Soil Physical Properties and Hydraulic Conductivity of Compacted Sandy Clay Loam Planted with Maize *Zea Mays*

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Abstract

Land degradation from soil compaction has a major influence on the hydraulic conductivity, total porosity (PT), micro porosity (MIC), macro porosity (MAC), roots growth and grain yield. Field experiment was conducted in a tilled and compacted sandy clay loam soil under different machinery passes to determine compaction effects on soil bulk density, total porosity (PT), micro-porosity (MIC), macro-porosity (MAC), hydraulic conductivity and growth characteristics of maize. Four plots; A, B, C and D, each of area 5 x 10 m^2 were used. Plot A was tilled with a tractor-mounted disc plough and the remaining three plots; B, C and D were subjected to 5, 10 and 15 passes, respectively of heavy duty Mercy Fergusson tractor model 4355 (3.82 Mg). Compacted plots progressively increased in bulk density between 1.63g cm^{-3} to 1.90 gcm^{-3}, while total porosity decreased from 38 to 28.3 % in plots under 5 and 15 traffic passes, respectively. Soil micro-porosity decreased from 9.6 % to 7.84 % and from 17 % to 9.17 % in the soil superficial layer (0-10 cm) and at the 10-20 cm layer, respectively while the macro porosity ranged from 28.64 % to 20.45 % and 24.3 % to 19.12 % in the 0 - 10 and 10 - 20 cm soil layers, respectively. At suction of 2 cm s^{-1}, tilled plot had the highest cumulative infiltration rate of 3.42 cm s^{-1} and hydraulic conductivity of 9.09 x 10^{-3}. Results show that different machinery passes poses different restrictions to rooting depths of maize.

Keywords: Bulk density, hydraulic conductivity, total porosity, micro porosity, macro porosity.

Introduction

As farm tractors and field equipment become larger and heavier, there is a growing concern about soil compaction. Soil compaction can be associated with a majority of field operations that are often performed when soils are wet and more susceptible to compaction. Soil structure is important and must not be damaged because it determines the ability of a soil to hold and conduct water, nutrients, and air necessary for plant root activity.

Soil compaction, as well as changes in soil physical properties, is a major factor that causes high mechanical impedance or excessive soil strength (Yamauchi, 1993; Iijima et al., 1991; Masle 2002). Soil compaction is the main form of soil degradation, which affects 11% of the land area in the surveyed countries of the world (Tamari et al., 1993; Morath et al., 1997). Compaction is caused by the use of heavy machinery, pressure from wheels, trampling by animals, frequent use of chemical fertilizers and ploughing at the same depth for many years. Agricultural processes, such as soil compaction, tillage fertilization and irrigation, have impact on soil structure, and degrade field drainage. These processes are mostly conducted near the surface, and affect topsoil structure over short time scales. Consequently, many studies have examined changes in topsoil structure (Mapa, 1986; Hill, 1990). Recently, the importance of persistence of subsoil compaction for soil structure change has been reported (Voorhees, et al., 1986; Hakansson, 1994; Horn et al., 2000; Arvidsson, 2001).

Over the years, physical properties of the soil that control water movement and retention in the soils are largely affected due to human, animal activities as well as use of machine for soil tillage purposes. Among such soil properties affected is the soil bulk density, which according to Wellings *et al.,* (1985) is the density for a volume of the soil as it exits naturally, including any air spaces and organic materials (OM) in the soil volume. Since bulk density is used to calculate the total water storage capacity per soil volume and to evaluate compaction within, which invariably determines soil layer root penetration or adequate aeration (Van Remorted and shields, 1993), the bulk density of soil depends greatly on the mineral make up of soil and degree of saturation (Buckman et al; 1960). Bulk density of soil is usually determined on core samples, which are taken by driving a metal core sampler into the soil at the desired depth and horizon. The samples are then oven-dried and weighed. A loosed soil, with an increased total pore space, will have a small weight after it is compacted. Thus, the bulk densities can be used to estimate differences in compaction of soil when subjected to different traffic machinery passes. This can be used to calculate total water storage capacity per soil volume and to evaluate soil layers with respect to the degree of compaction, allowable root penetration and air permeability (Donahue, 1990). The bulk density of soil is inversely related to the porosity of the same soil: the more pore space in a soil the lower the value for bulk density.

