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RESEARCH ARTICLE

THE SHORT TERM EFFECT OF TILLAGE SYSTEM ON SOIL MOISTURE RETENTION IN BAYELSA STATE, NIGERIA

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ABSTRACT

The objective of the study was to determine the short time effect of tillage system on the water retention capacity of soils in the Niger Delta University Teaching and Research Farm, Bayelsa State. Five treatments (No-till, Digging, Hoeing, Hoeing+Digging once, and Hoeing+Digging twice) were considered. Plant Available Water Content (PAWC) and the Soil Water Holding Capacity (SWHC) were used to determine the soil water retention capacity. The results revealed that the crude tillage methods had a significant ($P<0.05$) impact on some soil properties. The highest bulk density (1.18g/cm^3) was found in the No-till zone, while the lowest (0.89g/cm^3) was in the Hoe+Digging twice method. The tillage methods also affected the hydraulic conductivity as the highest value (4.67cm/hr) was found in the hoe+digging zone and the lowest (2.61cm/hr) in the no-till area. Furthermore, the PAWC and SWHC were highest (0.14cm^{3}cm^{-3} and 2.03cm) at the No-till zone and lowest (0.06 cm^{3}cm^{-3} and 0.95cm) at the Hoe+Digging twice zone. It is therefore recommended that, for unrestricted flow of water through the soils, compacted soils should be pulverized using tillage implements. Also, for optimal plant water availability, there should be less tillage on coarse-textured soils, as the disturbance promotes rapid leaching.

KEYWORDS

hydrology, soil and water conservation, tillage, Bayelsa

1. Introduction

The agricultural practice of preparing soil through various types of mechanical disturbances, such as digging, stirring, and overturning, is known as tillage. It is a fundamental and crucial part of agricultural production technology that has an impact on soil processes, soil characteristics, and crop growth (Khursheed et al., 2019). The physical state of soils, such as its structure, can be largely affected by various tillage practices. Different research has shown that these soil properties change with increased tillage intensity and recommendations have been made for soils to be kept at their natural and optimum state (Husnjak et al., 2002), especially as tillage practices can result in soil modification and eventual degradation. Soil water status is not left out, as tillage can affect its availability to plants and its capacity to be utilized. Tillage can also increase the entry of water into the soil, increase hydraulic conductivity and improve water use efficiency (Li et al., 2007; Bhattacharyya et al., 2008).

Tillage also influences soil wetness through reduction in evaporation and weed control. Due to its impact on soil characteristics, the environment, and crop productivity, tillage is one of the most important soil management techniques in agricultural land use (Abdollahi et al., 2015).

No-tillage system has a higher water content than a conventional tillage system, according to and also exhibit higher soil penetration resistance compared to all other tillage treatments (Sharratt et al., 2006; Hussain et al. 2018). The surface and subsurface hydrology of agricultural fields can be affected by tillage techniques, according to certain authors and this is especially true when a similar tillage system has been used for a long time (Gómez et al., 2019; Hill, 2010; Ozgöz et al., 2007).

The aim of this study was to investigate the short term effects of tillage methods on water retention capacity and hydraulic conductivity in the soils of Niger Delta University (NDU) Teaching and Research Farm, Wilberforce Island, Amassoma, Bayelsa State. The research will expose land users to the impact of indiscriminate tillage on soil water conservation and plant utilization.

2. Materials and Methods

2.1 Study Area

The research was carried out at the Niger Delta University Teaching and Research Farm, located in Amassoma Community, Southern Ijaw Local Government Area in Bayelsa State. Bayelsa lies at approximately Latitudes 4°55' 36.30"N and Longitudes 6°16' 3.50"E with an elevation of about 206m above sea level and is situated in the southern part of the Niger Delta Region of Nigeria. In Bayelsa, the wet season is warm and overcast, the dry season is hot and mostly cloudy, and it is oppressive year-round. The predominant environment is distinguished by a humid tropical climate with yearly rainfall of about 4900 mm and a relative humidity of 85%. Maximum rainfall is acquired from June to September, while minimum rainfall is achieved from November to March, during the dry season. The annual minimum and maximum temperatures are 25°C and 31°C, respectively.Amassoma is covered by trees (56%), water (16%), and grassland (14%), within 10 miles by trees (56%) and shrubs (19%), and within 50 miles by trees (33%) and water (20%).

2.2 Sample Collection

A total of thirty (30) samples were collected from the sampling points. In three replicates, samples were taken at two depths: 0-15 cm and 15-30 cm.

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Samples were taken by the use of a soil auger. Each soil sample was put into a clean polythene bag and then properly labeled with an indelible marker. The soil samples were transferred to the Soil Science Laboratory where they were air dried, crushed and passed through a 2 mm sieve. The air-dried samples were then sent for laboratory analysis. Soil core samplers were used to take samples for bulk density, porosity, hydraulic conductivity, and soil water retention determination. A core was carefully hammered into the different depths using a hard wood. Excess soil was then cut off using a knife to create an equilibrium between the soil column and the core. The undisturbed and properly labeled core samples were placed in an airtight bag for analysis of bulk density, hydraulic conductivity, and soil water retention.

2.3 Laboratory Analysis

Using a 1:2.5 soil water ratio and pH and Electrical conductivity (EC) meters in a soil water suspension, the pH and electrical conductivity of the soil were measured. Soil samples weighing 10g were sieved with a 2mm diameter sieve, weighed, and then placed in a thoroughly cleaned bottle for laboratory analysis. With a soil water ratio of 1:2.5, the distilled water was poured into the bottle. 15 minutes were spent agitating the closed bottle at 300 rounds per second. After allowing the agitated solution to settle for about 30 minutes, the pH and EC were measured.

