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Groundnut (*Arachis hypogea* L) Growth and Yield as affected by Soil Compaction

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Abstract

Soil compaction increases soil strength which can result in decreasing soil aeration, hydraulic conductivity, infiltration rate and crop yield. A green-house experiment was carried out at the University of Ibadan to examine the effect of soil compaction on root growth and yield of groundnut. Five kilograms of soil occupying a height of 12.9cm in the pot was compressed to heights of 12.7cm, 12.6cm, 12.4cm, 12.3cm, 11.8cm, and 11.5cm resulting in bulk densities of 1.1, 1.2, 1.3, 1.4, 1.5, 1.6 and 1.7 Mg m^{-3} respectively. It was replicated five times. The sowing of two seeds of groundnut per pot was done before placing the loads on the soils. The results indicated that soil compaction had significant (P=0.001) effect on number of roots and root length with soil bulk density of 1.4Mg m^{-3} giving the best with respect to the two plant parameters. Total fresh biomass at harvest (12WAP) was higher in 1.4 Mgm^{-3} than in 1.7, 1.6, 1.5, 1.3, 1.2 and 1.1Mg m^{-3} bulk densities by 30.6, 28.6, 20.4, 22.5, 28.6 and 34.7% respectively. However, soil with bulk density of 1.3 Mgm^{-3} had significantly higher pod dry weight and seeds fresh weight than other treatments. The number of groundnut seeds per pot obtained from the soils with bulk densities of 1.7, 1.6, 1.5 and 1.3Mg m^{-3} were however not significantly different from one another but were significantly higher than groundnut seeds from soils with 1.2 and 1.1 Mg m^{-3} bulk densities. The force of harvesting groundnut increases with increase in soil compaction ($R^2 = 0.55$) requiring more energy to uproot groundnut from compacted soil. Soil bulk densities of 1.5, 1.4 and 1.3 Mg m^{-3} gave the best results with respect to root density, root elongation, weight of pods and seeds. Therefore, compressing the type of soil used in this experiment beyond 1.3 Mg m^{-3} could have adverse effects on root growth and yield of groundnut. Farmers should be discouraged from using heavy implements to cultivate their farms.

Key words: *Soil compaction, Bulk density, Force of harvesting, Root growth, Groundnut pods and seeds*

Introduction

Soil compaction is defined as the process of increasing the density of soil by packing the particles closer together, causing a reduction in the volume of air (Wierman *et al.*, 1999). Soil compaction is seen as a serious agricultural problem because of its negative effects on soil properties and crops grown on the soil. Carman (2002) stated that soil compaction directly affects traffic-ability, soil workability and harvest-ability of root crops. According to Al-Adawi and Reeder (1996), many soil properties are negatively affected by compaction. Compaction reduces soil pore and may increase its shearing strength. It reduces transmission of water and air through the soil profile, changes the heat capacity, and increases surface run-off and potential erosion. When a soil is compacted, the mechanical strength of the soil is increased, the water holding capacity is lowered and water infiltration capacity is reduced (Carman, 2002). These changes can significantly reduce crop yield. The reduction can range from effect on seed germination and emergence (Boone *et al.,* 1994), shallow root system and malformed roots (Mamman and Ohu, 1997) and growth depression (Lowery and Schuller, 1994) to yield reduction (Lipiec *et al.,* 1991). The negative effects of compaction on soil and crops are therefore many and varied.

Soil compaction is a problem in many agricultural soils because fields are trafficked and tilled when soils are in conditions prone to compaction (Hakansson and Reeder, 1994). The first pass of a wheel on loose soil does 80 percent of the total compaction resulting from four passes (Shafi *et al.,* 1994). The most common causes of agricultural compaction are trampling by livestock, pressure imposed by tractor tyres, tillage implements, raindrop impact and minimal crop rotation and plants with large root or tuber (Boone *et al.,* 1994). Out of all the causes of soil compaction, the one caused by agricultural machinery which was grouped into tillage-induced and traffic-induced compaction, was singled out as being responsible for most of the soil compaction (Ohu *et al.,* 2006). Compaction caused by these machines, especially the ones below the plow layer, is of more concern since it is not easily self-correcting and is therefore difficult if not impossible to totally reverse or correct it(Shafi *et al.,* 1994).