Another soil properties that is affect by machinery passes is the soil hydraulic conductivity, which depends on soil structure and varies in both space and time. Temporal variation of hydraulic conductivity is caused by growth and decay of plant root (Meek et al., 1992), activity of soil organism (Beven and Germann, 1982; Willoughby et al., 1996), precipitation that forms surface crusts (Messing and Jarvis, 1993), shrinking and swelling (Messing and Jarvis, 1990; Bagarello et al., 1999), freezing and thawing (Scott et al., 1994), and agricultural activities, such as tillage and wheel-traffic compaction (Ankeny et al., 1990; Logsdon and Jaynes, 1996). Hydraulic conductivity, which reflects soil structural properties such as total porosity, micro porosity, macro porosity, pore–size distribution and pore continuity, is used as an index for field drainage. When soil become compacted, changes in total porosity, micro porosity, macro porosity and pore-size distribution cause the hydraulic conductivity to decrease, and penetration resistance and bulk density to increase (Lowery and Schuler, 1994). The change in hydraulic conductivity does not always result from the changes in dry bulk density (Mc Queen and Shepherd, 2002). For instance, tillage, which is the mechanical manipulation of soil to control weeds, breaks crusts to help infiltration and seedling emergence, dispose pests or crop residues and helps to develop a desirable soil tilth for seedbeds and crop establishment (Kepner et al., 1978). It is aimed at easing soil compaction, results in soil particle re-arrangement, break-down of aggregates and pore discontinuity, except increase in total porosity, and would thus affect hydraulic conductivity.

According to International Agricultural Engineering Conference and exhibition, (December 1990), field experiments were conducted to study the effect of soil compaction caused by tractor tyres on various soil properties as well as on maize yield in a heavy clay soil. The compaction treatments were given before sowing and after sowing with wheel passes varying from 1 to 5 at a constant tyre inflation pressure. The results were compared with the control having zero passes. It was observed that the dry bulk density and penetration resistance increased with increase in number of wheel passes while porosity showed a decreasing trend. The maize yield was highly affected due to compaction. In both treatments the average reduction in the grain yields due to compaction ranged from 1.5 to 41% compared to control plots. The limitation of this was that, the result was only compared with the plots having zero passes. Several studies have evaluated the effect of tillage on root growth (Anderson, 1987; Barber, 1971). However, there is limited information on the combined effects of tillage practices and compaction under different traffic machinery passes on sandy clay loam planted with maize. The signs of soil compaction can often be seen by observing the crops growing in a compacted soil (OSHA Part 1982.650, 1998). Slow plant emergence, thin stands, un-even early growth, small grain heads, abnormal rooting patterns, shallow or horizontal root growth and reduced nutrients concentration can be a reflection of compaction. Excessive soil compaction impedes root growth and therefore limits the amount of soil explored by roots (Van Lynden, 2000). This, in turn, can decrease the plant's ability to take up nutrients and water. From the standpoint of production, the adverse effect of soil compaction on water flow and storage may be more serious than the direct effect of soil compaction on root growth. However, the objective of this study is to determine the effect of compaction on soil physical properties, such as bulk density, total porosity, micro porosity, macro porosity, and hydraulic conductivity, of sandy clay loam soil in the humid tropical climate of Nigeria on tilled soil and under different traffic machinery passes (Compaction).

Material and Method

Site Description

The research was conducted at the Federal University of Technology, Akure (FUTA) Step B (science and Technology Education Post-Basic) Project Site located on latitude 7^0 10'N and longitude 5^0 05'East. The soil of the study area is a sandy clay loam according to USDA textural classification.

Field Experimentation

Field experiment was conducted to determine the effects of soil compaction under different machinery passes. Field experiments were carried out between the months of March and June, 2011. There were four soil treatments plots; conventional tillage (CT) – plot A, using a tractor-mounted disc plough, compacted soil under five passes - plot B, 10 passes – plot C and 15 passes – plot D. The soil was compacted using heavy duty Mercy Fergusson tractor, model 4355 (3.82 Mg). The four treatments were tested to determine their influence on maize shoot, root growth and yield considering soil properties, such as Bulk density, hydraulic conductivity, total porosity, infiltration, micro and macro–porosity, of tilled and compacted plots. The treatments were replicated three times following a randomized complete block design.

Measurements

Measurements taken included bulk density, total porosity, hydraulic conductivity and crop measurements such as leaf count, root depth, root density, stem diameter, leaf area and maize height.

