Soil Porosity and Water Infiltration as Influenced by Tillage Practices on Federal University of Agriculture Abeokuta, Ogun State, Nigeria Soil

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Abstract: **The relations between soil pore structure induced by tillage and infiltration play an important role in flow characteristics of water and solutes in soil. The effects of agricultural management practices on soil physical parameters aid the effective sustainability of soils. In this study, three tillage methods common to the study area on porosity and water infiltration were assessed. Tillage treatments include zero tillage (Plot covered with vegetation (conservation tillage)), disc plough (ploughing to the depth of 16 cm, conventional tillage (CT)) and disc harrow (harrowing to a depth of 16 cm, conventional tillage (CT)). Porosity was determined by the core method, water infiltration by the double-ring infiltrometer and hydraulic conductivity from the steady state flow rate. Based on the result obtained there was no significant difference between the zero tillage and disc plough tillage while there was significant difference between the zero tillage and disc harrow tillage. More so, there was significant difference between the plough tillage and harrow tillage. Based on analysis and comparison of results, it's indicated high soil sorptivity, porosity and infiltration capacity values for zero tillage follow by disc plough tillage and disc harrow tillage respectively. The bulk density decreased with depth for all the tillage practice while moisture content and porosity increased with depth for all the tillage practices. Furthermore, it has been found that porosity decreased in the order disc harrow tillage (49.90 %) follow by disc plough tillage (42.62%) and zero tillage (41.17 %) respectively. Meanwhile, infiltration capacity increased in the order zero tillage (24.40 cm/hr) follow by disc plough tillage (32.30 cm/hr) and disc harrow tillage (39.40 cm/hr). It was also observed that there was positive correlation between the infiltration capacity and porosity. The infiltration capacity increased with porosity.**

Keywords: **Soil porosity, Water infiltration, Tillage practices, bulk density**

I. INTRODUCTION

Tillage practices profoundly affect soil physical and hydraulic properties. It is essential to select a tillage practice that sustains the soil physical properties required for successful growth of agricultural crops (Stevens, 2009). It is generally accepted that the type of tillage system adopted for soil manipulation prior to planting does affect the geometry of the root systems, nutrient accessibility to plants and consequently, crop establishment and growth (Ashraful *et al*., 2001). However, any manipulation that changes soil condition may be considered as tillage.

Hillel, 1971; Klute, 1986; Reynolds and Elrick, 2002 state that the rate at which water enters into the soil surface (infiltrability) and transmits through the soil profile (saturated hydraulic conductivity) depends on soil structure, pore size distribution and pore continuity. More so, porosity is also a function of pore size distribution, pore continuity and hydraulic conductivity of pore size distribution, pore continuity and hydraulic conductivity (Benjamin, 1993).

Two of the most commonly measured soil physical properties affecting hydraulic conductivity and other hydraulic properties are the soil bulk density and effective porosity, as these two properties are also fundamental to soil compaction and related agricultural management issues (Strudley *et al*., 2008). Although in-situ saturated hydraulic conductivity (k_s) is considered as one of the most important parameters for water flow and chemical transport phenomena in soil (Reynolds and Elrick, 2002), relatively few studies have evaluated and compared the effects of various tillage practices on physical and hydraulic properties of the soil.

These soil properties are all affected by tillage, one of the most influential management practices influencing soil physical and hydraulic characteristic (Lal and Shulka, 2004). Tillage can alter soil structure by creating macropores that considerably increase saturated hydraulic conductivity (Bouma, 1991). Tillage can affect pore size distribution by creating temporary pore spaces that either collapse or seal during the growing season as result of raindrop impact, wetting and dry cycles (Topaloglu, 1999) and tillage practices can disrupt pore continuity and macropores, reducing water flow between the plough layer and subsoil (Bouma, 1991)

At the soil surface, the impact of raindrops on a bare soil surface can decrease porosity through the formation of surface seals and crust. These limit the rate of infiltration, leading to runoff. Any traffic in the field, such as machinery, ploughing or impact of human feet or animal hooves can put pressure on the sub-soil. Pressure destroys pore spaces, in particular the interconnected pore spaces. The soil becomes compacted and water infiltration and storage capacity are reduced. Plant roots have difficulty in penetrating compacted soil and their root system does not develop well.

