INFILTRATION THROUGH TRAFFIC COMPACTED SOIL

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ABSTRACT

Infiltration tests were conducted on a sandy loam soil subjected to three levels of compaction using 5, 7, and 12 tractor passes with a tractor weighing 40 kN. Results indicated that 5 tractor passes induced average soil bulk density of 1.72 Mgm^{-3}, hydraulic conductivity of 1.74 x 10^{-6} cm/s, and penetration resistance of 479.55 kPa at a moisture content of 14.91 %. The 7 tractor passes produced average bulk density of 1.81 Mgm^{-3}, hydraulic conductivity of 1.24 x 10^{-5} cm/s and penetration resistance of 514.7 kPa at a moisture content of 12.54 %, while the 12 tractor passes produced average bulk density of 1.91 Mgm^{-3}, hydraulic conductivity of 1.69 x 10^{-5} cm/s, and penetration resistance of 474.35 kPa, at a moisture content of 12.11 %. The findings revealed that the number of tractor passes imposed did not significantly ($p> 0.05$) influence water infiltration into the soil. However, soil strength increased with compaction without a corresponding decrease in infiltration. It is concluded that soil type, soil moisture content and machinery capacity are crucial factors in the infiltration process.

KEYWORDS: Tractor capacity, tractor passes, soil strength, soil water intake.

1. INTRODUCTION

The quest and urge to make agriculture less rigorous, more interesting and to reduce the drudgery associated with agricultural practices gave rise to the mechanization of agriculture. As useful and time-efficient as agricultural machinery and equipment may be in the execution of field operations, the heavy weight of these equipment results to soil compaction which has adverse effects on the rate of water infiltration into soils.

Compaction increases the bulk density of soil due to a decrease in the number and volume of large pores, which in turn alters aeration, water infiltration, and hydraulic conductivity, and increases soil strength (Blouin et al. 2008). The detrimental effects of compaction are not universal, and are affected by soil type (Gomez et al. 2002) and the level of compaction (Sanchez et al. 2006). Low soil oxygen level caused by soil compaction is the primary factor limiting plant growth. Soil compaction is difficult to correct, being the resulting effect from field traffic of farm machinery. Excessively compacted soil results in problems such as poor root penetration, reduced internal soil drainage, reduced rainfall infiltration, and lack of soil aeration from larger macro pores. According to Soanne and Van Ouwerkerk (1994), soil compaction is responsible for the degradation of an estimated 83 million hectares of land worldwide. Traffic over the soil is the major contributor to soil compaction e.g. a moist soil could reach 75% maximum compaction the first time it is stepped on and 90% by the fourth time it is stepped on (Whiting *et al.* 2010). According to FAO (2008), soil compaction can lead to reduction in the pore size and spaces through which air and water flow through the soil thereby leading to runoff, erosion and causing emergence of agricultural wastelands.

Studies have shown that most soil compaction at the urban lot scale leads to increased storm water runoff and this is particularly crucial in low impact development strategies where storm water is intended to infiltrate rather than flow through a traditional network to a detention basin (Pitt *et al*. 2002). Therefore, identifying the presence of compaction is crucial to understanding its effect on the infiltration rate and relating such to crop yield and environmental problems of runoff and erosion.

Soil can be an excellent temporary storage medium for water, depending on the type and condition of the soil. Infiltration rate and cumulative infiltration are two parameters commonly used in evaluating the infiltration characteristics of a soil; infiltration being a dynamic process, variable in time and space plays a vital role in the replenishment of soil water which is responsible for the growth and development of crops (Ahaneku, 2011). Decrease in infiltration or increase in saturation above a compacted layer can also cause nutrient deficiencies in crops. Either condition can result in anaerobic conditions which reduce biological activity and fertilizer use efficiencies (Duike 2004).

There has been relatively little research done on the effects of traffic-induced compaction on water infiltration in Nigerian soil. The essence of this study was to determine the effects of different levels of compaction by tractor passes on infiltration rates and physical properties of a sandy loam soil.