Bulk Density

Soil bulk density was determined using the method described by Black and Hartge (1986). Soil samples were taken from soil core at depths 0 - 10 cm and 10 – 20 cm using ring cylinders with height 10 cm and diameter 4.8 cm. The samplers were driven vertically into the soil enough to fill the sampler, the sampler and its contents were carefully removed to preserve the natural structure and packing of the soil as best as possible. The soil extending beyond each end of the sample holder was trimmed to ensure soil is contained in exactly the volume of the cylinder. Thus, soil sample volume was established to be the same as the volume of the sampler holder. The soil cores were wrapped in polyethylene, placed in wooden box and transported to the laboratory for analysis. The soil samples were transferred to a container, placed in an oven at 105^0 C, and dried to constant weight. The weight of soil was recorded and bulk density was calculated from the relationship in equation 2.1.

$$\text{Bulk Density } (\rho) = \frac{weight\ of\ oven\ dreid\ soil}{volume\ of\ the\ soil} \qquad (1)$$

Total Porosity

Total porosity (% pore space) was worked out using the same soil samples collected for soil bulk density. According to Suzuki et al., (2004) total porosity of the soil was calculated from bulk density assuming a particle density of 2.65 mg/m^3 with the following formulae:

$$PT = \left[1 - \frac{DS}{DP}\right] \times 100 \qquad (2)$$

$$Mic = \frac{[\ Ww - Wd\ ]}{Vc} \times 100 \qquad (3)$$

Macro porosity (Mac) = PT – Mic (4)

where PT is total porosity (%), Mac is the soil macro porosity (%), Mic is soil micro porosity (%), Ds is the bulk density (g cm-3), Dp is the particle density (g cm^{-3}), Ww and Wd are wet weight and dry weight of samples (g respectively and VC is the volume of soil in the cylinder (cm^{-3}).

Hydraulic Conductivity

The mini disk infiltrometer model was used for measuring soil hydraulic conductivity. The infiltrometer enabled the correct and accurate measurement of the hydraulic conductivity of sandy clay loam soil. The soil hydraulic conductivity was determined following the procedure described in Ale and Manuwa (2011). The process involved using mini disk infiltrometer to measure the hydraulic conductivity of soil under different machinery passes. The bubble chamber was filled up to the ¾ of its volume by running water down the suction control tube or removing the upper stopper. Immediately the upper chamber was full, the suction control tube was slided and the infiltrometer was inverted to remove the bottom elastomer and the porous disk, and the water reservoir was then filled. The position of the end of the tube with respect to the porous disk was carefully set to ensure a zero suction offset while the tube bubbles. After filling of the water reservoir, the bottom elastomer was replaced; making sure the porous disk is firmly in place. No water leaked out when the infiltrometer was held vertically.

Suction rate of 2 cm per seconds was chosen on the field for the soil infiltration measurement on tilled soil and soils under different machinery passes; 5 passes, 10 passes and 15 passes. After the adjustment of the suction rate, the starting water volume was record at time zero, the infiltrometer was then placed to a smooth spot (scraped to make a level surface) on the soil surface. Instantaneously, water begins to leave the lower chamber and infiltrate into the soil at a rate determined by the hydraulic properties of the soil. The infiltration measurements were recorded every 30 seconds for the duration of the experiment in all the plots; plot A (tilled soil), plot B (5 passes), plot C (10 passes) and plot D (15 passes). The infiltrometer was run for not less than 5 minutes on each of the plots so as to ensure the infiltration of between 15-20 mL of water needed for the accurate calculation of hydraulic conductivity. The water reservoir was refilled during the experiment. The data collected in each of the plots were used to determine the water infiltration rates of the soil. The hydraulic conductivity of soil in the entire plot was then calculated using the method of Zhang (1997). The method requires measuring cumulative infiltration vs. time and fitting the results with the function

$$I = C_1 t + C_2 \sqrt{t} \qquad (5)$$

where C_1 (m s^{-1}) and C_2 (m s$^{-1/2}$) are parameters related to hydraulic conductivity and the soil sorptivity, respectively**.**

The hydraulic conductivity of the soil (k) was computed from

$$K = \frac{C_1}{A} \qquad (6)$$

where C_1 is the slope of the curve of the cumulative infiltration vs. the square root of time, and A is a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk. A is computed from:

$$A = \frac{11.65\left(\mathrm{n}^{0.1}-1\right)\exp[2.92(\mathrm{n}-1.9)\alpha \mathrm{h}_0]}{(\alpha \mathrm{r}_0)^{0.91}} \qquad \mathrm{n} \geq 1.9 \qquad (7)$$

$$A = \frac{11.65\left(n^{0.1}-1\right)\exp[7.5(n-1.9)\alpha h_0]}{(\alpha r_0)^{0.91}} \qquad n \quad 1.9 \qquad (8)$$

where *n* and α are the van Genuchten parameters for the soil, r_0 is the disk radius and h_0 is the suction at the disk surface. Since the soil is sandy clay loam, the values for *n* and α according to van Genuchten parameters are 1.48 and 0.059, respectively which were used to calculate the hydraulic conductivity of tilled and compacted soils under different machinery passes.

