	16.67	30.67	1.130
	CM	17.33	14.67	22.67	19.33	26.00	0.981
	CR	20.00	16.00	22.00	16.00	26.00	1.041
BA	CG	18.00	10.00	17.33	14.67	40.00	0.888
	CM	14.00	14.67	20.00	17.33	34.00	0.873
	CR	25.33	11.33	16.00	14.67	32.67	1.039
LSD (p≤0.05): Aggregate size = 0.756**							ns

Table 3: Soil aggregate distribution and mean-weight diameter relative to treatments for Year 3

BIOMASS	CROP SEQ	4-2 mm	2-1 mm	1-0.5 mm	0.5- 0.25 mm	<0.25 mm	MWD mm
C	CG	36.00	10.00	14.67	14.67	24.67	1.407
	CM	15.33	12.67	24.00	18.00	30.00	0.894
	CR	20.00	11.33	19.33	14.67	34.67	1.007
CO	CG	38.67	10.00	16.00	11.33	24.00	1.462
	CM	14.00	14.00	24.00	19.33	28.67	0.877
	CR	23.33	14.67	19.33	13.33	29.33	1.097
PM	CG	25.33	14.00	18.00	18.00	24.67	1.148
	CM	16.00	16.00	22.67	14.00	31.33	0.948
	CR	32.00	13.33	20.67	14.00	20.00	1.336
BA	CG	38.67	8.67	12.00	12.00	28.67	1.424
	CM	17.33	12.00	20.67	20.00	30.00	0.943
	CR	40.00	12.67	16.00	14.67	16.67	1.479
LSD ($p \leq 0.05$): Aggregate size = 2.097**				ns			

3.2 Effect of treatments on carbon sequestration for Year 1, Year 2 and Year 3

Application of biomass generally increased the carbon sequestered in the soil but without significant difference. BA had the highest value of carbon sequestered (5.245 kg/m^2) followed by PM with the value 5.144 kg/m^2 then CO with the value 5.124 kg/m^2 while control had the least value of carbon sequestered (5.073 kg/m^2) in the 1st year, however, in the 2nd year BA reduced the carbon sequestered by 0.12 % lower than its control while CO had higher value of carbon sequestered (5.192 kg/m^2) than it had in the 2nd year. Higher biomass application rates corresponded with increased carbon storage potential. Application of biomass significantly affect the carbon sequestered in the 3rd year with PM having the highest carbon sequestered with the value 5.001 kg/m^2 while BA had the lowest value of 4.743 kg/m^2 .

Cropping system significantly affect carbon sequestered, CM had the highest value of carbon sequestered in the 1st year, followed by CR with the value 5.146 kg/m^2 while CG had the lowest with the value 5.047 kg/m^2 . The 2nd and 3rd year followed the same trend of the 1st year. The carbon sequestered values reduced down (Table 4).

Table 4: Effect of treatments on carbon sequestration for Year 1, Year 2 and Year 3

TREATMENTS	OC Seq* (Kg/m ²) 2020	OC Seq* (Kg/m ²) 2021	OC Seq* (Kg/m ²) 2022
Biomass (B)			
C	5.073	5.046	4.875
CO	5.124	5.191	4.942
PM	5.144	5.092	5.001
BA	5.245	5.035	4.743
Cropping system (CS)			
CG	5.047	4.876	4.820
CM	5.245	5.291	4.977
CR	5.146	5.106	4.874
LSD ($P \leq 0.05$)	0.156*	0.119**	0.128*
Interaction			
B × CS	Ns	0.237*	ns

Ns = not significant, * means significant ** means highly significant

4.0 CONCLUSION

The combined use of biomass and rotation offers a superior management option for maize-groundnut production on alfisols, improving soil quality and mitigating greenhouse gas emissions.

