Sustainable Agriculture Research; Vol. 5, No. 2; 2016
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Maize Yield Response to Induced Compaction in a Sandy-Loam Soil

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Received: October 19, 2015 Accepted: March 14, 2016 Online Published: April 6, 2016

doi:10.5539/sar.v5n2p57 URL: http://dx.doi.org/10.5539/sar.v5n2p57

Abstract

In this paper the compaction level of a sandy-loam soil in a humid tropical climate, most suited for maize cultivation for high productivity was investigated. This involved studying the yield of maize under varying compaction conditions of the soil. Five experimental plots of land at the teaching and research farm of the Rivers State University of Science and Technology, Port Harcourt, Nigeria were used for the exercise. Four of the plots were tilled, while one was left in its original state. Three of the four tilled plots were compacted by wheel traffic; and the compaction values of all the five plots, measured by their bulk densities are 1.17g/cm^3, 1.20g/cm^3, 1.23g/cm^3, 1.28g/cm^3, and 1.35g/cm^3. The plot that was left in its original untilled and un-compacted state was used as the control plot. Irrigation of the field, weed and pest controls were done uniformly for all the plots. The maize plant was cultivated between October and February and its growth and yield estimated in terms of plant height, leaf area, number of plants to reach maturity, and quantum of dry matter and grain obtained. Results of early shoot emergence showed that plots with lower bulk densities had higher percentage emergence than the ones with higher bulk densities. Furthermore, it was found that the maize yield was significantly affected by the soil bulk density at $P<0.05$. A compaction value of 1.31g/cm^3 is determined as optimal for maize cultivation in a sandy-loam soil in a humid tropical environment.

Keywords: maize, yield, induced compaction, bulk density, sandy-loam soil, mechanization

1. Introduction

The growing use of farm machinery for cultivation on Nigerian farms requires a better care for farmlands. In 1990, it was reported that Nigeria had 82 million hectares of land that are arable, out of a total land area of 91 million hectares. About 42 percent of this arable land mass was cultivated mainly under the bush fallow system. Although the remaining portion of land was not cultivated in the main, it had the potential to support crops. Nigeria is said to be very low in its use of machinery for agricultural operations, which accounts for her huge expenses in importation of food. In deed it is one of the least mechanized farming countries in the world, with less than three tractor per thousand hectares (Udunze, 2013, April 22). This assertion has been corroborated by several researchers, including Promoting Pro-poor Opportunities through Commodity and Service Markets (PrOpCom. 2011), which stated that during the rainy season of 2010, only 6 percent of the country's farmers used tractors, either their own or rented.

The alert that Nigeria was the world's least mechanized farming country was actually raised by the Managing Director of Dizengoff for West Africa, Mr. Richard Hargrave. In that same breath, he stated his company's determination to support Nigeria become self-sufficient in food production, in which regard the company had committed to investing over two million dollars to mechanize food production in Nigeria. In support of this plan, a partner of Dizengoff, AGCO, also set aside eighty million dollars for investment in sub-Saharan Africa, with Nigeria as its main priority.

These efforts at engendering mechanization in Nigeria's agricultural operations are actually to complement what the governments of the country at the state and federal levels are doing. Mbanasor and Onwusiribe (2014), referring to a 2011 publication of PrOpcom, said that as part of efforts of government at facilitating agricultural mechanization and enhancing food production, government has embarked on the provision of tractor services to agricultural producers. On the 14th of February, 2014 the federal government injected three billion, six hundred million naira into the National Agricultural Mechanization Transformation Agenda, a public private partnership scheme, to address the imposing low level of agricultural mechanization in the country. By August 25 of the same year, the then President of Nigeria, Dr. Goodluck E. Jonathan, directed the Central Bank of Nigeria to set aside fifty billion naira as intervention fund for farm mechanization (Premium Times Newspaper, 2014, August 25).

Field reports seem to suggest that farmers are beginning to feel the impact of government intervention programmes. Kandi (2014, February 17) wrote: "The era of low level agricultural mechanization will soon fade away in Nigeria, thanks to the country's Ministry of Agriculture. More farmers are beginning to be optimistic that they could expand their cultivated areas, perform timely farm operations and achieve bumper harvest, if the on-going Agricultural Transformation Agenda, as well as the new policy on mechanization is sustained". Later that year, the country's Minister of Agriculture, Mr. Akinwunmi Adesina, said "Our food import bill has declined from N 1.1 trillion ($ 6.9 billion) in 2009 to N 684.7 billion ($4.35 billion) by December 2013.