Crop Measurement

Measurement of the yield components of maize plant such as leaf count, root depth, root density, stem diameter, leaf area and maize height was conducted weekly on each of the plots A, B, C and D from the 3 weeks after planting (3WAP) up to 12 WAP. The measurements were conducted on three representative plants per plot. Number of leaf (NOL) was determined by manual counting of maize leaves on representative plants. Leaf area (AOL) was determined using the equation proposed by Dwyer and Stewart, (1986). Dwyer and Stewart, (1986) reported a general equation to estimate individual leaf area of maize (Zea mays L.):

$$\text{Leaf Area} = L \times W \times A \qquad (9)$$

where LA, L, W, and A are leaf area, leaf length, leaf maximum width and a constant (A = 0.75), respectively.

Rooting depths (RL) were determined by digging of trenches around the soil profile that covers the roots of maize up to the root tip and measuring with steel rule. Maize height (HOP) and stem diameter (SD) were determined using steel rule and venier calliper, respectively. Root density (RD) was determined by sectioning the roots into 3- segment; 0 -2 (RD_1), 2 – 4 (RD_2) and 4 – root tip cm, (RD_3) the roots on each segment was counted and divided by the total number of roots and converted to percentages.

Statistical Analysis

Descriptive statistics such as mean, standard deviation (STD) and standard error (STE) were conducted on infiltration data, and ANOVA and multiple comparisons of mean infiltration and hydraulic conductivities were conducted using the statistical package for social sciences (SPSS)

Results and discussion

Bulk density

Result obtained showed that the bulk density varied among the plots i.e. plot A (tilled plot), plot B (5 passes), plot C (10 passes) and plot D (15 passes), and depths 0 – 10 and 10 – 20 cm. The bulk density was highest (1.90 g cm^{-3}) in plots compacted under 15 to and fro passes of heavy duty equipment (Table 1). Similar observation was made by Al-Ghazal (2002), who reported that soil bulk density increased significantly with an increase in compaction depending on the number of passes of tractor wheel. The results also agreed with the findings of Meek et al.

(1992) who reported an increase in soil bulk density from 1.67 - 1.92 t m^{-3} with a tire pressure of 408 kPa and wheel weight of 2724 kg at moisture contents near field capacity. Similar results were reported by Cassel et al. (1995) who found an increase in soil bulk density for tracked interrow areas of a controlled traffic area. Schuler (1994) also showed that values of bulk density of soil increased with increasing level of compaction by 8 and 10 tons of farm machinery. At tilled plot (plot A), the low bulk density was recorded due to the soil particle that has been broken into smaller aggregates.

Table 1: Mean bulk densities of sandy clay loam soil under different compaction levels

Depth (cm)	Bulk density (g/cm^3)			
	Plot A	Plot B	Plot C	Plot D
0 – 10	1.51	1.63	1.83	1.90
10 – 20	1.53	1.76	1.86	1.90

Porosity

Considerable influence of tillage and compaction on physical properties, such as total porosity, micro porosity and macro porosity of the soil was noticed as shown in Table 2. Plot A (tilled soil), on the average, has the highest total porosity of 42.5 %, which allow root growth and development in the soil and enhanced grain yield compared to the compacted plots. Plot B, on the average, has total porosity of 35.5 %, Plot C, 30.35%, and plot D, 28.3%, which resulted in poor root growth, stunted growth of maize and poor grain production. Maximum micro porosity of 14.3% was obtained at plot A, but decreased to 7.84% in plot D, which shows that micro porosity decreased in the order of soil compaction 5 < 10 < 15 passes. Similar effect was obtained for macro porosity. On the average, plot A has the highest macro porosity of 52.94% and 39.57% in plots under 15 passes of equipment. The effect of compaction was much more noticed within the 0 – 10 cm than 10 – 20 cm depth of soil in plot B, C and D which poses different restrictions to rooting depths of maize.

Table 2: Mean total porosity, micro porosity and micro porosity of soil under different compaction levels

Porosity	Depth (cm)	Plot A	Plot B	Plot C	Plot D
Total Porosity (%)	0 – 10	43	38	30.9	28.3
	10 – 20	42	33	29.8	28.3
Micro porosity (%)	0 – 10	14.3	9.6	8.93	7.84
	10 – 20	17	9.17	7.5	9.17
Macro porosity (%)	0 – 10	28.64	28.38	22.16	20.45
	10 – 20	24.3	23.82	22.22	19.12