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Effect of Implement Weight on the Performance of the Disc Plough

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ABSTRACT

Crop production is the business of maximizing profit in growing crops for food, feed and fibre, while ensuring environmental sustainability. Profit maximization implies reduction in the cost of field operation while environmental sustainability requires that the soil be left in state in which it serves the next generation optimally. Unfortunately, tillage that is meant to prepare the soil for improved crop production has been described as the single most expensive factor in crop production, and yet leaves the soil in an undesirable condition of compaction in the long run owing to the heavy machineries used, thereby negating the principle of sustainability. A lot of research has gone into proffering solutions to these problems but most have not considered the contribution of implement weight to the problem. It is generally believed that higher implement weight aids tool soil penetration. This work therefore aims at studying the actual effect of implement weight on the depth of cut of the disc plough in a gravelly sandy soil. A two factor Latin Square with repeated treatment of weight was used to study the effects of weight on depth of cut using ANOVA. Factors considered were tilt angle ($\alpha_1=16^\circ$, $\alpha_2=22^\circ$, $\alpha_3=26^\circ$), disc angle ($\beta_1=37^\circ$, $\beta_2=40^\circ$, $\beta_3=43^\circ$) and weight ($\lambda_1=253.1\text{kg}$, $\lambda_2=327.7\text{kg}$, $\lambda_3=370.4\text{kg}$). The implement was powered by a 47.7kW (64 hp) tractor, weighing 2757 kg. Results obtained showed that there was insufficient evidence to prove that implement weight had significant effect on the depth and width of cut of the disc plough. Disc angle was significant on width of cut at 5% only while tilt angle was significant on both depth and width of cut, even at 1%. It may be concluded therefore that varying the weight of the disc plough may not significantly affect its depth and width of cut, and that depth and width of cut are affected by tilt angle while disc angle only affected the width of cut. It is recommended from this result, that ploughs with lighter weight be designed so as to be pulled by smaller tractors to reduce energy requirement and soil compaction.

KEYWORDS: Implement Weight, Disc plough, Tilt angle, Disc angle

1. INTRODUCTION

The disc plough is the most popular primary tillage implement used in southern and north central regions of Nigeria. Tillage in agriculture is the mechanical manipulation of soil with the aim of changing the structure of the soil, making it suitable for crop production. Tanam (1994) explained that tillage is the most energy intensive operation in farming, and described by Sheruddin *et al* (1988) and davis (1983) as the single most expensive input. Similar observation was made by Kepner *et al* (1987). Moitzi *et al* (2009), cited by Oduma *et al* (2021) reported that land preparation by conservative tillage methods consumed over 50% of energy input. Manian *et al* (2000) cited by Olatunji *et al* (2009) gave a range of 30 – 35% of total energy consumption. This is equally considered high when compared to other inputs. Conservation tillage practices however, requires that soil be manipulated, if necessary, up to conventional tillage, and be left in

state that meets present, and continuous future needs for crop production. Moitzi *et al* (2006) further explained that energy consumption in land preparation increases progressively with depth of cut. Results reported by Oduma *et al* (2021) however, showed that high speed ploughing and soil type were major contributors to depth and hence, increase in energy requirements. ASABE (2015) agrees with this assertion by stating that draught requirements for tillage depends primarily of implement width, depth of cut, operating speed, soil texture and tool geometry.

The high cost of tillage operation can be traced the complex and heavy design of the implement. Mamman and Oni (2005) reported that the first consideration in the design of a tillage tool is its shape and size, and added that size determines the energy required to pull the tool through the soil. This agrees with the findings of Upadhyaya *et al* (1981), cited by Sale *et al* (2013). Size refers to the physical dimensions and weight of the implement. In attempts to reduce the energy requirements, and hence, the cost of tillage operations, much work (McGreery and Nicholas, 1956, Kawuyo *et al*, 2017, Asoegwu *et al*, 2018, Fadele *et al*, 2021,) has been done to determine an optimum tillage practice. None of these however, has considered the contribution of the weight of the implement to energy consumption, yet implement weight remains a major contributor to soil compaction (Chamen *et al*, 1990, Adeoti, 1992, Tanam, 1994 and Kalu *et al*, 2023) thereby negating the principles of sustainability due to its adverse effects on the soil.