There are, therefore, indications that the Nigerian government is concerned about its backwardness in agriculture, and is taking steps to upgrade agricultural performance, especially from the prism of mechanization. So, very likely there would soon be a mechanization boom in the country, which will literally translate to the use of heavy machinery and equipment on farmlands. Raper (2005) explains that the cultivation of agricultural crops by mechanized devices imposes heavy vehicular traffic on the field. So, as an incidence of the mechanized operation the very medium that is responsible for producing and supporting agricultural crops – the soil – is damaged. He states that soil compaction may be the most devastating effect of vehicle traffic. Ramazan, Khan, Hanif and Ali (2012) agree with this, as they identify soil compaction as the main form of soil degradation which affected 11% of the land area in the various countries of the world they surveyed. When agricultural soils are compacted, the resulting soil condition affects soil-plant interaction in terms of plant root penetration, moisture and nutrient uptake, percolation and infiltration properties of the soil, etc. These eventually affect plant growth performance.

Maize (*Zea mays*) is a major important cereal being cultivated in the rainforest and the derived Savannah zones of Nigeria (Iken & Amusa, 2004). They express that, contrary to the subsistence level of production of maize in Nigeria about two and a half decades ago, current production of maize is now on a commercial basis. So, many agro-based industries now depend on maize as raw material. This is easily attributable to the growing demand of the product as a staple food item in Nigeria. It is edible on its own in various forms of preparation, viz boiling, roasting, frying; and can be processed into several other secondary products like akamu (pap), maize flour (maizolina). Maize is highly yielding, easy to process, readily digested and cost less than other cereals. It is also a versatile crop, allowing it to grow across a range of agro-ecological zones (International Institute of Tropical Agriculture, IITA, 2001). Olaniyi and Adewale (2012) say maize "is an important source of carbohydrate and if eaten in the immature state, provides useful quantities of Vitamin A and C" and that it 'thrives best in a warm climate and is now grown in most of the countries that have suitable climatic conditions", of which Nigeria is one.

It had been noted that "The problems of agriculture in Nigeria begin with the soil. Most of the farmable land in Nigeria contains soil that is low to medium in productivity. According to the Food and Agriculture Organization of the United Nations (FAO), with proper management, the soil can achieve medium to good productivity".

As a result of the little time available to maize from planting to harvesting (an average of ninety days), and the tender root structure, the maize plant would easily be predisposed to harm in unfavorable soil conditions. Therefore, the objective of this paper is to establish the compaction level of a sandy-loam soil in a tropical climate most suited for maize cultivation for high productivity.

2. Research Theory

Soil Compaction is the application of stress on soil to compress the soil particles in order to reduce the pore spaces. Yiljep and Yusuf (2001) say compaction takes place when external pressures exceed soil bearing capacity and shear strength. This causes densification of the soil, as air is displaced from the pores between the soil grains, and increases the soil bearing capacity. In general soil management, this increase in soil strength is usually a plus for soil usage, as, for instance, in civil constructions, it enhances the ability of the soil to bear foundation and structural loads. The case for agricultural soil is somewhat different. Agricultural "soil compaction is usually a combination of both engineering compaction and consolidation, and so may occur due to a lack of water in the soil, the applied stress being internal suction due to water evaporation as well as due to passage of animal feet. Affected soils become less able to absorb rainfall, thus increasing runoff and erosion. Plants have difficulty in compacted soil because the mineral grains are pressed together, leaving little space for air and water, which are essential for root growth. Burrowing animals also find it a hostile environment, because the denser soil is more difficult to penetrate. The ability of a soil to recover from this type of compaction depends on climate, mineralogy and fauna" (Wikipedia, 2015).

The major cause of agricultural soil compaction are off-road vehicles (Raghavan, McKyes, Gendron, Borglum, & Le, 1978); and the degree of compaction depends on soil type, soil moisture and machinery traffic, i.e. number of passes and contact pressure (Barnes, Carleton, Taylor, Throckmorton, & Vanderberg, 1971; Raghavan, McKyes, Beaulieu, Merineau, & Amir, 1976). When soil is compacted there is an alteration in the soil physical conditions. Primarily, the soil volume decreases.

The volume relationships of soil is expressed by the formula:

$$V = Vs + Ve \tag{1}$$

where:

V-total in-place volume (L^3),

V_s-volume of solid particles (L^3),

V_e-volume of voids, either air or water (L^3)

The void ratio (e) is expressed by:

$$e = V_e/V_s \tag{2}$$

These volume relationships are necessary in the analysis of agricultural soil behavior, because the soil density is defined as the oven dry mass per unit volume of soil in place; and there is usually an optimum water content at which maximum density occurs for a given amount of energy applied during the compaction process.