2. MATERIALS AND METHODS

2.1 Description of Study Site

The study site is the Federal University of Technology, Gidan Kwano campus, Minna, Niger state, Nigeria. The site was relatively undisturbed as no cultural or tillage activities had been carried-out on it for six months prior to the experiment.

Minna is in the southern Guinea Savannah vegetation of Nigeria (latitude 09 ^{0} 31.8' N and longitude 06 ^{0} 27.1'E). Niger state lies in the semi-arid zone and has two distinct seasons, wet and dry season. The wet season starts in April and ends in October with the maximum annual rainfall recorded in August. Minna has a mean annual rainfall of 1220 mm. The average maximum and minimum temperature for Minna is 31 ^{0}C and 28 ^{0}C, respectively with annual relative humidity of 59 %.

2.2 Specifications of Tractor Used

The specifications of the tractor used to achieve compaction is given in Table 1

Table 1.Tractor specifications

Tractor Model	Steyr 8075
Engine Type	4-cylinder diesel engine
Weight	Maximum gross weight: 4000kg Maximum gross axle weight: 1500kg
Effective output	64hp (47.7kW)
Tyre inflation pressure	Front wheel: 275.79 kPa Rear wheel: 103.42 kPa
Speed of operation	10km/hr
Gear selection	Gear 2 (high)

2.3 Compaction Test

The experimental site was divided into three plots for the purpose of the compaction test. The treatment consisted of three levels of compaction: 5 tractor passes, 7 tractor passes, and 12 tractor passes, with one level imposed on each of the three plots. A tractor of known specification was used to achieve the compaction by driving it between two points at the specified number of passes.

2.4 Determination of Infiltration rate

Prior to the tests, soil samples were collected from the site and taken to the laboratory for determination of soil physical properties like bulk density, particle density, moisture content, porosity and the soil textural class.

Infiltration tests were carried-out on each level of compaction at varied time intervals within a two-hour frame with three (3) replicates at each level of compaction. The infiltration measurement was done using double ring infiltrometers. The inner ring of the infiltrometer is 34cm in diameter, while the outer ring has a diameter of 65cm with a height of 25cm. The rings were inserted into the soil and left overnight and the infiltration tests carried out the next day. The field data was used to determine the infiltration rate, cumulative infiltration and the average infiltration rate of the soil.

2.5 Determination of Soil Penetration Resistance

Soil penetration resistance was measured in each plot in three replicates using a hand-held penetrometer. The shank with a cross-sectional area of 4.84 cm^2 was used for 5 passes level of compaction, while shank with a cross-sectional area of 6.45 cm^2 was used for 7 passes and 12 passes compaction, respectively.

2.6 Soil Texture and Moisture Content determination

Soil texture was determined by the hydrometer method, while soil moisture content was determined gravimetrically. Soil samples were collected from the field after compaction and taken to the laboratory; the soil was weighed and placed in the oven and heated at 105 ^{0}C for 24 hours after which it was weighed again. The change in mass represents the moisture content.

2.7 Soil Bulk Density Determination

Soil bulk density was determined from oven dried undisturbed cores as mass per volume of oven dried soil.

2.8 Soil Porosity Determination

Porosity was determined using the relationship between bulk density and particle density as:

$$\% \text{ Porosity} = 1 - \left[\frac{Bulk\ density}{Particle\ density}\right] \times 100 \qquad (1)$$

2.9 Determination of Field Capacity

Three 65 cm infiltrometer rings were used to pond water on each of the compacted sites and left undisturbed for 24 hours. This was done to allow the water within the ring to drain through the soil profile completely after which soil samples were taken from each of the locations and oven-dried for 24 hours to determine the average moisture content.

2.10 Determination of Hydraulic Conductivity

The hydraulic conductivities of the soil at the three levels of compaction were determined in the laboratory using constant-head permeameter method (Israelsen and Hansen, 1962).

2.11 Data Analyses

The SPSS IBM version 20 software was used for the statistical analyses. To test the equality of means of the treatment parameters, one-way analyses of variance (ANOVA) was applied and mean comparison evaluated using Chi-square test.