Hydraulic Conductivity

At suction of 2 cm s^{-1}, tilled plot had the highest cumulative infiltration rate of 3.46 cm s^{-1} (Table 3), when compared with compacted plots B, C and D, where the highest infiltration rate were 0.88 (Table 4), 0.66 (Table 5) and 0.35 cm s^{-1} (Table 6) respectively. This resulted into significant reduction of soil hydraulic conductivity to 9.3 x 10^{-4} cm s^{-1}, 8.8 x 10^{-4} cm s^{-1} and 8.6 x 10^{-4} cm s^{-1} in plots under 5, 10 and 15 passes, respectively. The cumulative infiltration of soil in plot A, B, C and D are presented in Figures 1, 2, 3, and 4 respectively. The highest soil hydraulic conductivity (at 2 cm suction) in plot A, plot B, plot C and plot D were 9.09 x 10^{-3}, 9.3 x 10^{-4}, 8.8 x 10^{-4} and 8.6 x 10^{-4} cm s^{-1} respectively (Table 7). This observation must have been caused by the effect of tillage, which according to Bouma (1991), Kepner et al. (1978) and Van Lynden (2000), creates macropores that cause saturated and near-saturated hydraulic conductivities to increase considerably and helps to dispose pests or crop residues, which in turn help in the development of a desirable soil tilth for seedbeds and crop establishment.

Table 3: Infiltration data at suction 2cm s^{-1} on plot A (tilled soil)

Time (s)	Sqrt (t)	Volume (mL)	Infiltration (cm)
0	0	76.5	0.00
30	5.48	73	0.22
60	7.75	68	0.53
90	9.49	60.5	1.01
120	10.95	53.5	1.45
150	12.25	45.5	1.95
180	13.42	38.0	2.42
210	14.49	33.0	2.74
240	15.49	28.5	2.02
270	16.43	24.5	2.27
300	17.32	21.5	3.46

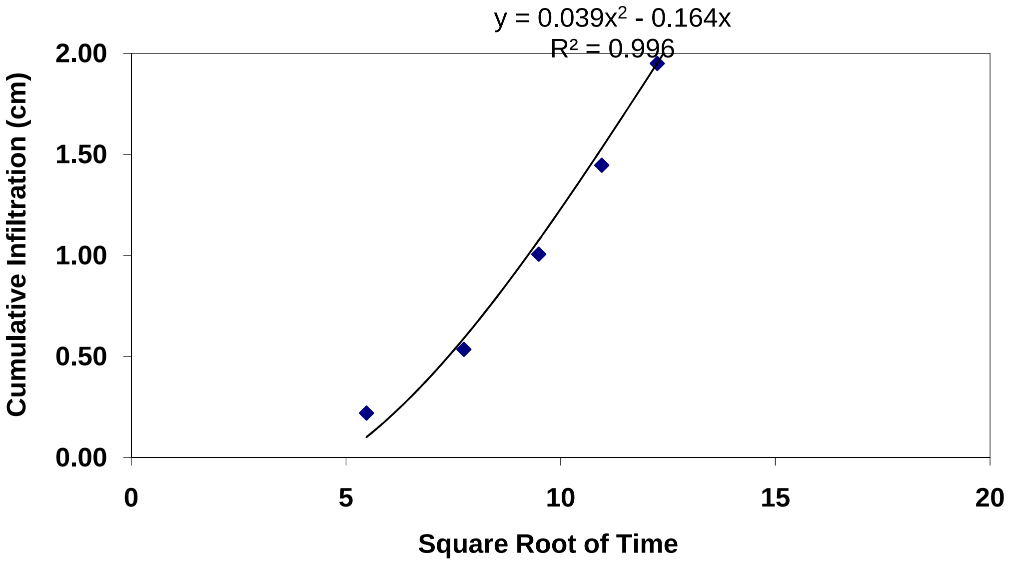
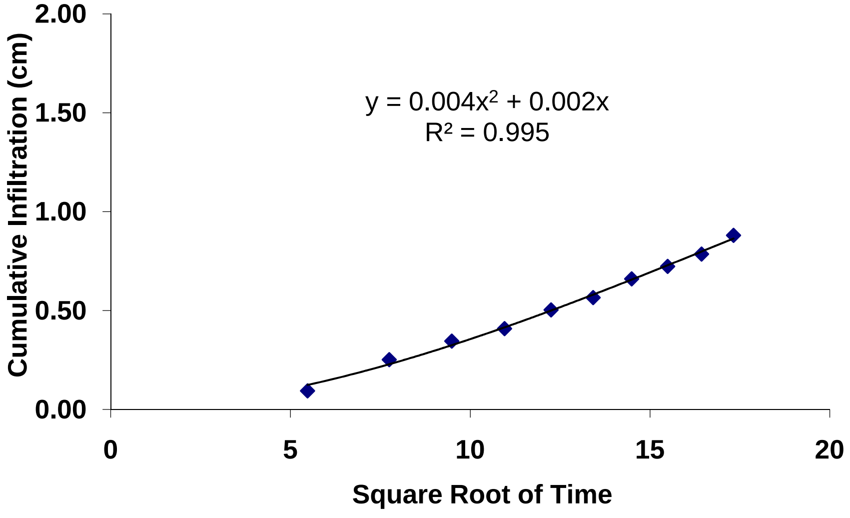