Soil compaction affects agricultural soil in various ways, and because of its more devastating effects on both the soil physical and mechanical characteristics, and the crops, there have been several researches on the subject. Goldhammer and Peterson (1984) say that the major effect of soil compaction in an irrigated sandy loam soil may be the reduction in infiltration rate resulting in the infiltration of insufficient water. They are not alone in this view. Kooistra, Bouma, Boersma and Jager (1984)) explain that the level of compaction of a tilled sandy loam soil affects its overall infiltration rate. This was summed up by Agrawal, Jhorar, Dhankar and Raj (1987) when they said that the infiltration rate of a sandy loam soil that has been compacted will usually be correlated with bulk density. Meek, Rechel, Carter, DeTae and Urie (1992) investigated effects of traffic, tillage and plant root on infiltration rate of a sandy loam soil, and found that an increase in bulk density of the soil from 1.6 to 1.8Mgm^3 decreased infiltration rate by 54%.

Apart from the effect of compaction on soil properties, crop performance, which is paramount in the maintenance of good soil quality is also impaired. In their investigation in a farm in Pakistan, Ramazan et al (2012) found that the plant height and yield of maize decreased with increasing number of tractor passes, which resulted in increasing bulk density of the soil. Eje, Oluka and Onwudinjo (2001) investigated the effect of tillage methods on cowpea yield and physical properties of acrisol soil and found that the bulk density, moisture content and soil resistance to root penetration varied with tillage treatments. Especially they discovered that higher growth rate and cowpea yield were obtained with tillage methods that reduced the bulk density of the soil. In Ajav and Oyelami (2001), the effect of mechanical induced compaction on soybean growth for loam and clay soils were investigated. They discovered a significant difference in crop emergence, leaf number and elongation, and plant height for the two different soils. They concluded that soybean response to soil compaction depends on soil type and environmental conditions.

It has been shown by Yiljep and Yusuf (2001) that under different nitrogen regimes maize grain yield is significantly influenced by the tillage treatment applied. They found that the grain yield of maize reduced when critical soil bulk density was exceeded, and there was a negative linear correlation between penetration resistance and maize grain yield. Raghavan et al (1978) established a relationship between maize yield and soil bulk density. Working in a Ste. Rosalie clay soil during the growing season of 1976 in Quebec, Canada, they discovered that yield, ear yield and grain yield all decreased with increases in machine contact pressure and passes, which of course resulted in increase in soil bulk density.

There is, therefore, abundant evidence that soil compaction affects different crops differently, depending on the soil type, degree of compaction and climatic conditions.

3. Methodology

The research experimentation was conducted in two parts. The field work was at the teaching and research farm of the Rivers State University of Science and Technology, Port Harcourt, Nigeria, while the bench work was at the laboratory of the Department of Soil and Crop Sciences of the same University.

The teaching and research farm is located in Port Harcourt, Nigeria, which is on latitude 05^o 21'N and longitude 06^o 57'E. The area is characterized by a humid tropical climate, sub-divided into two main seasons of wet (May – October) and dry (November – April). The mean annual rainfall in the area is 2280mm and average minimum and maximum temperatures are 25.1^{o}C and 30.3^{o}C (Fubara-Manuel, Ozogu, & Igoni, 2000). An analysis of the soil, which colour ranges from light to dark brown, showed the field was predominantly sandy loam.

The experimentation was begun in late October and ended early February, 2002. It took approximately fifteen (15) weeks to complete. Usually, maize takes about twelve weeks to grow to maturity; the additional three weeks were allowed for collection of confirmatory data. The experimental field, which had been left fallow for two years before this research, had a total land area of 72m^2 (18m x 4m). This was further sub-divided into five (5) experimental blocks of 3m x3m (9m^2) each, with a demarcating pathway of 0.5m between respective plots and round about the plots. This spacing between the plots was used to irrigate the plots.

The plots were marked 1 to 5. The first plot was left in its original fallow state, and served as the control plot. Plots 2 to 5 were ploughed using a Massey Ferguson (MF) 90 disc plough mounted on an MF 260 tractor. Thereafter, plot 2 was left in the ploughed state, while plots 3 to 5 were compacted to varying degrees, using the MF260 wheels to run through them in several passes. Plot 3 had two passes, plot 4, four passes and plot 5, six passes.