Today, soil compaction is recognized as an agricultural problem of increasing severity as it plagues many parts of the world and affects many different crops (Carman, 2002). Many areas now have compacted sub-soils due to increased soil working and poor timing of field operations (Alakuku and Elonen, 1995). Lipiee and Stepniewski (1995) stated that though mechanization of the traditional planting land has helped to bring large areas under cultivation, this has been brought about with a complete disregard to soil characteristics and their constraints. Soil compaction caused by vehicular trafficking is a severe problem in tropical arable land as infiltration and water transmission are reduced and erosion is accelerated (Lipiee and Stepniewski, 1995).

Problems of soil compaction are increasing in Nigeria as more farmers are daily adopting the use of tractors on their field without considering their possible negative effects on the soil. Thus, the country has lost a vast area of arable land through increased use of tillage implements and improper agricultural patterns (Ohu *et al.,* 2006).

The problem of compaction of agricultural soil is therefore of growing concern in the country due to its potential in reducing the productive capacity of farm lands. This study was therefore carried out to simulate effect of vehicular compaction of a sandy loam under a greenhouse condition. Its objective is to assess the effect of soil compaction on root growth, root density and yield of groundnut.

Materials and Methods

The experiment was conducted at the screen-house of the Department of Agronomy, University of Ibadan, Ibadan, Nigeria. The site has an elevation of 183 m above sea level and it is situated at latitude 07° 27^{I}N and longitude 03° 53^{I}E. Soil sample used for the compaction experiment was taken from furrow slice (0-15 cm), air-dried and passed through a 2- mm sieve to remove un-decomposed plant materials and stones. The sieved soil samples were analyzed for pH in a 2:1 soil: water ratio using the Coleman's pH meter. Particle size distribution was determined by hydrometer method (Gee and Or, 2002). Available phosphorus was extracted by Bray 1 method (Bray and Kurtz, 1945) and read on the spectrophotometer. Organic carbon was determined by the Walkley and Black procedure (Nelson and Sommers, 1982). Total nitrogen was determined using Kjeldahl apparatus while exchangeable cations (potassium, calcium, sodium, magnesium,) were extracted with 1N ammonium acetate (Bartels *et al.*, 1996). Exchangeable acidity was determined using standard procedure (Bartels *et al.,* 1996).

Five kilograms of soil sample was weighed into plastic pot. The soil sample occupied a height of 12.9 cm (control) having a bulk density of 1.1 Mg $m^{-3.}$ The sowing of two seeds of groundnut per pot was done before placing the loads on the soils. The soil was moistened before compressing to heights of 12.7 cm, 12.6 cm, 12.4 cm, 12.3 cm, 11.8 cm, and 11.5 cm resulting in bulk densities of 1.2, 1.3, 1.4, 1.5, 1.6 and 1.7 Mg m^{-3} respectively as presented in Table 1.

Table 1: Soil samples at different levels of compaction showing bulk densities and bulk volumes

IHBC (cm)	FHAC (cm)	BD (Mg m^{-3})	Soil volume (cm^3)
12.9	12.9	1.1	4,545.45
12.9	12.7	1.2	4,166.67
12.9	12.6	1.3	3,846.15
12.9	12.4	1.4	3,571.43
12.9	12.1	1.5	3,333.33
12.9	11.8	1.6	3,125.00
12.9	11.5	1.7	2,941.18

IHBC = Initial Height before Compaction,
FHAC = Final Height after Compaction,
BD = Bulk Density

It was replicated five times. Plant parameters such as plant height, number of leaves, number of branches and leaf area were measured on each plant at 2, 4, 6, 8, 10, and 12 weeks after planting. Leaf area was determined by measuring the length and breadth of the leaves for each plant and then multiplied with the correction factor for groundnut (0.821) as recommended by Kathirvelan and Kathirvelan (2007).

Soil strength at 5.0 cm depth as described by Bradford (1986) was measured at harvesting period using a gauge penetrometer with a 60° cone and base area of 10.37 cm^2. The cone indices in kg cm^{-2} were converted to kPa. The force of harvesting was determined by using spring balance to harvest groundnut. The hook of the balance was fitted to the base of the plant. The groundnut plant was pulled with the aid of spring balance. Balance reading was carefully monitored by another person to ensure the highest reading during the process of pulling out of the plant before the reading drop-in. The weight (g) was multiplied by acceleration due to gravity to obtain force (N). Energy (J) used in harvesting was calculated by multiplying force obtained by distance.