The Bouyoucous hydrometer method (1962) was used to determine the texture of the soil. The organic carbon in the soil was assessed using the Walkley-Black wet oxidation procedures (Walkley and Black 1934). It has calculated the organic material by multiplying the value of organic carbon by 1.75 (Douglas, 2010). Total nitrogen was determined using the standard micro Kjeldahl method described by (Bremmer and Mulvaney, 1982). Ca, Mg, K, and Na were extracted with 1N ammonium acetate solution (1N NH_4OAc) buffered at pH 7.0. Ca and Mg were determined from the extract using the 0.01m EDTA (ethylenediaminetra-acetic acid) titration method, while K and Na were determined using a flame photometer (Jackson, 1962).

The core method was used to calculate the bulk density of the soils at both depths. A stainless steel core sampler was used to collect soil samples at random from each plot. The collected soil cores were trimmed to the exact capacity of the cylinder and oven dried for 24 hours at 105^0c. To avoid compaction within the core sampler, precautions were taken. The bulk density was calculated using the mass of dry soil per unit volume of soil core ratio (Aikins and Afuakwa, 2012).

$$\text{Bulk density} = \frac{mass\ of\ oven\ dried\ soil\ (g)}{total\ volume\ of\ soil\ (cm^3)} \quad (1)$$

Using Equation 2, the total porosity was determined using the bulk density and an assumed particle density of 2.65 g/cm3. (Aikins and Afuakwa, 2012).

$$TP = 1 - \left(\frac{Bulk\ density}{particle\ density}\right) \times 100 \quad (2)$$

Klute and Dirksen (2012) constant head method for determining saturated hydraulic conductivity (Ksat) in the laboratory was utilized. The undisturbed soil cores were retrieved from the field and carefully trimmed to the size of the core ring before being secured with a piece of muslin cloth, kept together with a rubber band on both ends to prevent spilling while allowing water to pass through. After that, the samples were saturated for 24 hours before water percolation experiments were performed. The volume of water passing through the soil sample was then measured and recorded until a consistent average was obtained. The Ksat was calculated as;

$$Ksat = QL / \Delta hAt \quad (3)$$

Where Q represents the discharge or percolate through the soil (cm^3), L represents the length of the soil core (cm), A represents the cross-sectional area of the soil core (cm^3), T represents the time taken (hours), and h represents the hydraulic head difference (cm).

2.4 Plant Available Water Capacity (PAWC)

Field Capacity (at 0.01bar), Permanent Wilting Point (at 15bar), and Plant Available Water Capacity (PAWC) were calculated using the formula of (Romano and Santini, 2002). The difference between water retention at 10 kPa, i.e. Field Capacity (FC), and water retention at 1500 kPa, i.e. Permanent Wilting Point (PAWC), was estimated (PWP).

$$PAWC = FC - PWP. \quad (4)$$

2.5 The Soil Water Holding Capacity (SWHC)

It is the depth of water in the soil available for plant growth. SWHC is also known as

Total Available Water (TAW); SWHC = TAW = (PAWC) (z) (5)

Where SWHC or TAW = soil water holding capacity or total available water, z = root zone depth (Waller and Yitayew, 2016; Azuka and Oka, 2021).

2.6 Experimental Design

The study used a Randomized Complete Block Design (RCBD) with five tillage treatments: no tillage (NT), hoeing (H), digging (D), hoe plus digging once (H+D 1), and hoe plus digging twice (H+D 2). Each plot size was 5 x 5m, with a buffer zone of 1 m between plots, for a total of fifteen (15) plots. Tillage activities were carried out with simple tillage tools such as hoes and diggers.

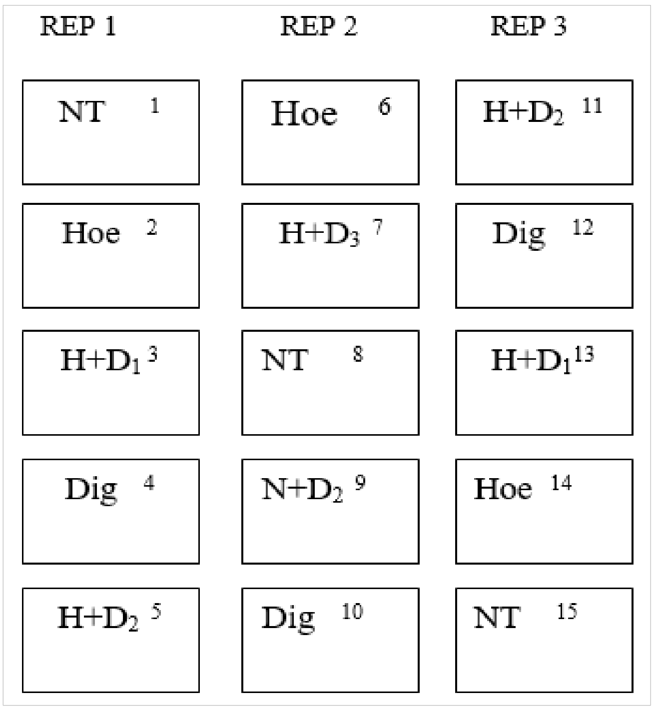

Figure 1: Field Layout, Design and Replication of the Different Tillage Methods
H – Hoeing, H + D_1 – hoeing plus digging once, H + D_2 – hoeing plus digging twice

3. Statistical Analysis

The data was statistically analyzed by using technique for randomized complete block design and means were compared using Duncan's multiple test range at 0.05 level of probability.