3. RESULTS AND DISCUSSION

3.1 Effect of level of Compaction on Infiltration and Soil Physical Properties

The soil particle size distribution revealed the soil texture at the experimental site to be sandy loam (Table 2). Infiltration tests carried out on 5 tractor passes plot showed that final infiltration rate ranged from 1.5 mm/hr to 2.75 mm/hr. Soil penetration resistance of between 466.20 kPa and 492.50 kPa was observed with average soil moisture content of 14.91 % and bulk density of 1.72 Mgm^{-3}. Observed infiltration rate for the 7 tractor passes ranged from 7.75 mm/hr to 17.5 mm/hr. The penetration resistance was found to be between 509.5 kPa and 520.2 kPa at an average soil moisture content of 12.54 % and bulk density range of 1.81 Mgm^{-3}. Soil compaction for the 12 tractor passes yielded final infiltration rate ranging from 12 mm/hr to 18.75 mm/hr. The soil penetration resistance was found to be between 471.5 kPa and 477.2 kPa at average moisture of 12.11 % and bulk density of 1.91 Mgm^{-3}.

Table 2.Particle size distribution of test soil

Site	Compaction Level	Sand (%)	Silt (%)	Clay (%)	Textural Class
A	5 Passes	68.62	17.90	13.48	Sandy Loam
B	7 Passes	71.52	16.40	12.08	Sandy Loam
C	12 Passes	66.12	20.20	13.68	Sandy Loam

3.2 Impact of Compaction on Infiltration and Soil Properties

The values of the control parameters are presented in Table 3. Comparison of means of soil properties are shown in Table 4, while the average infiltration rates and cumulative infiltration are shown in Figs.1 and 2, respectively. As can be seen from Table 4, no significant difference was found in all the parameters with the treatments. The result of the infiltration tests showed a lot of variability, with the lowest level of compaction (5 tractor passes compacted soil), having the least infiltration rate of between1.5 to 2.75 mm/hr, while the highest level of compaction (12 tractor passes) exhibiting higher infiltration rate of between 12 mm/hr to 18.75 mm/hr. The observed cumulative infiltration for the 5 tractor passes compacted site ranged between 3 mm to 5.5 mm, while those for the 7 and 12 tractor passes were 15.5 mm to 35 mm and 24 mm to 37.5 mm, respectively. The median initial infiltration rate for 5 passes compacted soil is 3.5 mm/hr. The 7 tractor passes compacted soil had initial infiltration rate ranging from 10.5 mm/hr to 22 mm/hr, while that of 12 passes compacted soil ranged from 16 to 22 mm/hr. This shows that within the first hour, the 12 passes compacted soil had a higher initial infiltration rate than the 5 and 7 passes compacted plots which was not anticipated.

Table 3. Values of control parameters

MC (%)	FC (%)	IR ($mmhr^{-1}$)	HC ($\times10^{-6}$ cms^{-1})	PR (kPa)	BD (Mgm^{-3})	Porosity (%)
18.24	22.44	21.47	1410.00	349.40	1.34	41.50

MC = Moisture content, FC= Field capacity, IR = Infiltration rate, HC = Hydraulic conductivity, PR = Penetration resistance, BD = Bulk density

Table 4. Comparison of mean soil properties and their standard deviations in the studied treatments

Number of Tractor Passes	MC (%)	IR (mm hr^{-1})	HC x 10^{-6} (cm s^{-1})	PR (kPa)	BD (Mg m^{-3})	Porosity (%)
5	14.91±2.23	2.17±0.14	1.74±0.03	479.55±45.01	1.72±0.04	34.34±0.30
7	12.54±2.00	12.00±0.19	12.40±0.51	514.70±13.90	1.81±0.03	31.70±0.01
12	12.11±1.08	15.92±0.74	16.90±0.11	474.35±2.28	1.91±0.04	27.92±0.05
Sig. (2-tailed)	0.076	0.083	0.072	0.060	0.063	0.56