The yield and its components determined at harvest included total fresh biomass, fresh pod weight, weight of seeds and number of seeds per plant. Data collected were subjected to Analysis of variance (ANOVA) and means separated using Duncan's multiple range test (DMRT) at 5% level of probability (SAS, 2002).

Results and Discussion

Physico-chemical properties of soil used

Some physico-chemical properties of soil used for the experiment were presented in Table 2. Results showed that the soil was slightly acidic with low nutrient concentrations of P, N, C, K and Ca. The soil was coarse textured with a high bulk density value of 1.7Mg m^{-3}.

Table 2. Some physico-chemical properties of the soil used for the experiment

Parameter	Value
pH (H_2O)	6.42
pH(KCl)	5.43
P(mg kg^{-1})	11.41
Total N(g kg^{-1})	1.18
Org.C(g kg^{-1})	11.41
K(cmol kg^{-1})	0.41
Na(cmol kg^{-1})	0.40
Ca(cmol kg^{-1})	1.28
Mg(cmol kg^{-1})	0.96
Ex.Acidity(cmol kg-1)	0.08
Sand(g kg^{-1})	764.00
Silt(g kg^{-1})	160.00
Clay(g kg^{-1})	76.00
Textural Class	Sandy loam

Plant height, number of leaves and branches

Compressing the soil from 1.1 Mg m^{-3} to 1.7Mg m^{-3} had significant influence on plant height right from two weeks after planting (WAP) to the point of harvesting as presented in Fig. 1. Throughout the growing period, soil with bulk density 1.5 Mg m^{-3} had the highest plant height with exception of early stage (2WAP) when soil with bulk density of 1.4 Mg m^{-3} had the highest plant height value of 11.3 cm. Little soil compaction, ranging from 1.1 Mg m^{-3} to 1.4 Mg $m^{-3,}$ is needed to force contact between soil and plant root to make water close to the root vicinity. This was responsible for higher plant heights observed on soils with 1.1 to 1.4 Mg m^{-3} than 1.5 to 1.7 Mg $m^{-3.}$ Compressing the sandy loam beyond 1.4 would have adverse effect on groundnut plant height as a result of reduction in water and air pores which will consequently reduce the amount of water and air available to plant roots. Carman (2003) reported that soil compaction reduced

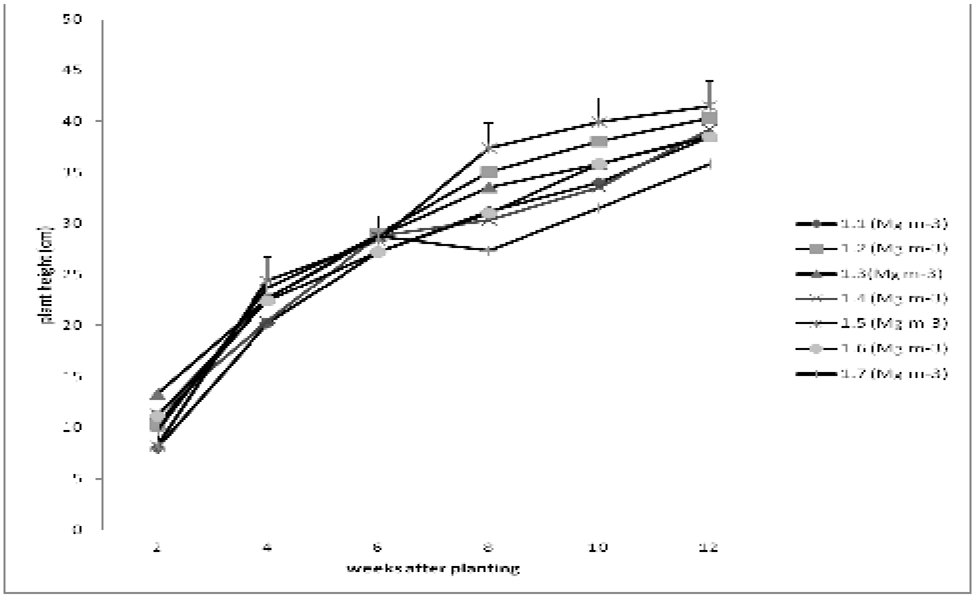

Fig. 1. Groundnut plant height as influenced by soil compaction

transmission of water and air through the soil profile which caused reduction in the crop growth. The number of groundnut leaves obtained from soils with bulk densities between 1.4 Mg m^{-3} and 1.7 Mg m^{-3} were significantly higher than that of 1.1 Mg m^{-3} for 2, 3, 4, 6, 8, 10 and 12 WAP (Fig. 3).