The purpose of tillage is to create soil conditions favourable for seed germination and crop production. It greatly affects water resources, particularly surface water. Tillage management is an important factor to be considered when attempting to reduce soil erosion and sedimentation. Tillage practices that control soil erosion also protect water quality (Weston, 1994). Although incorrect soil tillage due to a failure to understand the objective and limitation of tillage techniques, can give rise to negative effects. Incorrect tillage is one of the causes of erosion and physical degradation of soil.

Furthermore, excessive tillage or tillage undertaken when the soil moisture content is not appropriate causes adverse effects. Excessive tillage on the surface breaks up the aggregates, favouring the formation of surface crusts, increased run off and the erosive transport of the soil particles. According to Topaloglu (1999), he found that tillage practices had no appreciable effect on infiltration rates in sandy clay loam soils. Ankeny *et al.* (1990) noted no differences in infiltration rates between tilled and untilled soils, while Heard *et al*. (1988) observed higher infiltration rates in tilled soils and attributed the difference to soil surface sealing in untilled soils.

Fabrizzi *et al*, (2005) concluded that there is greater soil bulk density under conservation tillage than conventional tillage. In contrast Hill and Cruse (1985) reported no significant effect of tillage methods (no-tillage, ploughing-tillage, and minimum tillage) on bulk density of a leoss- derived lowa soil. Studies conducted By Blevins and Frye (1993) in Kentucky found, no significant effect on bulk density after 20 years of corn production compared no- tillage and moldboard plough. The surface 0-5cm of the no-tillage soil had slightly lower bulk density than the surface of the moldboard- plough system. This research work investigated the influence of tillage practice on soil porosity, water infiltration and other soil physical properties at Federal University of Agriculture, Abeokuta (FUNAAB), Alabata, Ogun State, Nigeria weather condition.

II. JUSTIFICATION

Relatively few studies have evaluated and compared the effects of various tillage practices on physical and hydraulic properties of the soil. It is also clear that reports of tillage effects on soil structure, macropore modifications and other physical properties at the field scale are often contradictory (Lal and Van Doran, 1990; coutadeur *et al*., 2002).

Based on the nature of ambiguity in the research finding, there is need to demonstrate further studies on the effect of tillage practices on soil physical and characteristics on our own soil. In light of this, we sought to evaluate the effects of different tillage practices on soil parameters at 0-8 cm and 8-16 depths at UNAAB, Alabata.

III. MATERIALS AND METHODS

A. Experimental Site and Setup

The project was in two phases which are the field and laboratory experiments. Both experiments were carried out in UNAAB (70^0N, 30^0E), Alabata. The site used for the field experiment is located behind female hostel. The soil is categorized under Iwo soil series. It is a sandy soil based on the particle size analysis conducted by Akintola (2010) which has 830 g/kg of sand, 16 g/kg of silt, and 154 g/kg of clay.

The experimental field was divided into nine plots. Three tillage practices were replicated three times in a randomized complete block design. These are no tillage (NT), conservational tillage (disc plough (DP) and disc harrow (DH) tillage). For the no tillage there was vegetation in the soil.

B. Measurement of soil physical properties

The materials used for the measurement of these physical properties were:

Core sampler

The core sampler was of 6cm in diameter and 8cm long. The edges were well sharpened so as to be easily buried into the soil. The core sampler was used to collect soil samples from three points on each plot at 0-8cm depth and 8-16cm depths under each tillage system on the sites.

Hammer and flat wooden plank

After placing the core sampler on the ground or soil the flat wooden plank was placed on top of it, afterward the hammer was then used to strike the sampler into the soil.

Cutlass

For easy remover of the core sampler after been buried was done by using the cutlass to scrape the soil round the core sampler.