4. Results and Discussions

4.1 Physical and Chemical Properties of the Soils of Niger Delta University Teaching and Research Farm under the different tillage methods

Table 1 embodies the values of some physical and chemical properties of the soils and their effects under the considered tillage practices. The 0–15cm depth was considered as the surface soils, while the 15–30cm depth was the subsurface soils.

4.2 pH

The outcome demonstrates that the soils under the NO TILL (NT) zone had a pH that was strongly acidic (4.33) on both the surface and subsurface levels. The surface and underlying soils remained very acidic after hoeing (4.60 and 4.37 respectively). On both surface and subsurface soils with pH values of 4.30 and 4.40, digging (D) had no discernible effect ($P<0.05$). The pH remained significantly acidic (4.37 and 4.47) at both levels despite hoeing and digging ONCE [H + D 1] having no significant impact (P 0.05). Additionally, HOEING AND DIGGING TWICE [H + D 2] revealed no appreciable impact on the soils' pH condition in the surface and subsurface zones, which were 4.20 and 4.63, respectively.

4.3 The Short Term Effect of Tillage Methods on Soil pH

As shown in Table 2, increased tillage intensity (No till, Hoe, digging, H+D 1, and H+D 2) on soils worked with tillage equipment did not significantly alter the pH of the soil. The university's Teaching and Research Farm's regular soil cultivation by students for academic, practical, and research purposes may be to blame for the low pH. The relatively acidic condition of the soils may be linked to intensive cropping, which caused the assimilation of the majority of basic cations by the crop, and heavy rainfall, which encourages leaching of basic cations from the soil. (Nta et al., 2017).

4.4 Electrical Conductivity (EC)

The EC on the surface soils and the subsurface soils in the NT Zone were both 0.076 ds/m. The EC was 0.094 ds/m on the surface soil and 0.062 ds/m on the subsurface soil following hoe use. After digging, the EC on the soil's surface and subsurface was 0.065 ds/m. An EC of 0.083 ds/m on the surface soil and 0.081 ds/m on the subsurface soil were measured using the H + D (1) technique. The EC was 0.070 ds/m at the surface and 0.078 ds/m at the subsurface soil after H+D (2).

The mean values for the five tillage techniques revealed that the H + D (1) site had the greatest EC value of 0.082 ds/m and the H + D (2) zone had the lowest (0.074 ds/m). All five tillage techniques had electrical conductivities below 4, which indicated that neither saline barrier to root and seed development nor soil structure aggregation was present (Ganjegunte et al*.,* 2018).

4.5 Organic Carbon

Under the NT Zone, the average amount of organic carbon in the surface and subsurface soils was 18.98 g/kg, ranging from 16.43 to 21.53 g/kg. The organic carbon levels at the surface and subsurface soils after hoeing were 24.87 and 18.23 g/kg, with a mean of 21.55 g/kg, respectively. In the surface and subsurface soils, the organic carbon values and means for digging, H+D 1 and H+D 2 were 17.57 and 19.47g/kg, 18.03 and 23.40g/kg, and 20.53 and 17.83g/kg.

4.6 Organic Matter

Under the NT Zone, the average amount of organic matter in the surface and subsurface soils was 37.97 g/kg, with a range of 32.87 to 43.07 g/kg. Surface and subsurface weights during hoeing were respectively 49.73 and 36.47 g/kg, with a mean of 43.10 g/kg. In the surface and subsurface soils, the organic carbon values and means for digging, H+D 1 and H+D 2, were 35.13 and 38.93g/kg, 36.07 and 46.80g/kg, and 41.07 and 35.67g/kg, with means of 37.03, 41.44, and 38.37g/kg.

4.7 The Short Term Effect of Tillage Measures on Soil Organic Carbon and Organic Matter

The findings show that tillage practices had no discernible impact ($P<0.05$) on organic carbon and organic matter (Table 2). The organic matter under the tillage techniques was of a moderate amount. The reasonable amount of organic carbon and organic matter found on the field despite constant use may be due to students' use of organic manure for crop cultivation throughout time. The mean values for the five tillage practices for organic carbon are as follows: NT (18.98 g/kg), Hoe (21.55 g/kg), Digging (18.52 g/kg), H + D (1) (20.72 g/kg) and H+D (2) (19.18 g/kg) while organic matter: (NT (37.97 g/kg), Hoe (43.10 g/kg), Digging (37.03 g/kg), H + D (1) (41.44 g/kg) and H+D (2) (38.37 g/kg). Clay and organic materials can be carried to the subsoils by heavy rains when intensive tillage machinery considerably expands soil pore spaces. Because the tool has a lighter mechanical structure than large machinery, the organic carbon and matter have a steady, consistent quality (Nta et al., 2017). The research of showed that simplified tillage systems have high conservative power, and as such retain and sustain higher organic carbon and organic matter concentrations (Szostek et al., 2022).

4.8 Total Nitrogen (TN)

Total nitrogen levels in the NT region ranged from 6.30 g/kg in the surface soil to 11.43 g/kg in the subsoil. Total Nitrogen was 14.63g/kg at the surface soil and 9.70g/kg at the subsurface soils during hoeing. It was 10.93 g/kg during digging and rose to 12.33 g/kg below. TN was 6.13g/kg in the surface soils and 9.63g/kg in the subsoil under H+D (1). H+D (2) measured 10.73g/kg at the surface and 11.73g/kg underneath.