Soil type and bulk density have been reported as other critical factors affecting soil compaction (Klenin *et al*, 1985, Adeoti, 1992 and Kalu *et al*, 2023). For a given soil type and bulk density, moisture content is critical. Danbaba and Tanam (2023) stated that soil workability becomes low in soils with high moisture content as a result of increased share strength from pore water pressure, or as wheel slip in molten state of the soil. Danbaba and Tanam (2023) reported that optimum tillage time is when the soil is in its friable stage. Unfortunately, this is the period the soil is most susceptible to compaction, and heavy machinery trafficking the soil would aid this. Although many factors lead to soil degradation, this paper focuses on the contribution of implement weight, with the hope mitigating its undesirable consequences.

2. MATERIALS AND METHOD

2.1 Implement Description Location of Site

A NARDI ITALIA model 3-bottom disc plough was used in this test. It has a gang ground clearance of 67 cm and disc spacing of 55 cm. The implement has provision for adjusting the tilt and disc angle. Tilt and disc angles selected were 16°, 22° and 26°, and 37°, 40° and 43° respectively. Three weights of the implement were test. The first weight (λ_1) was the dead weight of the plough (253.1 kg). An iron block weighing 74.6 kg was added to the plough to form the second weight (λ_2 , 327.7 kg) while a precast concrete block weighing 42.7 kg was added to λ_2 to form the third weight (λ_3 , 370.4 kg). The implement was pulled by a 47.7kW (64 hp) tractor, weighing 2757 kg. Figure 1 is a photograph of the plough. The plough was pulled at an average speed of 7 km/h.



Figure 1: The 3-Bottom Disc Plough with adjustable Tilt and Disc Angles used for this work

Experiment was conducted on the demonstration farm of the university of Ilorin. Ilorin is the capital city Kwara State, Nigeria, located on latitude $8^{\circ} 29' 50''$ North and longitude $4^{\circ} 32' 32''$ East at an altitude of 307 m above sea level with average annual rainfall between 1200 mm and 1500 mm.

2.2 Soil Test

2.2.1 Soil Particle Size

Standard sieve method, employing British Standard Sieve model BS 410 was used to the texture of soil in the field. Sieve set shaking was however done manually. Soil samples were collected from two random locations on the field and percentage soil passing through each sieve was determined using Equation 1.

$$P_s = \frac{M_p}{M_o} \times 100 \quad (1)$$

where

P_s = Percentage of soil passing through each sieve

M_p = Mass of soil passing through each sieve

M_o = Original mass of soil placed on top-most sieve

2.2.2 Moisture Content

Standard oven method was used to determine soil moisture content. Three samples were collected and Equation 2 was used to determine the moisture content.

$$M_c = \frac{M_w}{M_T} = \frac{M_T - M_s}{M_T} \quad (2)$$

where

M_c = Moisture content (wet basis)

M_w = Mass of water removed

M_T = Total mass of wet soil

M_s = Total mass of dry soil

2.2.3 Bulk Density

Standard method described by Tanam (1994) was used to determine the bulk density of the field soil. With the aid of Core Samplers, soil samples were collected from three random locations and their bulk densities were determined using Equation 3.

$$\rho_b = \frac{M_s}{V} = \frac{4M_s}{\pi D^2 L} \quad (3)$$

Where:

ρ_b = Bulk Density

M_s = Mass of dry soil

V = Volume core sampler = volume of soil

D = Diameter of core sampler

L = Length of core sampler

2.3 Experimental Design

A two factor Latin Square experimental design with implement weight as treatments was used for data collection. Factors considered were highlighted in section 2.1 above, weight of the implement being the central focus. Factors measured were depth of cut and width of cut. A general layout of this design is presented in Table 1.

Table 1: General Layout of a Latin Square Experimental Design

	α_1	α_2	α_3
β_1	λ_1	λ_2	λ_3
β_2	λ_3	λ_1	λ_2
β_3	λ_2	λ_3	λ_1

Nine strips of plots measuring 50 m each were selected. On each strip 25-m lengths portions were marked out as shown in Figure 2.