Nylon

Nylons were used to collect the soil core or sample in the core sampler. Afterward, the nylon is doubled and tight immediately to prevent the moisture from escaping. Meanwhile, the soil samples collected were conveyed to the laboratory for the determination of the soil parameter.

Crucibles/ tins

The soil cores in the nylons were transferred into crucibles and placed in an oven in order to dry all the moisture content in the soil core.

Oven

The soil physical properties were determined through an oven dry method. The oven was used for drying the moisture content in the soil samples. The crucibles with the soil cores are placed in the oven for 24 hours at 105^0C i.e. until it has a constant weight.

Electrical weight balance

It was used for weighing the soil sample before and after drying.

C. Measurement of hydraulic properties

The materials used for the determination of these soil hydraulic properties were:

A double ring infiltrometer

The double ring infiltrometer consists of two concentric rings, driving plate, with handles, for inner and outer rings. The inner ring is 23cm diameter and the outer ring is 36cm diameter. The two rings were driven into the ground and partially filled with water for the determination of infiltration rate and capacity of the soil.

Hammer/ flat wooden plank

The flat wooden plank was placed on top of the infiltrometer and the hammer was used to strike the infiltrometer into the soil at 10cm depth.

Stop watch

The stop watch was used to measure the time of drop in water level in the inner ring.

Ruler

It was used to measure the drop in water level in the inner ring.

D. Determination of soil physical properties

The soil physical properties under each tillage operation like the bulk density, porosity, gravimetric water content GWC and volumetric water content VWC were determined in the laboratory. The soils used for the laboratory experiment were collected in the experimental plots while, the soil hydraulic properties under each tillage practice were determined on the field i.e. in-situ.

Bulk density

Using a core sampler, soil samples were collected from three points on each plot at 0-8cm and 8-16cm depths under each tillage system on the sites. The total soil samples collected was 54. Then the samples in the core sampler were transferred into nylon and were conveyed to the laboratory.

In the laboratory, the mass of each empty crucible was found, m_1. The soil sample was then transferred from the nylon into the crucible and then reweighed as m_2. Afterward, the crucible with the soil samples were keep in the oven for 24 hours at 105^0C for total dryness of the moisture in the soil sample.

However, the crucible was then removed from oven and then reweighed as m_3. From this, the bulk density was calculated as mass of oven dried soil per volume of core (g/cm^3) and gravimetric water content as mass of water in the soil sample per mass of the oven dried soil (g g$^{-1.}$). Volume of the core sampler, V, is 226.19 g/cm^3.

$$\text{Bulk density} = \frac{Mass\ of\ the\ oven\ dry\ soil}{Volume\ \ of\ the\ core} = (\text{g/cm}^3) \qquad (1)$$

Where,

m_2 – the mass of each empty crucible, g

m_2 – the mass of the soil sample and the crucible, g

Porosity

Total porosity was determined from the relationship between bulk density and particle density. While, Particle density was taken as 2.65 g/cm^3. However, Porosity was determined on all plots based on bulk density values at depths 0-8 cm and 8-16 cm.

$$\text{Porosity} = 1 - \frac{Bulk\ densi\ ty}{Particle\ \ density} \quad (\%) \qquad (2)$$

Gravimetric water content:

The gravimetric water content was determined by the use of soil cores to collect samples from tillage treatment plots. Mass of water in soil sample was determined and later oven dried at a temperature of 105^{oC} until constant weight was achieved.

$$\text{Gravimetric water content} = \frac{Mass\ of\ water\ \ in\ soil}{Mass\ of\ oven\ dry\ soil} (\%) \qquad (3)$$

E. Determination of water infiltration and saturated hydraulic conductivity

Double ring infitrometer method

The double ring infiltrometer is a device used to measure the rate of water infiltrate into the soil or other porous media. The instrument was driven into the soil using hammer and flat wooden plank to a depth of 10cm for each of the plot. The double ring is design to help to prevent divergent flow in layered soil. The outer ring acts as a barrier to encourage only vertical flow from the inner ring.

The water was supplied at falling head. The falling head is referred to as condition in which water is supplied into the ring and the water is allow to be dropping with time. A ruler was inserted in the inner ring to measure the drop in water level. The inner and outer rings were ponded with water and the measurement on how the water goes into the soil for a given time period was taken.