4.9 The Short Term Effect of Tillage Measures on Soil Total Nitrogen

Total nitrogen under the NT region ranged from 6.30 g/kg at the top soil to 11.43 g/kg in the subsurface. Total nitrogen was 14.63g/kg on the surface soil and 9.70g/kg on the subsurface soils at the time of hoeing. It was 10.93 g/kg during digging and rose to 12.33 g/kg underground. TN was 6.13g/kg in the surface soils and 9.63g/kg in the subsoil under H+D (1). H+D (2) measured 10.73g/kg below ground and 11.73g/kg above ground (Table 1).

The average total nitrogen for NT, Digging, Hoeing, H+D 1 and H+D 2 was 8.87, 12.17, 11.63, 7.88, and 10.87 g/kg, according to table 2. The mean separation shows that the tillage techniques had no discernible impact on total nitrogen. Since total nitrogen and organic carbon have been found to be connected, total nitrogen levels under different tillage techniques tend to be moderate (Brady and Weil, 2005).

4.10 Exchangeable Acidity (EA)

Exchangeable acidity was low in the NT Zone, measuring 1.65 and 1.76 cmol/kg at the surface and subsoil, respectively. Digging produced 1.50 and 1.70 cmol/kg, whereas hoeing produced 1.50 cmol/kg (surface) and 1.60 cmol/kg (subsurface); H+D (1) produced 1.59 and 1.63 cmol/kg; and H+D (2) produced 1.41 and 1.63 cmol/kg. The five tillage measurements' two depths did not differ substantially at $P<0.05$.

4.11 Effect of Tillage Measures on Soil Exchangeable Acidity

Under NT, hoeing, digging, H+D 1 and H+D 2, the mean exchangeable acidity was 1.71, 1.55, 1.60, 1.61, and 1.52 cmol/kg, respectively. The results showed no statistically significant differences, suggesting that using these tillage tools when used more intensely had no effect on the soil's exchangeable acidity table 2. The decreased exchangeable acidity was a result of the higher organic content.

4.12 The Short Term Impact of Tillage on Soil Exchangeable Bases (Na, K, Ca, and Mg).

The results show that Na was not significantly different in the surface and subsurface soils and across the five tillage practices. The means further confirmed it with values of 0.21 cmol/kg in the NT area, 0.19 cmol/kg in hoeing, 0.13 cmol/kg in digging, 0.28 cmol/kg in H+D (1) and 0.20 cmol/kg in H+D (2). A similar trend was observed in the K values with a mean of 0.51, 0.33, 0.24, 0.62, and 0.54 cmol/kg under No till, Hoeing, Digging, H+D 1 and H+D 2 respectively. The result shows that the mean values of calcium (Ca): 1.23, 1.51 and 1.28 cmol/kg were similar at the NO TILL Zone, H+D 1 and H+D 2; and also at hoeing (0.80 cmol/kg) and digging (0.55 cmol/kg). This states that Ca is retained when the soil is at its natural state and can also increase with increased tillage activities. Mg values were statistically similar at the NT zone (0.95cmol/kg), Hoeing (0.50cmol/kg) and digging points (0.46cmol/kg), and showed significant difference ($P<0.05$) with H+D (1) – 1.51cmol/kg and H+D (2) – 1.21 cmol/kg. This result indicates that increased tillage practices can cause an increase in Mg availability.

4.13 Soil Texture

In the NT zone, the soil texture found at the surface and subsurface was sandy loam and sandy clay loam. It was loamy sand to sandy loam in the hoe treatment, sandy loam in the digging zone and H+D (1) zone; and sandy loam to loamy sand in the H+D (2) zone.

4.14 The Short Term Impact of Tillage Methods on Soil Textures

The tillage measures showed no significant difference ($p<0.05$) in the soil textures. The coarseness of the soils reveals the innate characteristics of the parent material found in the region (Jamala and Oke, 2013).

4.15 Bulk Density, Porosity, and Hydraulic Conductivity

At the surface level of 0–15 cm, the mean bulk density, porosity, and hydraulic conductivity values (Table 3) under the NT plot were 1.17 g/cm3, 56%, and 2.65 cm/hr, respectively, whereas at the subsurface depth of 15–30 cm, they were 1.18 g/cm3, 55.3 %, and 2.57 cm/hr. Mean porosity and hydraulic conductivity were 55.3% and 2.57 cm/hr in the subsurface zone compared to 56% and 2.65cm/hr, respectively, above the surface.

The mean bulk density, porosity, and hydraulic conductivity at the plot where hoeing alone was used were 1.07 g/cm3, 59.7%, and 3.75 cm/hr at the surface soils, and 1.08 g/cm3, 59.2%, and 3.69 cm/hr at the subsurface soil.

Under the digging alone treatment, the mean bulk density, porosity, and hydraulic conductivity at the surface soil were 1.0 g/cm^3, 62.4%, and 3.64 cm/hr; and 1.06 g/cm^3, 59.9%, and 3.81 cm/hr at the subsurface soil.

The mean bulk density, porosity, and hydraulic conductivity of the surface soil found under the H+D (1) treatment were 0.89 g/cm^3, 66.5%, and 4.39 cm/hr. In the subsurface soils, they were 0.90 g/cm^3, 66.2% and 4.45 cm/hr.

The mean bulk density, porosity, and hydraulic conductivity at the surface soils were 0.87 g/cm^3, 67.2%, and 4.67 cm/hr, respectively, under the H+D (2) treatment. In the subsurface, they were 0.90 g/cm^3, 66.2%, and 4.66 cm/hr.