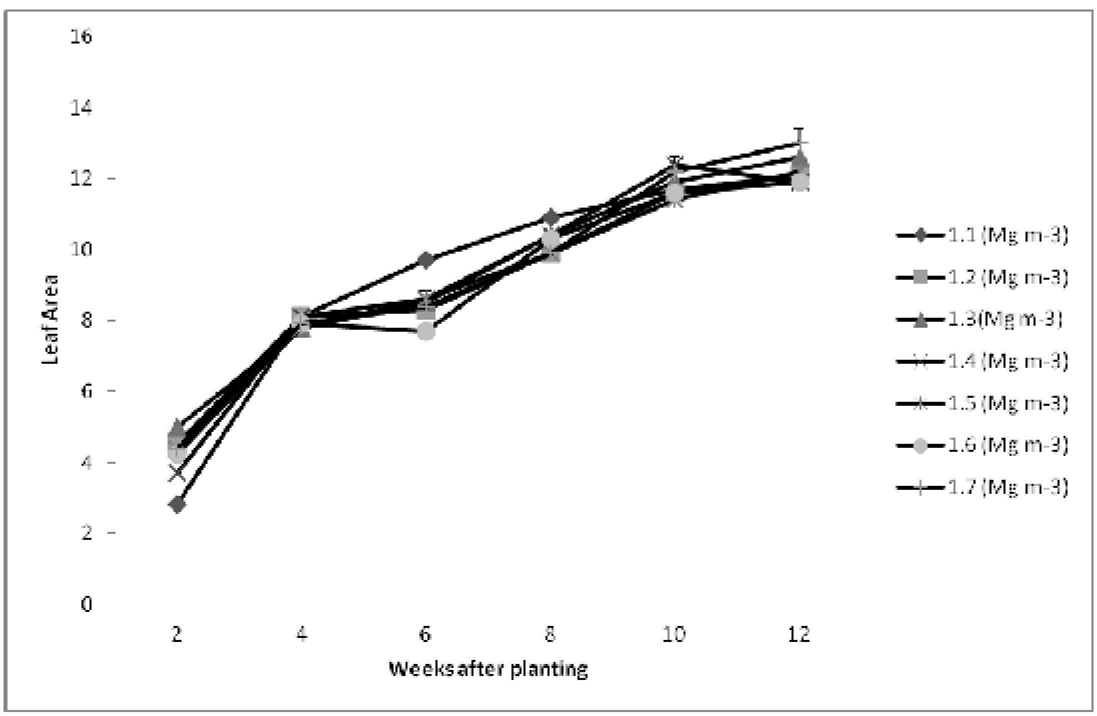

Fig. 3. Groundnut leaf areas (cm^2) as influenced by soil compaction

However, there was no significant difference among the number of leaves obtained from 1.1 - 1.3 Mg m^{-3} and from 1.4 – 1.7 Mg m^{-3} bulk densities throughout the study period. Among 1.4, 1.5, 1.6 and 1.7 Mg m^{-3} soil bulk densities, highest number of leaves was recorded on 1.5 Mg m^{-3}. The number of groundnut leaves obtained from 1.1 – 1.3 Mg m^{-3} was negatively affected because compaction limit crop growth by resisting crop root access to reserves of soil moisture and nutrients deeper down the soil layer (Lipiec *et al.*, 1991). Although, number of groundnut branches from various levels of compaction were not significantly different throughout the study period as presented in Fig 2.