However, the water is referred to as the initial level. This test was continued until the drop in the water level is the same over the same time interval. The rate at which water goes into the soil is related to the hydraulic conductivity using the empirical equations of infiltration rate. Furthermore, initial and final moisture contents before and after infiltration were taken on each plot.

Figure 1: Infiltration study with a concentric double ring infiltrometer.

F. Data Analysis

Statistical analyses of data were performed using the analysis of variance (ANOVA) in the General Linear Model procedure of SPSS (SPSS Inc, 1999). Differences between treatments were considered under significant if $P < 0.05$.

IV. RESULTS AND DISCUSSIONS

Soil Physical properties:

Shown in Table 1 is the result of the mean values of the soil physical properties at different depths in relation to tillage practices. The nature of the soil has tremendous effect on water movement in the soil. Gravimetric moisture content and porosity decreased with depth in all the tillage treatments while bulk density increased with depth in all the tillage treatments (Table1). This is in accordance to the results obtained by Mapa (1984).

In contradiction, Abdullah *et al.* (2008) and Osunbitan *el al.* (2005) results show that the bulk density decreases with depth for all the methods. While the total porosity increases with depth also for all the tillage methods. The difference in results may be due to difference in soil type and localities. It was also observed that bulk density was highest in the zero tillage plots followed by disc plough and disc harrow respectively while porosity and moisture content were in the reversed case. It is similar to the result obtained by Zhang *et al*. (2006).

The disc harrow had the highest value of moisture content while zero tillage had the least. This trend could be due to the loosed tilled soil having relatively highest moisture flow as a result of more uniform aggregates.

There is significant difference among the three tillage treatment ($p>0.05$) for the three tillage practices. Nevertheless, based on the results obtained, there is no significant difference ($p<0.05$) between zero tillage and disc plough tillage for all the soil physical properties while there is significant difference ($p>0.05$) between zero tillage and disc harrow tillage. More so, there is significant difference ($p<0.05$) between disc plough and disc harrow tillage practices for all the soil physical properties.

Table 1: Mean values of soil physical properties at different depths in relation to tillage practices

Tillage treatment	Depth (cm)	Moisture Content (%)	Bulk Density (g/cm^3)	Porosity (%)
Zero tillage	0-8	7.43	1.56	41.17
	8-16	5.05	1.65	37.90
Disc Ploughed	0-8	8.00	1.52	42.64
	8-16	5.18	1.54	41.93
Disc harrowed	0-8	11.92	1.33	49.90
	8-16	7.63	1.48	44.32

Infiltration Study:

*Soil hydraulic properties***:**

Table 2 shows the mean values of moisture content, infiltration rate and infiltration capacity under each tillage practices. It is observed that the initial moisture content determines the infiltration rate (Table 2). For each of the tillage practice, when there is low initial moisture content, the initial infiltration rate is high (Table 2). Disc ploughed plots had more moisture initially (9.89 %) but disc harrowed plots had a higher moisture content at the final stage of the infiltration test (17.01 %) (Table 2). This indicate that disc harrowed plots had the ability to take in water at a faster rate than disc ploughed and zero tillage plots, this observation could also be due to the porous nature of the disc harrowed plots and considering the fact that the soil is more loosened and finer than other tillage treatments.

Table 2: Mean values of moisture content, infiltration rate and infiltration capacity under each tillage practices.

Tillage treatments	Initial moisture content (%)	Final Moisture content (%)	Initial infiltration rate (cm/hr)	Infiltration capacity (cm/hr)
Zero tillage	4.03	8.42	78.00	24.40
Disc Ploughed	9.89	15.92	86.40	32.30
Disc harrowed	8.07	17.01	88.00	39.40

Figure 2-4 shows the graphs of average infiltration rate (cm/hr) and average accumulative infiltration (cm) against elapsed time (hrs) under zero tillage, disc plough tillage and disc harro tillage. It was also found that that Infiltration capacity was highest on the disc harrowed (39.4 cm/hr) plots followed by disc plough (32.30 cm/hr) and zero tillage (24.40 cm/hr) respectively (Fig. 5). Also, from the results, it was revealed that for a particular soil with high initial moisture content it takes shorter time to reach the infiltration capacity. These results were also similar to those found by Akintola (2010).