Figure 1: Cumulative infiltration against square root of time at plot A (Tilled soil)

Table 4: Infiltration data at suction 2cm s $^{-1}$ on plot B (5 passes)

Time (s)	Sqrt (t)	Volume (mL)	Infiltration (cm)
0	0	84	0.00
30	5.48	82.5	0.09
60	7.75	80	0.25
90	9.49	78.5	0.35
120	10.95	77.5	0.41
150	12.25	76	0.50
180	13.42	75	0.57
210	14.49	73.5	0.66
240	15.49	72.5	0.72
270	16.43	71.5	0.79
300	17.32	70	**0.88**



3 (5 passes)

Table 5: Infiltration data at suction 2cm s $^{-1}$ on plot C (10 passes)

Time (s)	Sqrt (t)	Volume (mL)	Infiltration (cm)
0	0	65	0.00
30	5.48	63.5	0.09

60	7.75	63.5	0.09
90	9.49	62.9	0.13
120	10.95	62.6	0.15
150	12.25	61.5	0.22
180	13.42	59.7	0.33
210	14.49	58.4	0.42
240	15.49	57.5	0.47
270	16.43	55	0.63
300	17.32	54.5	**0.66**

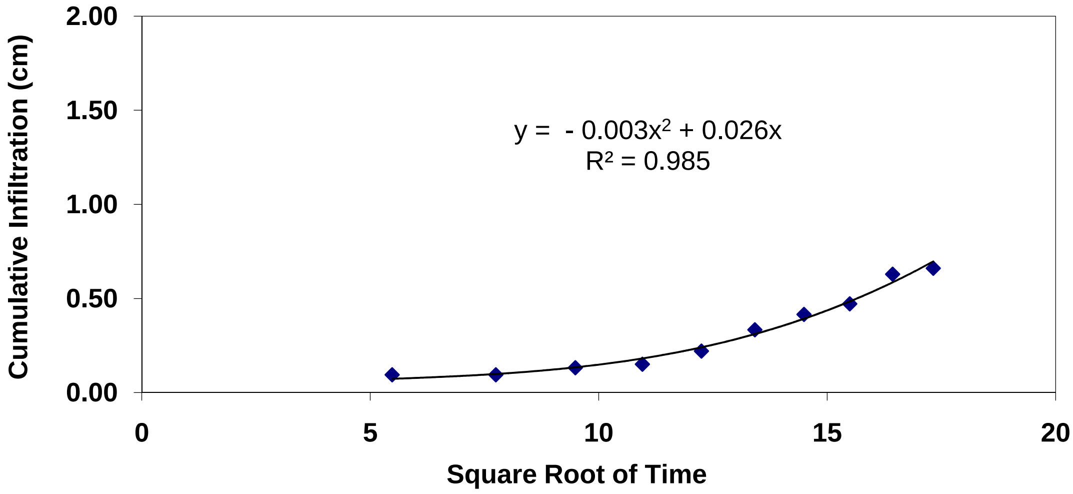


Figure 3: Cumulative infiltration against square root of time at plot C (10 passes)

Table 6: Infiltration data at suction 2cm s^{-1} on plot D (15 passes)

Time (s)	**Sqrt (t)**	**Volume (mL)**	**Infiltration (cm)**
0	0	76.5	0.00
30	5.48	75	0.09
60	7.75	74.5	0.13
90	9.49	74.5	0.13
120	10.95	74	0.16
150	12.25	73.8	0.17
180	13.42	73.5	0.19
210	14.49	73	0.22
240	15.49	72.5	0.025
270	16.43	71.5	0.31
300	17.32	71	**0.35**