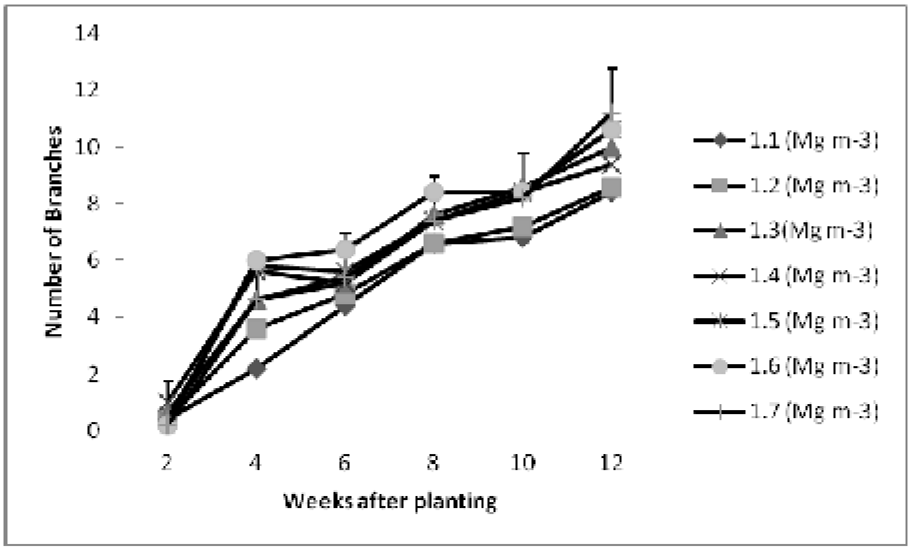

Fig. 2. Number of groundnut branches as influenced by soil compaction

Average number of branches over 12 weeks was in the decreasing order of 1.6 Mg m^{-3} > 1.7 Mg m^{-3} = 1.4 Mg m^{-3} > 1.3 Mg m^{-3} > 1.2 Mg m^{-3} >1.1 Mg m^{-3}. Soil compaction did not influence leaf area throughout the 12WAP except at 2WAP and 6WAP as presented in Fig.4.

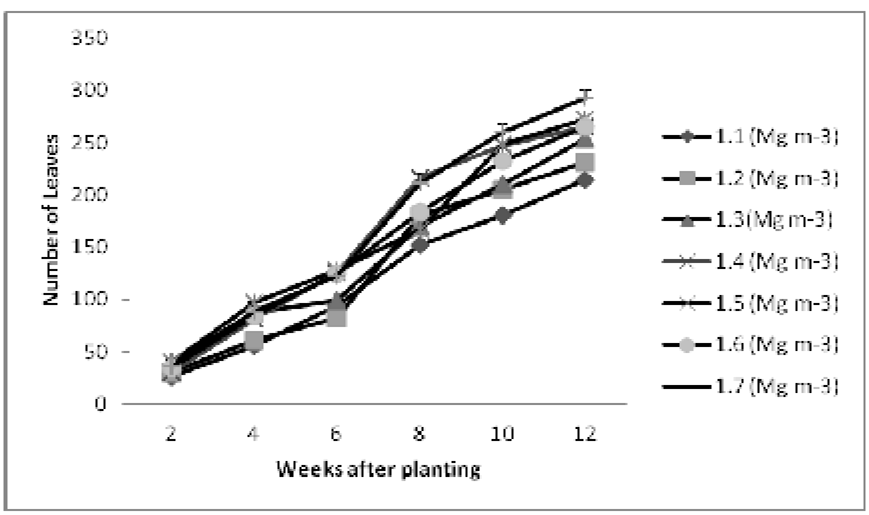

Fig. 4. Number of groundnut leaves $plant^{-1}$ as influenced by soil compaction

Result showed that once the plant has fully established, compaction may not have effect on leaf area especially at 8WAP upwards.

Plant yield and its components

Total fresh biomass obtained at harvest (12WAP) was significantly higher on 1.4 Mg m^{-3}soil bulk density than other treatments imposed (Table 4). Precisely, bulk density of 1.4 Mg m^{-3} had higher total fresh biomass than 1.7, 1.6, 1.5, 1.3, 1.2 and 1.1 Mg m^{-3} by 30.6, 28.6, 20.4, 22.5, 28.6 and 34.7%, respectively. Number of roots and depth of root penetration of groundnut at 12WAP were significantly influenced by soil compaction as presented in Table 3.

Table 3: Penetration resistance at 0 – 5 cm and force of harvesting groundnut as influenced by soil compaction

BD (Mg m^{-3})	Cone penetration resistance (KPa)	Force of Harvesting (N)	Energy used in harvesting (J)
1.7	32.0a	311.6a	93.4a
1.6	25.4b	211.7b	63.5b
1.5	21.6c	172.5b	51.75b
1.4	20.8c	150.9c	45.2c
1.3	20.0c	150.0c	45.0c
1.2	16.0d	72.5d	21.7d
1.1	7.4e	71.4d	21.4d

Means in the same column followed by the same letters are not significantly different at p = 0.05 using Duncan`s Multiple Range Test. BD = Bulk Density (Mg m^{-3})