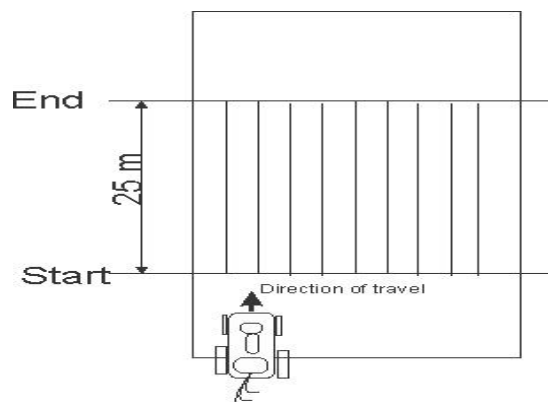


Figure 2: Layout of Treatment runs, showing direction of run

For each run, the tractor was allowed to attain uniform speed and hydraulic lever maintained at uniform level before reaching the start of the 25-m mark. This was maintained until the plough crossed the end of the 25-m mark. Five random locations along each run were selected where depth and width of cut were measured and treated as replicates for the treatment. Data obtained were analysed by methods described by Davies (1956) and Ott (1977) and subjected to Analysis of Variance (ANOVA) to determine the effects of the parameters. Table 2 shows the general layout of ANOVA for a Latin Square experimental design.

Table 2: General ANOVA Table for Latin Square Design

Source	Sum of Squares (SS)	Degree of freedom (df)	Mean Square (MS)	F-ratio
Treatment, λ	SSt	$b - 1$	$MSt = SSt/df$	$F\text{-ratio} = MSt/MSE$
Rows, β	SSR	$b - 1$	$MSR = SSR/df$	$F\text{-ratio} = MSR/MSE$
Columns, α	SSC	$b - 1$	$MSC = SSC/df$	$F\text{-ratio} = MSC/MSE$
Error	SSE	$rb^2 - 3b + 2$	$MSE = df$	
Total	SST	$b^2r - 1$		

b = number of parameters = 3

r = number of replications = 5

Significance was tested at 5% and 1%

3 RESULTS AND DISCUSSION

3.1 Soil Properties

Particle size analysis of soil from the field revealed that the soil is made up of 73.3% sand and 26.7% gravel. Oni (1981) described a soil of this nature as gravelly sand. Figure 3 is a graph from the soil particle size analysis. Coarse grained soils are usually not very compressible at low moisture content as the grains are mostly in contact with each other. This is evident from the value of the mean bulk density obtained ($1.39 \pm 0.02 \text{ g/cm}^3$) of the soil.

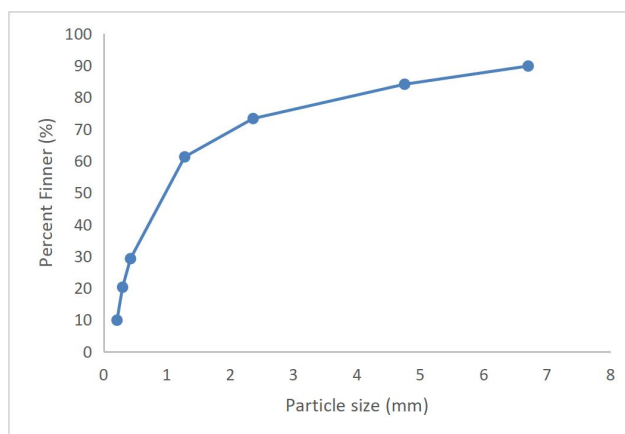


Figure 3: Graph of Soil Particle size Analysis

This bulk density falls within the range of 1.3 g/cm^3 and 1.8 g/cm^3 for coarse grain soils as reported by Millar *et al* (1965), cited by Kirkham (2023). This level of bulk density would normally require higher levels of energy to break. Moisture content of the soil was found to be 5.89% (wet basis).