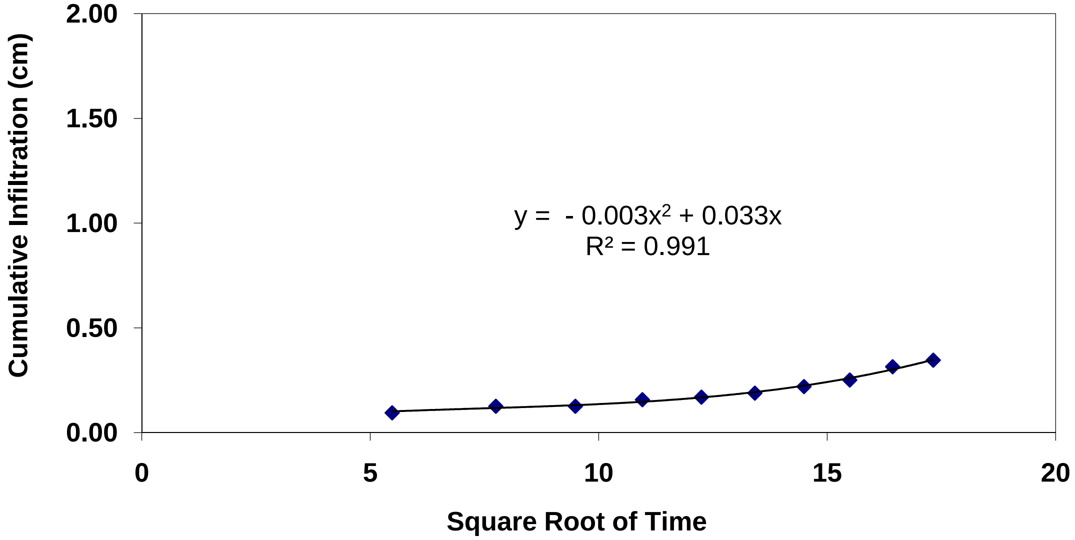


Figure 4: Cumulative infiltration against square root of time at plot D (15 passes)

Table 7: Hydraulic conductivity at suction 2cm s $^{-1}$ on all the plots

	Hydraulic conductivity (cms-1)			
	Plot A	Plot B	Plot C	Plot D
	9.09×10^{-3}	9.14×10^{-4}	8.9×10^{-4}	8.7×10^{-4}
	10.04×10^{-3}	9.46×10^{-4}	9.0×10^{-4}	8.6×10^{-4}
	8.14×10^{-3}	9.3×10^{-4}	8.5×10^{-4}	8.5×10^{-4}
Mean	9.09×10^{-3}	9.3×10^{-4}	8.8×10^{-4}	8.6×10^{-4}

Crop Measurement

At the 9th week after planting, plot A had the highest cumulative number of leaves (11) as shown in Table 8, area of leaves (854.8 cm^2), stem diameter (21.5 mm), height of plant (165.6 cm^2), length of root (21.4 cm) and root density RD_1 (29.4%), RD_2 (19.6 %) and RD_3 (50.9%) compared to the compacted plots. It was observed in plot A that, the root density at the 4 cm depth to the root tip was 50.9 %, which indicated the root potential to grow and penetrate into the soil and consequently how effective the plant make use of soil water and nutrient supplies for growth and production (Taylor and Gardner, 1960a). However, observations were different in compacted plots (Tables 9 – 11). Plot B which had 5 machinery traffic passes had number of leaves (9), area of leaves (539.5 cm^2), stem diameter (17.8 mm), height of plant (94.6 cm^2), length of root (14.7cm) and root density RD_1(45%), RD_2 (27 %) and RD_3 (27%) , At plot C (10 machinery traffic passes), the mean number of leaves was 8, area of leaves (466.62 cm^2), stem diameter (14.8 mm), height of plant (94.6 cm^2), length of root (14.cm) and root density RD_1 (55%), RD_2 (27.8 %) and RD_3 (16.7%) and at plot D 15 (traffic machinery passes), the lowest value was recorded; number of leaves (7), area of leaves (416.16 cm^2), stem diameter (13.8

mm), height of plant (82.6 cm^2), length of root (12.4cm) and root density RD_1 (50%), RD_2 (31 %) and RD_3 (18 %). The root density in plots B, C and D were higher at upper layer of the plant root just a little depth below the surface layer (0 – 2 and 2 – 4 cm) and lower from the 4 cm depth to the root tip. This was caused by soil compaction, which led to the higher concentration of roots in the upper root layers and reduced roots in the deeper layers. In strongly compacted soil, such root distribution can be partly attributed to the horizontal orientation of pores (Slowinska-Jurkiewicz and Domzal, 1999). Deeper but reduced root growth was attributed to excessive mechanical impedance, especially in dry seasons and insufficient aeration (air-filled porosity <10%) in wet seasons (Lipiec and Håkansson, 2000.) and (Medvedev et al., 2000).The crop parameters decreased with increased soil compaction (Taylor et al., 1964) and this must have resulted from root restriction caused by excessive soil strength that occur largely as a result of compaction. Better rooting was observed in loose soil of plot A (tilled soil), which can by warmer top layer compared to compacted soil early in the growing season (Lipiec et al., 1991).