Number of roots obtained from soils with bulk densities ranging from 1.3 to 1.7 Mg m^{-3}were significantly higher than from 1.1 to 1.2 Mg m^{-3} but there was no significant difference within1.3 to 1.7 Mg m^{-3}. Similar trend was observed for depth of root penetration indicating that compressing soil beyond 1.3 Mg m^{-3} would affect number of roots and root lengths of groundnut which are functions of groundnut yield. Reduction in the number of roots and root lengths with increasing soil compaction resulted to decrease in the weight of groundnut seeds obtained from 1.1 to 1.2 Mg m^{-3} bulk densities. Although, there was no significant difference in terms of fresh root weight, highest root weight was recorded on 1.4 Mg m^{-3} and least under 1.1 Mgm^{-3} bulk densities. Again, fresh pod weight and number of pods were not significantly affected by soil compaction.

However, the weight of groundnut seeds was significantly influenced by soil compaction as presented in Table 4.

Table 4: Root growth and yield of groundnut as influenced by soil compaction

BD (Mg m^{-3})	Total fresh biomass (g)	Root number	Depth of root penetration (cm)	*Fresh root weight (g)	Dry root weight (g)	*Pod number	*Fresh pod weight (g)	Seed number	Fresh seed weight (g)
1.1	64.0b	28.6b	7.2b	2.4	0.22b	12.0	14.4	19.2b	7.7b
1.2	70.0b	30.4b	8.6a	2.6	0.24b	14.6	11.4	19.2b	7.3b
1.3	76.0b	45.6a	10.5a	2.6	0.44a	18.4	14.8	26.0a	12.4a
1.4	98.0a	46.2a	11.8a	2.8	0.26b	16.8	14.6	29.4a	9.9b
1.5	78.0b	36.8a	9.9a	2.6	0.38b	14.2	12.8	23.2a	8.5b
1.6	70.0b	39.8a	11.6a	2.7	0.38b	13.4	13.0	21.8a	9.4b
1.7	68.0b	44.2a	10.2a	2.7	0.38b	13.6	12.6	24.0a	7.9b

Means in the same column followed by the same letters are not significantly different at p = 0.05 using Duncan`s Multiple Range Test. * = not significantly difference at p = 0.05. All data on root and yield were averaged per plant. BD = Bulk Density (Mg m^{-3})

Soil bulk density of 1.3 Mg m^{-3} had higher weight of groundnut seeds than 1.7, 1.6, 1.5, 1.4, 1.2 and 1.1 Mg m^{-3} by 41.0, 29.8, 36.5, 26.1, 45.5 and 42.5% respectively. Compressing soil beyond 1.3 Mg m^{-3} will not only affect plant growth parameters but the amount of groundnut seeds which determines largely the farmer's income. This is because soil compaction affects number of roots, root elongation and proliferation which determine the amount of water and nutrients available to plant for synthesis and formation of pods. Ohu *et al.* (2006) reported that soil compaction led to excessive soil hardness, reduced water, infiltration rate, and reduced soil aeration, alteration of root distribution pattern with a resultant low in crop yields. Also, Ohu *et al.* (1991) concluded that soil compaction caused crop yield to diminish and water and nutrients were not utilized efficiently.

Penetration resistance and force of harvesting as influenced by soil compaction

Soil compaction significantly influenced penetration resistance as presented in Table 3. A well compacted soil had higher penetration resistance as reflected in Fig.1 showing inverse relationship between soil bulk density and penetration resistance with correlation coefficient of 0.51. This is a serious problem in the case of groundnut since the number of roots determines to a very large extent the number of pods. Al-Adawi and Reeder, 1996 reported that soil compaction reduced soil pores and consequently increased its shearing strength. The force of harvesting groundnut increases with increase in soil compaction as presented in (Table 3). This could be explained by the linear relationship between force of harvesting and penetration resistance (R^2 = 0.98) indicating that more energy is needed to uproot groundnut from compacted soil (Fig 5).