MC = Moisture content, IR = Infiltration rate, HC = Hydraulic conductivity,
PR = Penetration resistance, BD = Bulk density

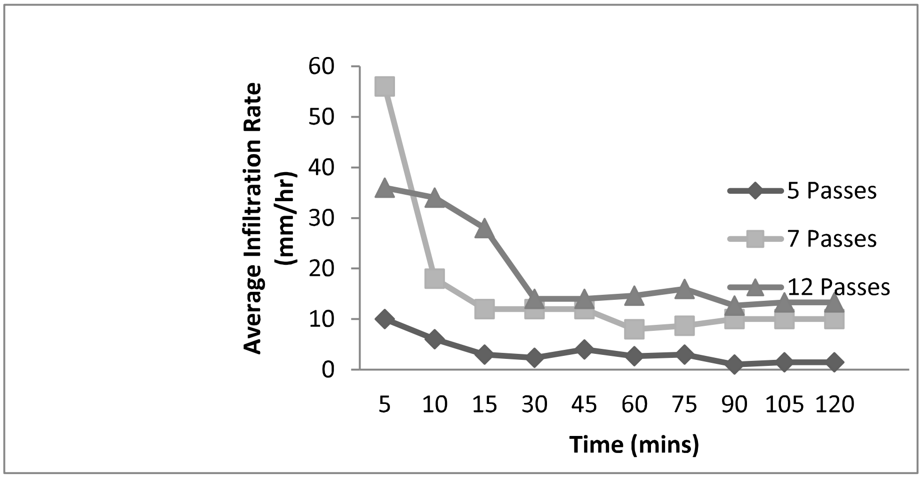

Fig. 1. Average infiltration rates for 5, 7, 12 Passes

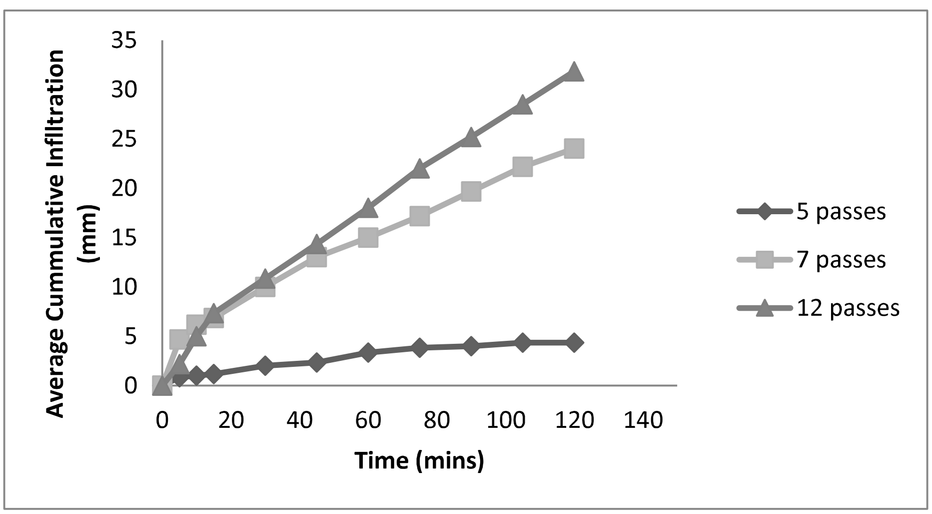

Fig. 2. Average cumulative infiltration for 5, 7, and 12 Passes

The observed results do not mean that compaction is a favourable phenomenon which enhances infiltration. Table 2 shows that there was more silt in the plot with 12 tractor passes than in the other two plots. The higher infiltration rate observed in the 12 tractor passes could probably be due to the heterogeneity of the soil (having more sand and silt in the lower horizon of the 12 tractor passes plot than in the other two plots). Also, compaction at near field capacity as was the case with the 5 tractor passes could reduce infiltration rates (Akram and Kemper, 1979).