More so, it is generally accepted that hydraulic conductivity is inversely related to bulk density (Mankin *el al*. 1996). Results agree with this premise that tillage with higher bulk density associates with lower hydraulic conductivity values.

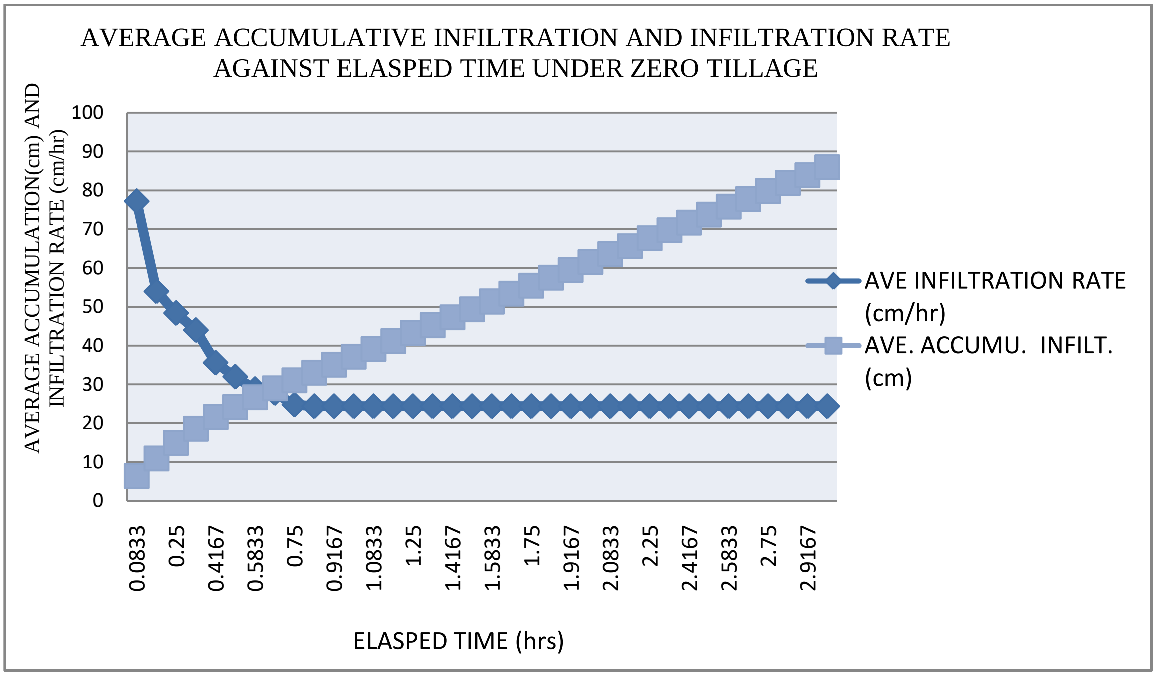

Figure 2: A graph of average infiltration rate (cm/hr) and average accumulative infiltration (cm) against elapsed time (hrs) under zero tillage.