Table 1: Physico-Chemical Properties of Niger Delta University Teaching and Research Farm Soils

TRTS	Depth	pH	EC	Org.C	Org.M	TN	EA	Na	K	Ca	Mg	Av.P	ECEC	Sand	Silt	Clay	Texture
			ds/m	g/kg			cmol/kg							g/kg			
NT	0-15cm	4.33a	75.67a	16.43a	32.87a	6.30a	1.65a	0.19a	0.48a	1.20a	0.93a	1.97b	4.47a	615	144.4	240.6	Sandy loam
	15-30cm	4.43a	77.00b	21.53b	43.07b	11.43b	1.76a	0.23a	0.54a	1.25a	0.96a	1.24a	4.73a	655	124.4	220.6	SandyClay loam
Mean		**4.38A**	**76.34C**	**18.98A**	**37.97A**	**8.87B**	**1.71A**	**0.21A**	**0.51A**	**1.23B**	**0.95A**	**1.61B**	**4.60C**	**635**	**134.4**	**230.6**	**Sandy loam**
Hoe	0-15cm	4.60a	93.67b	24.87b	49.73b	14.63b	1.50a	0.25b	0.42a	1.03b	0.66a	0.39a	3.87b	855	64.4	80.6	Loamy sand
	15-30cm	4.37a	61.67a	18.23a	36.47a	9.70a	1.60a	0.12a	0.24b	0.56a	0.34a	0.23a	2.87a	695	114.4	190.6	Sandy loam
Mean		**4.49A**	**77.67C**	**21.55B**	**43.10B**	**12.17E**	**1.55A**	**0.19A**	**0.33A**	**0.80A**	**0.50A**	**0.31A**	**3.37B**	**775**	**89.4**	**135.6**	**Loamy sand**
Digging	0-15cm	4.30a	65.67a	17.57a	35.13a	10.93a	1.50a	0.12a	0.24a	0.56a	0.45a	0.28a	2.87a	735	114.4	120.6	Loamy sand
	15-30cm	4.40a	65.67a	19.47b	38.93b	12.33b	1.70a	0.13a	0.24a	0.53a	0.46a	0.32a	3.07b	745	84.4	170.6	Loamy sand
Mean		**4.35A**	**65.67A**	**18.52A**	**37.03A**	**11.63A**	**1.60A**	**0.13A**	**0.24A**	**0.55A**	**0.46A**	**0.30A**	**2.97A**	**740**	**99.4**	**145.6**	**Loamy sand**
HOE + DIGGING (ONCE)	0-15cm	4.37a	82.67b	18.03a	36.07a	6.13a	1.59a	0.29a	0.63a	1.52a	1.14a	2.52a	5.20a	855	64.4	80.6	Loamy sand
	15-30cm	4.47a	81.33a	23.40b	46.80b	9.63b	1.63a	0.27a	0.61a	1.50a	1.18a	2.32a	5.20a	735	94.4	170.6	Loamy sand
Mean		**4.42A**	**82D**	**20.72B**	**41.44B**	**7.88A**	**1.61A**	**0.28A**	**0.62A**	**1.51B**	**1.16B**	**2.42C**	**5.20D**	**795**	**79.4**	**125.6**	**Loamy sand**
HOE + DIGGING (TWICE)	0-15cm	4.20a	70.00a	20.53b	41.07b	11.73b	1.41a	0.21a	0.47a	1.19a	1.14a	1.10a	4.40a	695	124.4	180.6	Sandy loam
	15-30cm	4.63a	78.00b	17.83a	35.67a	10.00a	1.63a	0.19a	0.60b	1.37a	1.28a	1.46b	5.13b	735	144.4.	120.6	Loamy sand
Mean		**4.42A**	**74B**	**19.18A**	**38.37A**	**10.87C**	**1.52A**	**0.2A**	**0.54A**	**1.28B**	**1.21B**	**1.28B**	**4.77C**	**715**	**134.4**	**150.6**	**Loamy sand**

T.N – Total Nitrogen, EA – Exchangeable acidity, Na – Sodium, K-Potassium, Ca – Calcium, Mg- Magnessium, Av.P – Available Phosphorus, CEC – Cation Exchange Capacity, ECEC, Effective Cation Exchange Capacity, µS/cm – microsiemens per centimeter, g/kg – gram per kilogram, cMol/kg – Centimole per kilogram; value(s) with the same lower case letters(s) and mean values in upper cases in the column are not significantly different from one another at a 5% level of probability in each tillage methods

Table 2: Effect of the Crude Tillage Measures on Soil Physical and Chemical Characteristics

TRTS	pH	EC	Org.C	Org.M	TN	EA	Na	K	Ca	Mg	Av.P	ECEC	Sand	Silt	Clay	Texture
		ds/m	g/kg			cmol/kg							g/kg			
NT	**4.38a**	**76.34c**	**18.98a**	**37.97a**	**8.87b**	**1.71a**	**0.21a**	**0.51a**	**1.23b**	**0.95a**	**1.61b**	**4.60c**	**635**	**134.4**	**230.6**	**Sandy loam**
Hoe	**4.49a**	**77.67c**	**21.55ab**	**43.10ab**	**12.17e**	**1.55a**	**0.19a**	**0.33a**	**0.80a**	**0.50a**	**0.31a**	**3.37b**	**775**	**89.4**	**135.6**	**Loamy sand**
Digging	**4.35a**	**65.67a**	**18.52a**	**37.03a**	**11.63d**	**1.60a**	**0.13a**	**0.24a**	**0.55a**	**0.46a**	**0.30a**	**2.97a**	**740**	**99.4**	**145.6**	**Loamy sand**
HOE + DIGGING (ONCE)	**4.42a**	**82d**	**20.72b**	**41.44b**	**7.88a**	**1.61a**	**0.28a**	**0.62a**	**1.51b**	**1.16ab**	**2.42c**	**5.20d**	**795**	**79.4**	**125.6**	**Loamy sand**
HOE + DIGGING (TWICE)	**4.42a**	**74b**	**19.18a**	**38.37a**	**10.87c**	**1.52a**	**0.2a**	**0.54a**	**1.28b**	**1.21ab**	**1.28b**	**4.77c**	**715**	**134.4**	**150.6**	**Loamy sand**