According to Pitt et al. (2001), a more detailed testing could explain some of the large variations observed. During the first hour it was also observed that there was no movement of water at certain intervals which may be due to subsurface compaction that occurred during the tractor passes or as a result of activities performed on the land years before the tests, as a reliable history of the site, two1 or more years prior to the tests was not available. After two hours of testing, the average final infiltration rates were 2.25, 12 and 15.92 mm/hr for the 5, 7 and 12 tractor passes compacted plots, respectively. The area with the poorest drainage (5 tractor passes compacted plot) had the least infiltration rate. The 12 tractor passes compacted plot showed the highest infiltration rate for the three replicates (17, 18.75 and 12 mm/hr).

Water infiltration into the soil was more during the first hour than in the second hour for all the replicates which conformed to literature (Siyal *et al.* 2002) that more water will be infiltrated in the early minutes of an infiltration test and as the time increases, the amount of water infiltrated reduces until a constant water level is attained.

The compaction at the three locations was found to reduce the infiltration rate from 21.47 mm/hr before compaction to an average of 2.17 mm/hr for the 5 passes making the soil behave like clay with a steady infiltration rate ranging from 1 to 5 mm/hr as shown in Fig.1. Average infiltration rates of 12 mm/hr and 15.92 mm/hr in the 7 tractor passes and the 12 passes, respectively showed infiltration rates characteristics of loam (Fig.1). The variability and inconsistency observed during the infiltration tests can be reduced if more tests are conducted and a smaller diameter infiltrometer ring used as recommended by Pitt et al. (2001).

Penetration resistance of soils is dependent on the moisture content of the soil. The values for the compacted soils were very high and may impact negatively on root penetration.

The bulk densities for the three compacted sites at 5, 7, and 12 tractor passes were found to have average values of 1.74 Mgm^{-3}, 1.81 Mgm^{-3}, and 1.91 Mgm^{-3}, respectively, in relation to 1.34 Mgm^{-3} for the control location. Infiltration rate was affected by the high bulk densities observed. In spite of this, the 12 tractor passes compacted soil showed the highest infiltration rate with an average value of 15.92 mm/hr. The observed results do not suggest that the more the traffic on soils, the less the infiltration rate. Similar findings were reported by Whiting *et al.* (2010). The observed results may be due to the fact that the soil was compacted within accepted moisture range for sandy loam soil (less than 28.2% dry basis) and the tractor capacity used was within the established safe loads (60kN) for sandy loam fields as reported by Kanali et al. (1997). Notwithstanding the observed infiltration figures, the high bulk densities may limit root penetration in accord with The Cooperative Soil Survey (2011) report that bulk density from 1.6 Mgm^{-3} will have severe negative impact on plant growth.

3.3 Compaction, Soil Moisture and Hydraulic Conductivity Relationship

As with infiltration rate, the hydraulic conductivities obtained at the three levels of compaction also indicate that the 5 tractor passes compacted soil with bulk density of 1.74 Mgm^{-3} had the least value of hydraulic conductivity (1.74×10^{-6} cm/s), while 7 tractor passes with bulk density of 1.81 Mgm^{-3} had a value of 1.24×10^{-5} cm/s, and the 12 tractor passes with bulk density of 1.91 Mgm^{-3} had a value of 1.69×10^{-5} cm/s. According to Kooistra *et al.* (1984), the higher the bulk densities of soils, the lesser the hydraulic conductivity, but this is not always true because clay with a bulk density of about 1.4 Mgm^{-3} can have hydraulic conductivity of between 10^{-9} to 10^{-6} cm/s (The Cooperative Soil Survey, 2011). The 5 tractor passes compacted soil with soil moisture of 14.91 % had the highest value of conductivity closest to the field of capacity of the soil (23.44 %), indicating that compaction was carried-out near field capacity leading to the reduced infiltration rate observed in that treatment with an average rate of 2.17 mm/hr after 120 minutes. The 7 tractor passes compacted soil with moisture content at 12.54 % had a higher observed average infiltration rate of 12 mm/hr after two hours. The 12 tractor passes with the least moisture content (12.11 %), had the highest average infiltration rate of 15.92 mm/hr at the end of two hours. The results show that soil moisture content before compaction strongly affected soil strength properties. The outcome of this study is in agreement with the findings of Blouin et al. (2008) in a similar study.