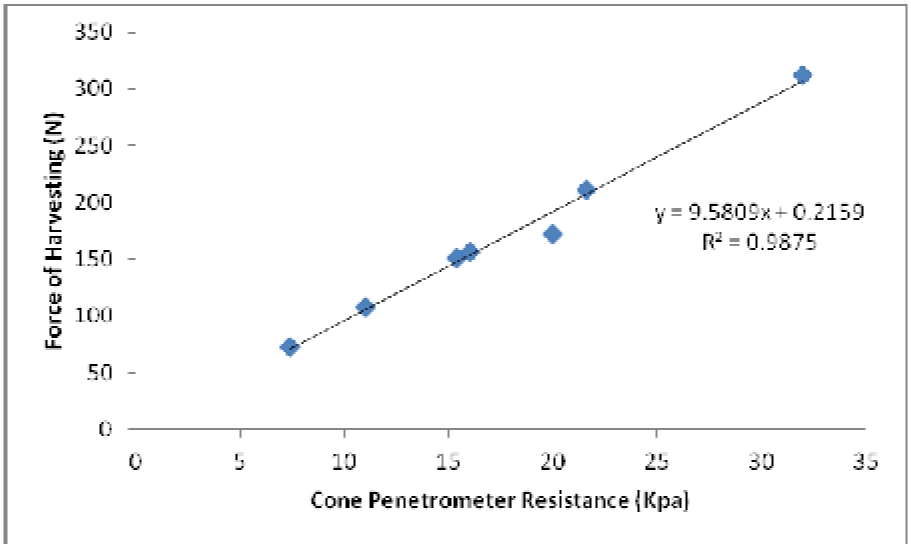

Fig. 5. Relationship between force of harvesting and cone penetrometer resistance on a soil planted to groundnut

Inverse relationship between force of harvesting groundnut and different levels of soil compaction (soil bulk densities) further explained that as the bulk density is decreasing, the amount of energy required by the farmer to harvest groundnut keeps on increasing (Fig. 6).

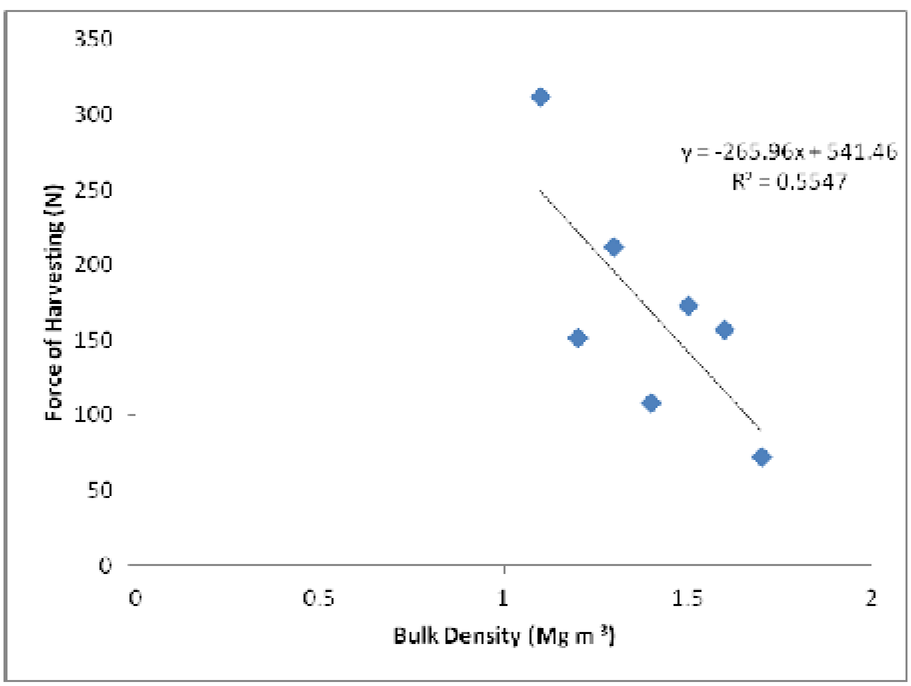

Fig. 6. Relationship between force of harvesting and soil bulk density on a soil planted to groundnut

This shows that the problem created by soil compaction is not limited to reduction in yield alone but more energy and time would be required to harvest crop with low yields under compacted soil condition.

Conclusion

Soil compaction had highly significant negative effects on some growth parameters and yield of groundnut. Compressing coarse textured soil beyond 1.4 Mgm^{-3} bulk density affected plant height, number of leaves, and total fresh biomass by reducing soil water and air availability and restricting crop roots access to reserves of soil moisture and nutrients. Increased soil bulk density resulting from compaction brought about increase in penetration resistance, indicating that root penetration becomes difficult with increase in soil compaction. Despite the differential effects of soil compaction on the distribution of soil moisture, number of branches and leaf areas of groundnut were not significantly different. The depth of root penetration and number of roots were significantly reduced under high soil compaction which resulted in lower groundnut yield. The results further showed that more energy would be needed in harvesting groundnut under compacted soil condition. Therefore farmers should be discouraged from using heavy implements to cultivate farms which could result in wastage of energy and time to harvest crop with low yields under compacted soil condition.