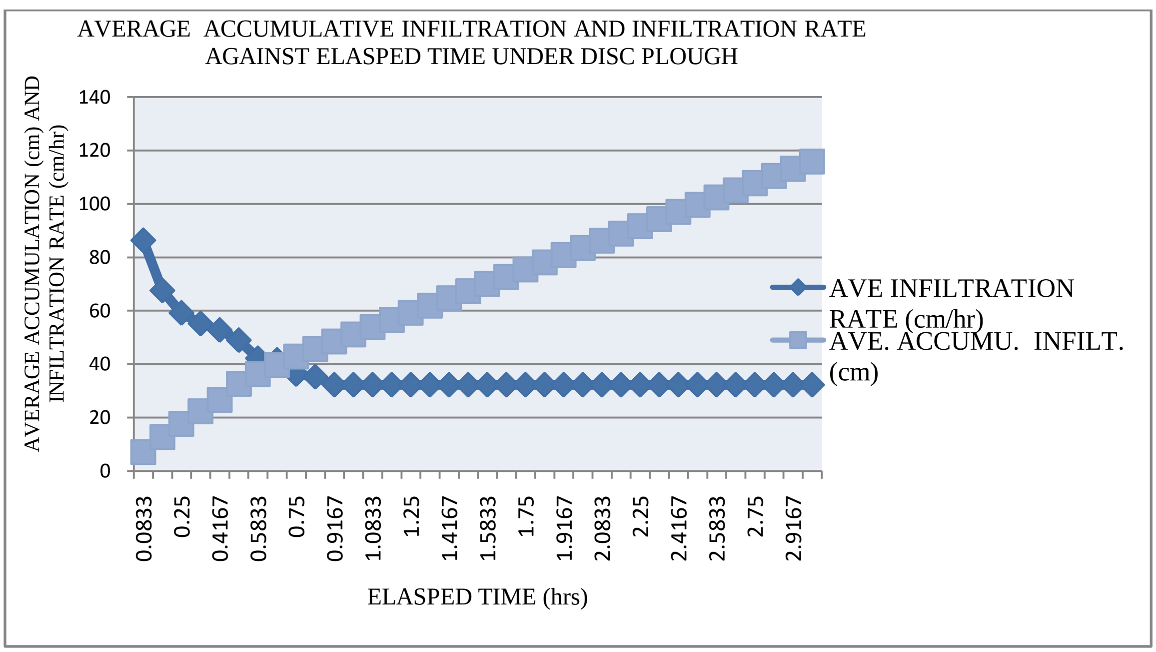

Figure 3: A graph of average infiltration rate (cm/hr) and average accumulative infiltration (cm) against elapsed time (hrs) under disc plough tillage.