3.2 Effect of Weight on Depth of Cut

Table 3 is the ANOVA for depth of cut. At 5% confidence, critical $_{0.05}F_{2,38} = 3.25$, while at 1% confidence, critical $_{0.01}F_{2,38} = 5.22$

Table 3: ANOVA Table for Depth of cut

Source	SS	df	MS	F-ratio
Weight, λ	52.03	2	26.02	2.40
Disc Angle, β	56.23	2	28.12	2.59
Tilt Angle, α	796.63	2	398.32	36.71 ⁺⁺
Error	412.41	38	10.85	
Total	1317.30	44		

⁺⁺ Significant at 1% confidence level

Table 3 shows that the computed F-ratios for implement weight and disc angle were less than critical values at 5%, therefore showing no sufficient evidence to prove a significant effect of weight and disc angle on the depth of cut. It is likely therefore that increasing implement weight may not necessarily increase depth of cut.

Figure 4 shows that at 16° tilt angle there was a significant increase in tool penetration. However, there was an insignificant difference in depth of cut with increase weight levels.



Figure 4: Effect of Implement Weight on Depth of Cut under varying Tilt Angle

Except at 22° tilt angle, increasing implement weight did not increase depth of cut. These results are not in agreement with general believe and the findings of. The variation could be due to differences in soil texture, operating speed and soil moisture. It is likely that as tilt angle increases, the convex area of the disc in contact with the ground increases thereby increasing soil reaction forces on the plough so that penetration is hampered. However, at low tilt angles, the edge of the tool forms a knife on the soil surface and so may be pushed down by the weight of the implement. Implement weight may therefore be significant only at low tilt angles.

Similar pattern was observed as disc angle was increased except at high disc angles where increasing implement weight was observed to increase tool penetration. This is presented in Figure 5. At lower disc angles however increasing weight did not show significant change in depth of cut. There was actually a drop in depth of cut with increase in weight at low disc angles.



Figure 5: Effect of Implement Weight on Depth of Cut under varying Disc Angle

3.3 Effect of Implement Weight on Width of Cut

Table 4 is the ANOVA for width of cut of the disc plough. Table 4 shows that the computed F-ratio for weight was lower than critical value, even at 5% level, indicating insufficient evidence to prove a significant effect of weight of implement on the width of cut of the plough. Disc angle was found to have a significant effect on width of cut and tilt angle was highly significant. It is clear therefore that implement tilt and disc angles are greater contributors to width of cut, in agreement with many researchers, than the weight of the implement. These are clear from Figure 6.

Table 4: Table 2: ANOVA Table for Width of Cut

Source	SS	Df	MS	F-ratio
Weight, λ	2047.60	2	1023.8	2.58
Disc Angle, β	3328.53	2	1664.27	4.20 ⁺
Tilt Angle, α	41876.13	2	20938.07	52.83 ⁺⁺
Error	15059.74	38	396.31	
Total	62312.0	44		

+ Significant at 5% confidence level

++ Significant at 1% confidence level



Figure 6: Effect of Implement Weight on Width of Cut under varying Tilt Angle

Although there was a high level of width of cut at 16° and 22° tilt angles, Figure 6 shows that there was insignificant difference in width of cut at different weight levels at all tilt angles. Figure 7 shows that a given disc angle, increasing implement weight reduced the width of cut. Again this is not in agreement with Olatunji *et al* (2009).