Mean value(s) with the same letters(s) in the column are not significantly different from one another at a 5% level of probability in each tillage methods

Table 3: Bulk Density, Porosity and Hydraulic Conductivity of the Study Area Under the Selected Crude Tillage Methods

TREATMENTS	Depth (cm)	BD g/cm³				**Mean**	POR %			**Mean**	HC cm/hr			**Mean**
		Rep 1	**Rep 2**	**Rep 3**			**Rep 1**	**Rep 2**	**Rep 3**		**Rep 1**	**Rep 2**	**Rep 3**	
NT	0-15cm	1.07a	1.2a	1.23a		**1.17A**	59.6a	54.7a	53.6a	**56.0A**	2.50a	2.70a	2.75a	**2.65A**
	15-30cm	1.18a	1.24a	1.13a		**1.18A**	55.5a	53.2a	57.4a	**55.3A**	2.56a	2.60a	2.55a	**2.57A**
Hoe	0-15cm	1.09a	1.05a	1.06a		**1.07A**	58.9a	60.4a	60.0a	**59.7A**	3.89a	3.67a	3.69a	**3.75A**
	15-30cm	1.1a	1.07a	1.07a		**1.08A**	58.5a	59.6a	59.6a	**59.2A**	3.70a	3.66a	3.70a	**3.69A**
Digging	0-15cm	1.01a	1.00a	0.98a		**1.00A**	61.9a	62.3a	63.0a	**62.4A**	3.57a	3.68a	3.66a	**3.64A**
	15-30cm	1.09a	1.10a	1.00a		**1.06A**	58.9a	58.5a	62.3a	**59.9A**	3.89a	3.85a	3.69a	**3.81A**
HOE + DIGGING (ONCE)	0-15cm	0.87a	0.90a	0.89a		**0.89A**	67.2a	66.0a	66.4a	**66.5A**	4.52a	4.35a	4.30a	**4.39A**
	15-30cm	0.89a	0.90a	0.90a		**0.90A**	66.4a	66.0a	66.0a	**66.2A**	4.56a	4.40a	4.39a	**4.45A**
HOE + DIGGING (TWICE)	0-15cm	0.86a	0.88a	0.87a		**0.87A**	67.5a	66.8a	67.2a	**67.2A**	4.67a	4.69a	4.66a	**4.67A**
	15-30cm	0.88a	0.89a	0.92a		**0.90A**	66.8a	66.4a	65.3a	**66.2A**	4.66a	4.68a	4.65a	**4.66A**

Mean value(s) with the same letters(s) in the column are not significantly different from one another at a 5% level of probability in each tillage methods. BD – Bulk Density, POR – Porosity, HC – Hydraulic Conductivity

Table 4: Effect of Crude Tillage Methods on Soil Bulk Density, Porosity and Hydraulic Conductivity

Tillage methods	BD (g/cm³)	POR (%)	HC (cm/hr)
No till	1.18a	55.65a	2.61a
Hoe	1.08b	59.45b	3.72b
Digging	1.03b	61.15b	3.73b
Hoe + Digging (once)	0.90c	66.35c	4.42c
Hoe + Digging (twice)	0.89c	66.70c	4.67c

Mean value(s) with the same letters(s) in the column are not significantly different from one another at a 5% level of probability in each tillage methods. BD – Bulk Density, POR – Porosity, HC – Hydraulic Conductivity