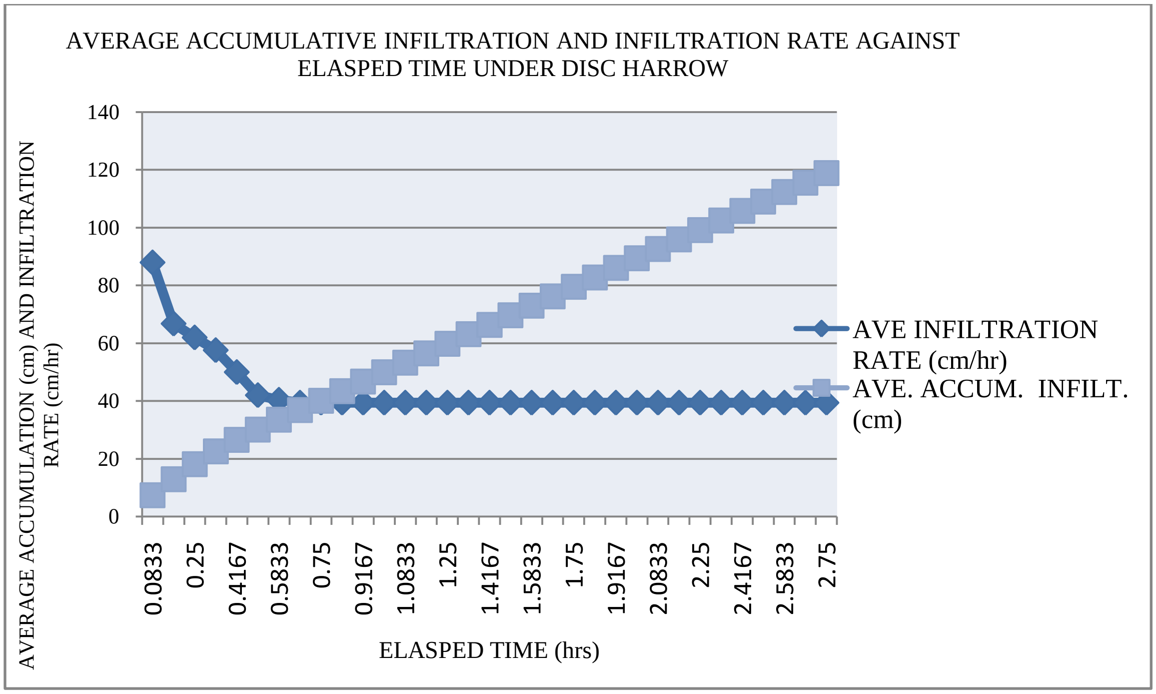

Figure 4: A graph of average infiltration rate (cm/hr) and average accumulative infiltration (cm) against elapsed time (hrs) under disc harrow tillage.

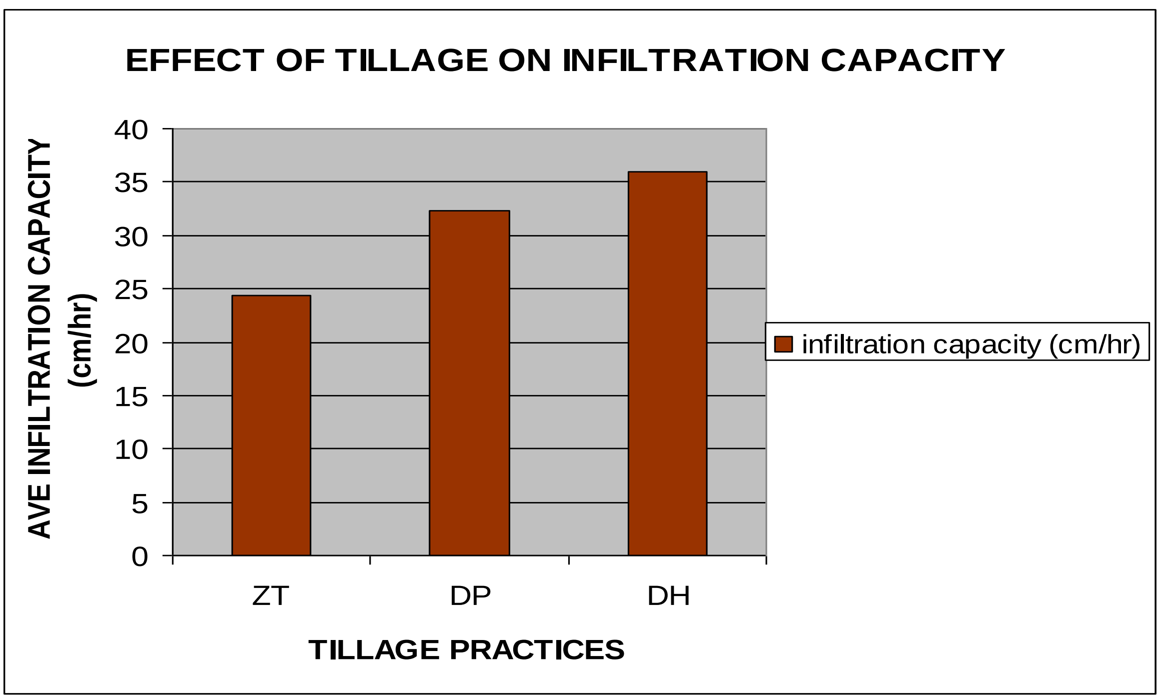

Figure 5: Comparison of the average infiltration capacity (cm/hr) under each tillage practice.

Effect of soil porosity on water infiltration capacity:

Table 3 shows the effect of soil porosity on infiltration capacity. There is a positive correlation between the two properties. Both increase due to the effect of tillage operation in this order, zero tillage plots followed by disc plough and disc harrow respectively. Disc harrow tillage produced the greatest volume of macropores and pore space due to the looseness of the soil compared to the other two tillage practices (Table 3). As a consequence, large volume of the water flows through the soil profile and macropore which result into high infiltration rate and infiltration capacity.

Table 3: Effect of soil porosity on infiltration capacity.