Table 8: Means of crop measurement at plot A (tilled soil)

Week	NOL	AOL (cm^2)	SD (mm)	HOP (cm)	LOR (cm)	RD1 (%)	RD2 (%)	RD3 (%)
3th	7	21	6.4	21	8.6	37.5	25	25
4th	7	28.56	9.3	29	9.1	45.5	36.4	18.2
5th	8	108.3	10.8	32.8	10.4	36.8	26.3	21.1
6th	9	213.6	15.5	58.8	11.6	58.3	25	16.7
7th	9	578.5	18	95	13.4	61	22	16.7
8th	10	777.4	19.8	135	18.3	47.8	19	32.6
9th	11	854.8	21.5	165.6	21.4	29.4	19.6	50.9
10th	11	894.3	22.8	187.6	22.7	28.8	19.7	51.9
11th	11	982.8	23.1	194	23.9	34.4	17.2	48.4
12th	11	1018.64	23.5	197	24.4	33	18	48.5

NOL – number of leaves, AOL – area of leaves, SD – stem diameter, HOP – height of plant, LOR – length of root, RD – root density

Table 9: Cumulative data for crop measurement at compacted plot B (5 passes)

Week	NOL	AOL (cm^2)	SD (mm)	HOP (cm)	LOR (cm)	RD1 (%)	RD2 (%)	RD3 (%)
3th	4	19.46	5.6	14	8.2	62.5	25	12.5
4th	5	24.16	8.3	25.4	8.7	55.6	22	22
5th	5	79.36	9.8	26.8	9.2	53.8	15.3	30
6th	6	183.54	12.5	42.1	10.1	50	21.4	28.5
7th	8	383.15	14.9	62	10.8	50	25	25
8th	9	480	15.2	92.6	13.2	44	33	22
9th	9	539.5	17.8	94.6	14.7	45	27	27
10th	9	566.06	18	158.5	18.3	40	28	32

11th	9	631.9	18.9	161.5	18.8	28	20	51
12th	9	640	19	162.7	18.9	28	20	51

NOL – number of leaves, AOL – area of leaves, SD – stem diameter, HOP – height of plant, LOR – length of root, RD – root density

Table 10: Cumulative data for crop measurement at compacted plot C (10 passes)

Week	NOL	AOL (cm^2)	SD (mm)	HOP (cm)	LOR (cm)	RD1 (%)	RD2 (%)	RD3 (%)
3th	4	15.4	4.9	15	7.4	66.7	22.2	11.1
4th	5	43.94	5.7	23.9	8.4	54.5	36	9.09
5th	5	68.52	9.05	26.1	8.9	54.5	36	9.09
6th	7	148.2	11.7	41	9.1	54.5	36	9.09
7th	7	22.52	13.3	48.6	9.8	50	33	16.7
8th	8	408.25	14.5	72.5	12.1	62.5	25	12.5
9th	8	466.62	14.8	94.6	14.0	55.6	27.8	16.7
10th	9	493.75	16.2	122.6	15.7	55.6	27.8	16.7
11th	9	576.24	16.7	140.5	16.4	42.8	35.7	21.4
12th	9	585.65	16.9	142.5	16.9	42.8	35.7	21.4

NOL – number of leaves, AOL – area of leaves, SD – stem diameter, HOP – height of plant, LOR – length of root, RD – root density

Table 11: Cumulative data for crop measurement at compacted plot D (15 passes)

Week	NOL	AOL (cm^2)	SD (mm)	HOP (cm)	LOR (cm)	RD1 (%)	RD2 (%)	RD3 (%)
3th	4	12.84	4.2	14.1	6.7	62.5	25	12.5
4th	4	27	5.5	21.1	6.9	55.6	22	22
5th	5	67.2	8.53	24.6	8.2	50	30	20
6th	6	135.42	9.9	36.7	8.4	50	30	20
7th	6	226.38	12.9	45.1	9.1	45	27	27
8th	7	364.32	13	67.4	11.7	41.7	33	25
9th	7	416.16	13.2	82.6	12.4	50	31	18
10th	9	423.5	16	116.5	13.9	50	31	18
11th	9	467.2	17.2	128.6	14.9	47.6	33	19
12th	9	488.4	17.2	130	15.1	41.3	37.9	20.6

NOL – number of leaves, AOL – area of leaves, SD – stem diameter, HOP – height of plant, LOR – length of root, RD – root density

Conclusion

Plot A (tilled soil) has the lowest bulk density of (1.51g cm^{-3}) but increased from 1.63 g cm^{-3} in plot B (5 passes) to 1.90 g cm^{-3} in plot D (15 passes), which implies, the more compaction of the soil is, the greater the bulk density. Plot A (tilled soil) has the highest total porosity (The amount of "void" space within sediment) and also highest cumulative infiltration rate, which resulted to the highest hydraulic conductivity when compared to the compacted plots (B, C and D under 5, 10 and 15 traffic machinery passes, respectively). An increase in soil compactness resulted to decreased root length, higher concentration of roots in the upper soil layer, most especially within the 0 – 4 cm soil depth and increased distance between successive root layers. Crop yield increased in tilled soil (plot A) and decreased in compacted plots. Yield reduction in compacted soil accounted for smaller leaf area of maize.

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