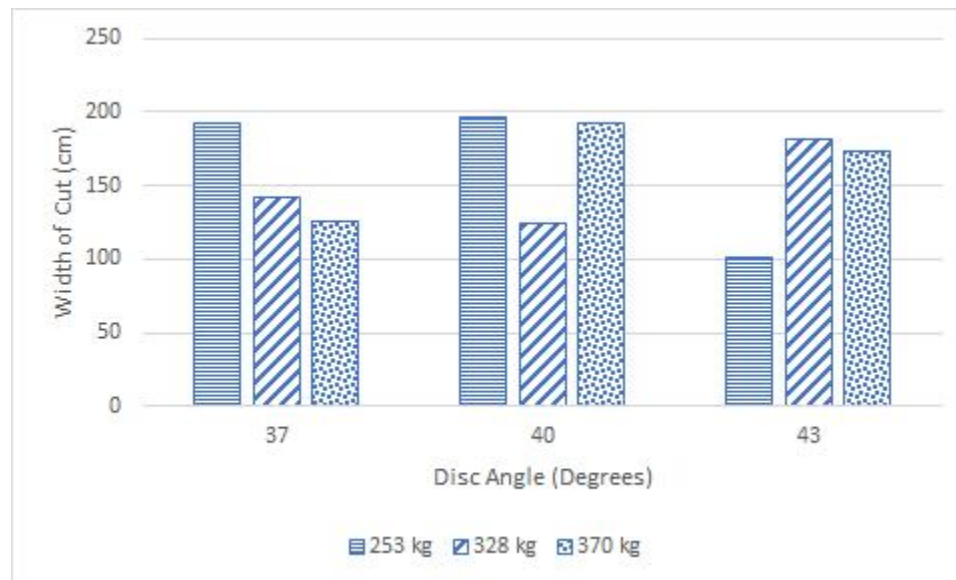


Figure 7: Effect of Implement Weight on Width of Cut under varying Disc Angle

CONCLUSION

Effect of weight on the depth and width of cut of a disc plough was studied in conjunction with its tilt and disc angles. Observations made showed that the implement tilt and disc angles made more contributions to depth and width of cut than the weight of the plough. It may be concluded therefore, that since there was insufficient evidence that implement weight aided tool penetration, increasing the weight of the plough may not have significant effect on depth and width of cut. A redesign of the disc plough may therefore be necessary with the aim of producing lighter ploughs that may be pulled by lighter tractors. This would reduce soil compaction and energy requirements for ploughing and hence, cost of operation

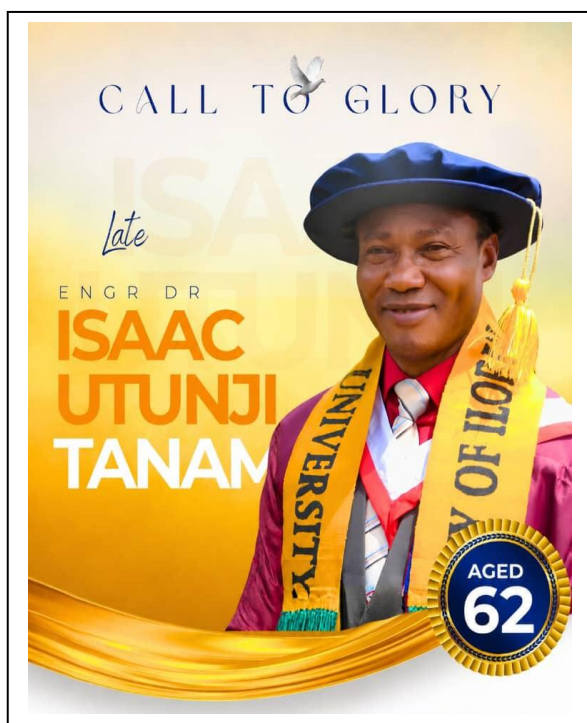
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Tribute to Late Engr. Dr. U. I. Tanam



The news this early morning of June 11, 2026, of the untimely death of our ISTRO Nigeria Branch Vice Chairman and our former ISTRO Nigeria Branch National Secretary, Dr Isaac Tanam is unbelievable! But what can we do? Life is transient. A good man has gone prematurely. He was a great, loyal, responsible and someone ready to take up any responsibility for the organization. I served under him as Assistant Secretary of ISTRO Nigeria Branch for almost 4 years and he was always there as reliable person easy to work with. He was always there in meetings, both

executive and general meetings, he was always there in all past Symposia held, he was always there in Abuja with other high-ranking officers in preparation for ISTRO World International Conference coming up in 2027 and always ready to spend his own money for the progress of the Organization. He volunteered and hosted ISTRO2025 Symposium in Bingham University, Nasarawa State.

O'God! May You please uphold and comfort us all. This is indeed very painful. May God forgive his shortcomings and grant him eternal rest. May God be with the family all the way.

Quite sad and unfortunate. May his soul rest in perfect peace amen. May his family be divinely comforted and strengthened in this difficult time. Amen

May we all be comforted and may 'dates' be far away distance and may be grow old in good health.

W. Agunbiade Lamidi
ISTRO-Nigeria, National Secretary
For National Executive



ISSN 647—9921