Reference

Al-Adawi, S.S. and R.C. Reeder (1996).Compaction and subsoiling effects on corn and soybean yields and soil physical properties. *Transactions of the ASAE,* 39 (5): 1641 – 1649.

Alakuku l. and P. Elonen (1995). Long-term effects of a single compaction by heavy field traffic on yield and nitrogen uptake of annual crops. *Soil and Tillage Research,* 36: 141–152.

Bartels, J. M., Bigham, J. M., Sparks, D. L., Page, A. L., Helmke, P. A., Loeppert, R. H., Soltanpour, P. N., Tabatabai, M. A., Johnson, C. T. and Sumner, M. E., (1996). Determination of exchangeable cations. Madison, USA, *Soil Science Society of America,* 1390pp.

Bradford, J. M. (1986). Penetrability. In: A. Klute (ed.) *Methods of Soil Analysis*. Part 1, 2nd Edition, America Society of Agronomy Publication, Madison, pp. 463 – 478.

Boone F.R., G.D. Vermeulen and B. Kroesbergen (1994). The effects of mechanical impedance and soil aeration as affected by surface loading on the growth of peas. *Soil and Tillage Research,* 32: 237 – 251.

Bray, R.H. and L.T. Kurtz (1945). Determinations of total organic and available form of phosphorous in soils. *Soil Science,* 59: 39-45.

Carman, K. (2002). Compaction characteristics of towed wheels on clay loam in a soil bin. *Soil and Tillage Research,* 65: 47 – 43.

Gee, G.W. and D. Or (2002). Particle-Size Analysis. In: Dane, J.H., Topp, G.C. (Eds)., *Methods of Soil Analysis.* Part 4. Physical Methods. SSSA, Inc., Madison, WI. Pp. 255-294.

Hakansson, I. and R.C. Reeder (1994). Subsoil compaction by vehicles with high axle load-extent, persistence and crop response. *Soil and Tillage Research,* 32: 277 – 253.

Kathirvelan and Kataiselvan (2007). Groundnut: Leaf Area determination. *Pakistan Journal of Botany*, 43(4): 2221 - 2224.

Lipiec J., I. Hakansson, S. Tarkiewicz and J. Kossowski (1991). Soil physical properties and growth of spring barley as related to the degree of compactness of two soils. *Soil and Tillage Research*, 19: 307 – 317.

Lipiec J. and W. Stepniewski (1995). Effects of soil compaction and tillage systems on uptake and losses of nutrients. *Soil and Tillage Research*, 35: 37 – 52.

Lowery, B. and R.T. Schuller, (1994). Duration and effects of compaction on soil and plant growth in Wisconsin. *Soil and Tillage Research*, 29: 205 – 210.

Mamman, E. and J.O. Ohu (1997). Millet yield as affected by tractor traffic in a sandy loam in Borno State, Nigeria. Soil and Tillage Research, 42: 133 – 140.

Nelson, D. W. & Sommers, L.E., 1982. Total organic carbon and organic matter. In: Methods of soil analysis Part 2: *Agronomy Monograph* 9: ASA, Madison WI, pp. 539-594.

Ohu J.O., O.A. Folorunso and E.I. Ekwue, (1991). The influence of tractor traffic on cotton production in a semi-arid region of Nigeria. Proc. 12th *ISTRO* Conference, July 8 – 12 July, IITA, Ibadan, Nigeria, 238 – 245pp.

SAS Institute, 2002. Statistical Analysis System ``SAS/STAT`` *User`s Guide*, Version 6, Fourth edition; Vol. 1. The SAS Instute Inc., Gray, N.C.

Shafiq, M., A. Hassan and S. Ahmad, (1994). Soil physical properties as influenced by induced compaction under Laboratory and field conditions. *Soil and Tillage Research*, 29: 13 – 22.

Wiermann, C., T.R. Way, R. Horn, A.C. Bailey and E.C. Burt, (1999). Effect of various dynamic loads on stress and strain behavior of a Norfolk sandy loam. *Soil and Tillage Research*, 50: 127 – 135.