Tillage treatments	Porosity (%)	Infiltration capacity (cm/hr)
Zero tillage	41.17	24.40
Disc Ploughed	42.64	32.30
Disc harrowed	49.90	39.40

Empirical equation of the infiltration rate

Regression analyses were used for the kostiakov and Phillips equations.

For kostiakov equation which states as

$f = k\ t^n$ (4)

where

f = Accumulative infiltration, mm/hr

t=time since the start of infiltration, mins

k and n are constants.

Log of both side of the equation was found.

$\log f = \log k + n \log t$

The graph of the log f was plotted against log t

For Phillips equation, he claims that

$F = at^{½} + C$ (5)

where

f = accumulative infiltration, cm

a = soil sorptivity (soil sorptivity is the affinity of the soil to absorb water without the influence of gravity), $cmmin^{-1/2}$.

C = transmissivity and t is time (mins)

The graph of f (cm) was plotted against $t^{1/2}$ ($min^{1/2}$)

Kositiatov equation:

Zero tillage practice: $f = 2.1880\ t^{0.6997}$ (6)

Disc plough tillage practice: $f = 2.3062\ t^{0.7562}$ (7)

Disc harrow tillage practice: $f = 2.1115\ t^{0.78137}$ (8)

Phillips equation:

Zero tillage practice: $f = 5.5874\ t^{½} - 6.4071$ (9)

Disc plough tillage practice: $f = 6.2956\ t^{½} - 13.2476$ (10)

Disc harrow tillage practice: $f= 7.3602\ t^{½} - 10.0147$ (11)

From the Phillips equation and the results obtained from the porosity values (table1), it was observed that the smaller the sorptivity can be associated with lower aggregate porosity. This was in agreement with the results obtained by Lipiec (2006).

V. CONCLUSION

The research on Ferderal University of Agriculture, Abeokuta, Ogun State, Nigeria soil has shown that tillage profoundly affect soil physical and hydraulic properties. The results had revealed that there is no significant difference between zero tillage and disc plough tillage on soil physical properties while there is significant difference between zero tillage and disc harrow tillage on the soil bulk density. More so, there is significant between the disc plough and disc harrow on the soil physical properties.

From analysis, i.e. making used of mean, it has been found that there is greater value of bulk density and lower value of porosity under conservation tillage than conventional tillage which is in accordance to Fabirrizi *el al.* (2005) report. Further more, it has been noted that based on the result obtained bulk density increase with depth for each tillage operation, while porosity and water content decrease with depth. These indicated that there is more water in the seed bed than in the root bed.

Also, in conclusion, disc harrow tillage has the highest moisture content while zero tillage had the least. This trend could be due to the loosed tilled soil having relatively highest and appreciable moisture flow as a result of more uniform aggregate. Based on this three tillage practices, the disc harrow is the best.

Nevertheless, it has been observed that the initial moisture content determines the initial infiltration rate. While the soil porosity is a determinant of the total amount of water that would be available in the pore space at point of saturation and the infiltration capacity. This aspect is very important in design of irrigation system. Further more, it had been found that infiltration capacity increases in the order zero tillage plots followed by disc plough and disc harrow respectively. This indicated that infiltration capacity increased with porosity. Lastly, it has been generally accepted that hydraulic conductivity is inversely related to bulk density (Mankin *et al*., 1996) which agree with the result.

VI. RECOMMENDATION

Most tillage operations performed by the farmer in the locality where the project was carried out are zero tillage, disc plough tillage and disc harrow tillage. Based on the research work this three tillage practices, the disc harrow tillage is the best but we should not forget the adverse effect this conventional tillage operation can cause i.e. soil erosion and physical degradation like distortion of the soil structure which lead to the lose of soil, nutrient and distortion of micro organism.

Since in the process of trying to increase the pore space of the soil, it causes the breakage of the soil aggregate which can easily cause transportation of the soil by wind and water erosion. I would recommend that further research must be employed to see whether other methods of conservation like the reduced tillage (such as ridge, terracing etc.) can compete with the harrow in terms of moisture in our own locality.

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