Two non-hybridized maize seeds were planted at 0.05m depth and inter-row spacing of 0.25m x 0.75m. The plots were kept relatively weed-free by hoeing and hand-picking at three-weekly intervals beginning from the 26th day after planting. Apart from a few late rains, the major source of water was irrigation, done by pouring water mainly in the inter-plot spaces. Grass mulch was applied to the soil surface to inhibit evaporative moisture loss. The plots were irrigated with equal amounts of water. At the 9th week, the plots were treated with KARATE 0.8% ULV pesticide to prevent pests' attack.

Plant heights were measured at weekly intervals from the third week after emergence, using a meter rule and measuring tape. Number of viable plants were recorded and area of leaves determined by tracing on graph sheets.

After the compaction of the plots, soil samples were taken randomly at five different points on each plot, at a depth of 0.3m, and the bulk densities determined, using the core method. Similar samples were taken for particle size analysis, using the hydrometer analysis as described by Foth (1990). Percentages of the different particles were determined by their rate of gravitational sedimentation, using Stoke's law.

$$v = [g(\rho_p - \rho_w)d^2]/18\mu \tag{3}$$

where:

v-terminal velocity of particle, m/s

g-gravitational acceleration, m/s^2

ρ-density of particle, kg/m^3

ρ_w-density of water, kg/m^3

d-diameter of spherical particle, m

μ-dynamic viscosity of water, N-s/m^{-2}

Based on the readings obtained, the soil textural classes were then determined using a textural triangle. The moisture contents of samples from the plots were also determined using the gravimetric method prescribed by American Society of Agricultural Engineers standards, ASAE (1984).

After harvesting, the wet root mass for each experimental plot was determined. The cobs above ground matter were oven dried for one week and weighed, and the maize grains shelled and weighed. All the data obtained were analysed using the analysis of variance (ANOVA) test following the procedure prescribed by Gomez and Gomez (1984).

4. Results and Discussion

4.1 Soil Classification

At the start of the investigation, the soil type for the different plots was determined as sandy-loam. The indication is that the soil has more than 50% of sand, followed by silt, which is higher than clay. Table 1 shows the distribution of the soil particles. The results show a fairly uniform distribution of the soil constituents for all the plots.

Table 1. Characterization of soil type

Plot No.	% Sand	% Silt	% Clay	Soil Type
1	57.7	25.1	17.2	Sandy-Loam
2	58.2	23.4	18.4	Sandy-Loam
3	57.8	24.1	18.1	Sandy-Loam
4	57.2	23.8	20.0	Sandy-Loam
5	57.6	20.6	21.8	Sandy-Loam

4.2 Bulk Densities of the Plots

The bulk densities of the plots are presented in Table 2. The results show that the passes made on the plots by the Massey Ferguson 260 tractor affected the bulk densities, in proportion to the number of passes. The more the number of passes, the higher the bulk density.

Table 2. Bulk densities of experimental plots

Plot no.	Field Treatment	No. of passes of tractor wheels	Bulk density (g/cm^3)	Moisture content (%)
1	Untilled and un-compacted (natural state)	0	1.20	5.17
2	Tilled and un-compacted	0	1.17	6.02
3	Tilled and compacted	2	1.23	4.89
4	Tilled and compacted	4	1.28	4.43
5	Tilled and compacted	6	1.35	3.91

An analysis of the results show a significant relationship between the number of passes of the tractor wheel and the bulk density of the soil. This corroborates the findings of Barnes et al. (1971); Raghavan et al. (1976); and Raghavan et al. (1978).

4.3 Soil Moisture Content

All the plots were irrigated with equal amounts of water in an attempt to maintain uniform soil moisture content. However, after compaction, soil moisture measurements showed a significant difference in the moisture contents of the various plots. The results of the soil moisture measurements are shown in Table 2. The moisture content reduced with increasing bulk density. The first indication of moisture level variation was the appearance of dark streaks on the surfaces of plots 3 -5, and not on plots 1 and 2. The streaks were more visible on plot 5, with the highest bulk density of $1.35 g/cm^3$, and lowest on plot 3, with the lowest bulk density of $1.23 g/cm^3$ after compaction. The indication is that the increased bulk density may have resulted in reduced soil porosity, thereby inhibiting moisture infiltration and percolation. Douglas (2002) says that dark streaks are caused by moisture which remained for a longer time above the compact zone compared to non-compacted zone. Again, this situation would most likely deprive the plant sufficient water at the root zone, as the high temperatures of the tropics may cause the water to evaporate before it is able to infiltrate the soil.