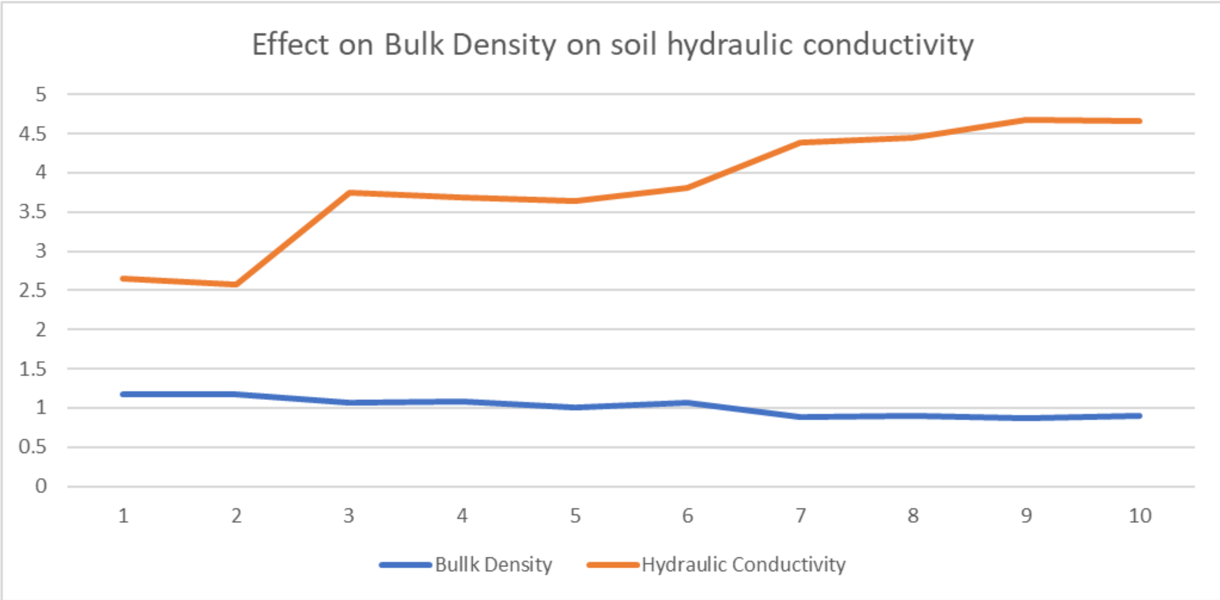

Figure 2: Impact of bulk density on soil hydraulic conductivity

4.16 The Short Term Impact of Tillage Methods on Soil Bulk Density, Porosity, and Hydraulic Conductivity

As shown in Table 4, the bulk density (1.18 g/cm³) in the NT treatment differed significantly ($P<0.05$) from the other tillage methods, while porosity (55.65%) and hydraulic conductivity (2.61 cm/hr) were the lowest. This is consistent with the research which shows that tillage increases hydraulic conductivity and improves water use efficiency (Li et al., 2007; Bhattacharyya et al., 2008). Hoeing and digging had no significant ($P<0.05$) effect on soil bulk density (1.08 and 1.03 g/cm³), porosity (59.45 and 61.15 %), and hydraulic conductivity (3.72 and 3.73 cm/hr). The depths also witnessed no significant change when disturbed by the implements. However, values of H+D 1 and H+D 2 exhibited no significant ($P<0.05$) difference in their bulk density (0.90 and 0.89 g/cm³), porosity (66.35 and 66.70%) and hydraulic conductivity (4.42 and 4.67 cm/hr). The result therefore shows the significant impact of tillage methods intensity on the soil bulk density, porosity, and hydraulic conductivity.

All treatments had bulk density values of less than the critical limit of 1.68 g/cm³, while porosity increased as bulk density decreased, indicating an inversely proportional relationship (Agbai and Kosuowei, 2022). The hydraulic conductivity, or ease of water movement rate, was low in the NT area but increased as tillage intensity increased. Furthermore, as bulk density decreased, hydraulic conductivity increased (Figure 2). The loosening effect of tillage, which created more pore spaces for free passage of air and water, could be attributed to the decrease in bulk density, increase in porosity, and increase in hydraulic conductivity. This is similar to the work which compared the effects of manual clearing, moulding, and ridging (Agbede, 2006).

4.17 Soil Moisture Retention at the Different Depths

The results shown in Table 5 show that the different tillage methods had no effect on the soil moisture content at different depths and pressure bars ($P<0.05$). As a result, a similar trend in Plant Available Water Capacity (PAWC) and Soil Water Holding Capacity (SWHC) was observed (SWHC). Under the NT Zone, moisture content at both surface and subsurface soil were 0.45 and 0.48 cm^3cm^{-3} at 0 bar (saturation), 0.21 and 0.23 cm^3cm^{-3} at 0.33 bar (Field Capacity-FC), 0.07 and 0.09 cm^3cm^{-3} at 15 bar (Permanent Wilting Point-PWP); 0.14 and 0.13 cm^3cm^{-3} at PAWC; 2.05 and 2cm at SWHC.

At hoeing, moisture content at 0-15cm and 15-30cm was 0.36 and 0.35 cm^3cm^{-3} under 0 pressure bar, 0.17

cm^3cm^{-3} at FC, 0.06 cm^3cm^{-3} at PWP, 0.11 cm^3cm^{-3} for PAWC, and 1.65cm for SWHC. At digging, it was 0.40 and 0.41 cm^3cm^{-3} at 0 bar, 0.18 and 0.19 cm^3cm^{-3} at FC, 0.06 and 0.07 cm^3cm^{-3} at PWP; 0.12 cm^3cm^{-3} for PAWC, and 1.75 and 1.8 cm for SWHC. Under H_D(1), it was 0.27 cm^3cm^{-3} at 0 bar, 0.12 and 0.11 cm^3cm^{-3} at FC, 0.05 and 0.04 cm^3cm^{-3} at PWP, 0.07 cm^3cm^{-3} for PAWC, and 1.1cm for SWHC. Under H+D (2), it was 0.27 cm^3cm^{-3} at 0 bar, 0.13 and 0.12 cm^3cm^{-3} at FC, 0.06 and 0.05 cm^3cm^{-3}, 0.07 and 0.06 cm^3cm^{-3} for PAWC, and 1 and 0.95cm for SWHC.

4.18 Short Term Effect of Tillage Methods on Plant Available Water Capacity and Soil Water Holding Capacity

The Plant Available Water Capacity was significantly (P<0.05) affected by the tillage methods as its highest was registered in the NT zone while the lowest was in the H+D (2) area (Table 6). Thus, the tillage methods reduced the volume of water readily retained in the soil for plant utilization. The PAWC and SWHC were 0.14 cm^3cm^{-3} and 2.03 cm in the NT Zone, 0.11 cm^3cm^{-3} and 1.65cm after hoeing, 0.12 cm^3cm^{-3} and 1.78 cm after digging, 0.07 cm^3cm^{-3} and 1.1cm after H+D (1), and 0.06 cm^3cm^{-3} and 0.95cm after H+D (2). This shows that hoeing and digging, respectively, and also H+D (1) and H+D (2), had similar effects on PAWC and SWHC.