4. CONCLUSIONS

The study evaluated the effects of traffic compaction on water infiltration and soil physical properties of a sandy loam soil. Results of the study showed that in all parameters measured, no significant difference was found between the treatments. However, there was appreciable increase in soil strength properties (bulk density and penetration resistance) with compaction. The findings of this study suggest that provided the soil is not too wet and the axle load of the machinery used in the field is within established limits for a particular soil type, compaction may not limit infiltration adversely within the limits of this experiment). With the results of this study, farm managers may make informed decisions on the effects of traffic compaction on soil productivity.

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REFERENCES

Ahaneku I.E., 2011. Infiltration characteristics of two major agricultural soils in north central Nigeria. Agricultural Science Research Journals 1(7): 166-171

Akram, M. and Kemper W. D. 1979. Infiltration of soils as affected by the pressure and water content at the time of compaction. Soil Service Society American Journal. 43: 1080-1086.

Blouin V.M., Schmidt M.G., Bulmer C.E., Krzic M., 2008. Effects of Compaction and Water Content on Lodgepole Pine Seedling Growth. Forest Ecology and Management 255:2444-2452.

Duiker S. W., 2004. Effects of soil compaction. Retrieved from www.cas.psu.edu (accessed June 6, 2011).

FAO, 2008. Retrieved from http://www.fao.com/landandwater. (accessed July 7, 2011).

Gomez A., Powers, R.F., Singer, M.J., Howarth, W.R., 2002. Soil Compaction Effects on Growth of Young Ponderosa Pine Following Litter Removal in California's Sierra Nevada. Soil Sci. Soc. Am. J. 66, 1334-1343.

Israelsen O.W.and Hansen, V.E., 1962. Irrigation Principles and Practices. John Wiley and Sons, Inc., New York.

Kanali C. L, Kaumbutho P.G., Maende C.M. and Kamau,J. 1997. Journal of Terramechanics, Vol. 34, No. 2, pp. 127-140.

Kooistra M.J., Bouma J., Boersma O.H., Jager A., 1984. Physical and morphological characterisation of undisturbed plough pans in a sandy loam soil. Soil Tillage Research 4:405-417

Pitt R., Shen-En Chen, Shirley C., 2001. Infiltration through compacted urban soils and effects on biofiltration design. Presented at the Low Impact Development Roundtable Conference, Baltimore, MD, July, 2001.

Pitt R., Shen-En Chen, Shirley C., 2002. Compacted urban soils effects on infiltration and bioretention stormwater control designs. Presented at the 9th International Conference on urban Drainage. IAHR, IWA, EWRI and ASCE. Portland Oregon, September 8-13, 2002

Sanchez F.G., Scott, D.A., Ludovici, K.H., 2006. Negligible Effects of Severe Organic Matter Removal and Soil Compaction on Loblolly Pine Growth over 10 Years. For. Ecol. Manage. 227, 145-154.

Siyal A.G., Oad, F.C., Samo M. A., Zia-Ul-Hassan, Oad N.L., 2002. Effect of compactions on infiltration characteristics of soil. Asian Journal of Plant Sciences. 1 (1): 3-4.

Soanne B. D., Ourwerkerk C. Van., 1994. Soil compaction problems in world agriculture. Scottish Centre of Agricultural Engineering, SAC, Penicuik, U.K. and Institute for soil fertility research (IB-DLO), Haren Gn, Netherlands. pp 2

The Cooperative Soil Survey, 2011. Soil Bulk Density-Physical Properties. Retrieved from soilsurvey.org accessed on 13 November, 2011.
Whiting D, Adrian C, Carl W Reeder J., 2010. CMG Garden Notes #215. Colorado State University Extension. Retrieved from www.cmg.colostate.edu (accessed June 6, 2011).