4.4 Growth Rate

The growth rate of the plant was assessed on the basis of the plant height and leaf area. The plant height was measured in weeks after planting (WAP), while the leaf area was measured in months after planting (MAP). The results are shown in Tables 3 and 4.

Table 3. Plant height at different stages of growth

Plot no.	Plant height (m)											
	3 WAP	4 WAP	5 WAP	6 WAP	7 WAP	8 WAP	9 WAP	10 WAP	11 WAP	12 WAP	13 WAP	14 WAP
1	0.360	0.470	0.560	0.722	0.752	0.790	0.843	0.874	0.879	0.898	0.930	0.941
2	0.376	0.572	0.710	1.020	1.023	1.030	1.296	1.280	1.272	1.440	1.380	1.380
3	0.330	0.500	0.631	0.790	0.800	0.810	0.837	0.855	0.741	0.863	0.872	0.872
4	0.291	0.393	0.494	0.610	0.650	0.693	0.745	0.810	0.855	0.900	1.124	1.146
5	0.290	0.331	0.470	0.514	0.763	0.766	0.880	0.913	0.934	1.131	1.143	1.402

*WAP - Weeks After Planting.

Table 4. Area of leaf of the growing plant

Plot No.	Leaf area (m^2)		
	1MAP	2 MAP	3 MAP
1	0.0527	0.0840	0.1150
2	0.0998	0.1097	0.1974
3	0.0667	0.0863	0.1112
4	0,0502	0.0735	0.1490
5	0.0446	0.0757	0.1561

*MAP – Months After Planting.

There is a significant effect of the bulk densities of the various plots on the crop emergence and growth. In the first week of planting, plot 2, which was tilled and un-compacted, and had the lowest bulk density of 1.17g/cm^3 recorded an emergence of 85.3%. This was followed by plot 1, the control plot, with a bulk density of 1.20g/cm^3, at 70.1%. Plot 3, with 1.23g/cm^3, had 68.7%. The situation with plots 4 and 5 were somewhat different. Although plot 5 had a higher bulk density, at 1.35g/cm^3, than plot 4, at 1.28g/cm^3, it had a higher crop emergence percent than plot 4, at 54.2 and 52.8 respectively. However, the growth competition became stiff in later weeks after planting. This may be attributable to stabilization of the root structure of the plants, and the variation in the weather of the area between the commencement of planting and the later growth periods, which fell into the early dry season. This is so because it has been shown (De-Jong-Hughes, Moncrief, Voorhees, & Swan (2001) that compacted soils perform better under dry conditions than under wet conditions.

4.5 Plant Yield

The results of the average plant yield obtained from the experimental plots are presented in Table 5.

Table 5. Maize yield at different bulk densities

Plot No.	Bulk density (g/cm^3)	% No. of plants to reach maturity	Maize yield ((kg/ha)		Wet root mass (kg/ha)
			Dry matter	No. of grains	
1	1.20	47	1192	2	309
2	1.17	72	2859	643	2431
3	1.23	30	1195	311	683
4	1.28	61	1311	577	1022
5	1.35	50	2320	552	2378

At P<0.05, there was a significant effect of the bulk density on the plant root formation, and this affected the average number of plants to reach maturity, the dry matter and number of grains. This result agrees with the works of Ramazan et al. (2012) and Mamman, Ohu and Crowther (2007). The noticeable turnaround is the performance of plot 1, where, in spite of the high percentage of plants that attained maturity, the maize yield, in terms of average dry matter and number of grains, was abysmally low, especially compared to plots 4 and 5 with higher bulk densities. The handy explanation to this occurrence was the visible change from wet to dry season after the 6^{th} week of planting. It further corroborates position of Raper (2005) that "soil compaction does not always decrease crop yields. Depending upon the climatic condition, yields can be slightly improved with moderate compaction".

5. Conclusion

Maize yield on a sandy loam soil in a humid tropical environment in Nigeria is reduced by compaction induced in the soil by tractor wheel passes. There is a range of compaction values below and above which the maize will be adversely affected; but generally, fields with lower levels of compaction, indicated by their bulk densities, performed better than those with higher levels of compaction. The compaction delays early shoot emergence, root formation, and stunts overall plant performance. This will inevitably affect the food content of the people, because maize is a staple food item in the country. This study has established a compaction value of 1.31g/mm^3, which is best suited for optimal maize yield.

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