The reduction in Plant Available Water Capacity and Soil Water Holding Capacity due to increased tillage could be attributed to the physical degradation of the soil structure and an increase in pore space diameter, which limited the soil cohesive force and supported leaching of water out of the soil. Less water will therefore be retained under this phenomenon. To confirm this phenomenon in their research by stating that conversion from conventional tillage to zero tillage increases the available water capacity of the soil (McGarry et al., 2000). This therefore implies that a change from zero tillage to any form of conventional tillage has the capacity to reduce plant available water capacity (Halvorson et al., 2001).

Table 5: Soil Moisture Retention Capacity Under the Different Crude Tillage Methods

TRT	Depth (cm)	Moisture Retention at 0 Bar Cm^3cm^{-3}			**Mean**	Moisture Retention at 0.33 Bar Cm^3cm^{-3}			**Mean**	Moisture Retention at 15 Bar Cm^3cm^{-3}			**Mean**	**PAWC** cm^3cm^{-3}	**SWHC cm**
		Saturation				Field Capacity (FC)				Permanent Wilting Point					
		Rep 1	**Rep 2**	**Rep 3**	**Mean**	**Rep 1**	**Rep 2**	**Rep 3**	**Mean**	**Rep1**	**Rep2**	**Rep 3**	**Mean**		
NT	0-15cm	0.48	0.47	0.41	**0.45a**	0.26	0.2	0.17	**0.21a**	0.06	0.09	0.07	**0.07a**	**0.14a**	**2.05a**
	15-30cm	0.47	0.45	0.53	**0.48a**	0.25	0.2	0.23	**0.23a**	0.1	0.08	0.1	**0.09a**	**0.13a**	**2a**
Hoe	0-15cm	0.36	0.36	0.36	**0.36a**	0.17	0.19	0.15	**0.17a**	0.06	0.06	0.06	**0.06a**	**0.11a**	**1.65a**
	15-30cm	0.37	0.34	0.34	**0.35a**	0.16	0.18	0.18	**0.17a**	0.06	0.07	0.06	**0.06a**	**0.11a**	**1.65a**
Digging	0-15cm	0.4	0.4	0.4	**0.40a**	0.18	0.17	0.19	**0.18a**	0.06	0.07	0.06	**0.06a**	**0.12a**	**1.75**
	15-30cm	0.4	0.43	0.4	**0.41a**	0.19	0.19	0.2	**0.19a**	0.08	0.08	0.06	**0.07a**	**0.12a**	**1.8a**
HOE+DIGGING (ONCE)	0-15cm	0.29	0.28	0.25	**0.27a**	0.11	0.12	0.13	**0.12a**	0.05	0.04	0.05	**0.05a**	**0.07a**	**1.1a**
	15-30cm	0.25	0.29	0.28	**0.27a**	0.1	0.12	0.11	**0.11a**	0.04	0.04	0.03	**0.04a**	**0.07a**	**1.1a**
HOE +DIGGING (TWICE)	0-15cm	0.27	0.28	0.26	**0.27a**	0.14	0.11	0.13	**0.13a**	0.06	0.06	0.06	**0.06a**	**0.07a**	**1a**
	15-30cm	0.26	0.27	0.28	**0.27a**	0.12	0.12	0.11	**0.12a**	0.06	0.05	0.05	**0.05a**	**0.06a**	**0.95a**

Mean value(s) with the same letters(s) in the column are not significantly different from one another at a 5% level of probability in each tillage methods. PAWC – Plant Available Water Capacity, SWHC – Soil Water Holding Capacity

Table 6: Mean Moisture Retention Capacity Under the Different Tillage Methods

	0BAR	0.33BAR	15BAR	PAWC	SWHC
NT	0.47a	0.22a	0.08a	0.14a	2.03a
HOE	0.36b	0.17b	0.06b	0.11b	1.65b
DIGGING	0.41b	0.19b	0.07a	0.12b	1.78b
H+D (1)	0.27c	0.11c	0.04c	0.07c	1.1c
H+D(2)	0.27c	0.12ca	0.05c	0.06c	0.95c

Mean value(s) with the same letters(s) in the column are not significantly different from one another at a 5% level of probability in each tillage methods. PAWC – Plant Available Water Capacity, SWHC – Soil Water Holding Capacity

5. Conclusion

According to the findings, crude tillage methods and their increased intensity had no effect on soil chemical properties such as pH, electrical conductivity, organic carbon, organic matter, total nitrogen, texture, and so on, but had a significant effect on soil bulk density, porosity, plant available water capacity, and soil water holding capacity. The NO TILL Zone had the highest bulk density value, while the HOE + DIGGING Zone had the lowest (once and twice). As a result, the HOE + DIGGING (Twice) treatment zone had the highest hydraulic conductivity and the NO TILL treatment zone had the lowest. Similarly, the NO TILL treatment had the highest Plant Available Water Capacity and soil water holding capacity, while the HOE + DIGGING (Twice) treatment had the lowest. It is therefore imperative to state that less destructive tillage practices and no tillage (NT) (zero soil disturbances) controls the negative impacts on soil quality.

The following recommendations are made based on the findings of this study: for unrestricted flow of water through the soils, compacted soils can be pulverized using crude implements, as this will increase the percentage of pore space availability. Tillage activities on coarse-textured soils should be reduced to promote leaching by gravitational force, to attain optimal and adequate water economy for plant utilization. Also, future studies should be carried out to determine the long term effect of tillage on soil water retention capacity and its structure, as this could lead to control of water erosion and loss of soil nutrients.

Authors' Contributions

Agbai W.P: Planning, Conceptualization, Supervision in all locations, conducted experiments in different locations and collected data, analysed data, validation and writing.

Joseph O.T: Editing, and revised the whole manuscript.

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Conflict of Interest

All authors declare that there is no conflict of interest either financially or otherwise.

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