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Effect of graded compaction of tilled and untilled sandy loam soil on growth and yield of maize

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The performance of maize on tilled and untilled sandy loam soil, under different levels of compaction of 0, 2, 4 and 6 tractor-wheel passes in a humid tropical environment was investigated with a Massey Ferguson (MF) 90-disc plough, mounted on an MF 260 tractor. The experimentation had different aspects, respectively conducted in the field and laboratory, at the Rivers State University, Port Harcourt, Nigeria. The experimental field was a 72 m^2 plot of land, which was left fallow for two years before the investigation. The plot was sub-divided into five experimental subplots of 9 m^2 each, numbered 1 to 5, with a furrow spacing of 0.5 m. Soil samples were taken randomly at a depth of 0.3 m for the determination of the soil physical properties. After the compaction treatments, maize seeds were manually planted at a depth of 0.05 m and the growth and yield of the maize monitored over a period of fourteen weeks after planting. The investigation showed that the maize crop performed optimally on subplot (2), which was tilled and un-compacted, with a dry matter content of 2,859 kg ha^{-1}, while the least performance was on subplot (1) that was untilled and un-compacted, with a dry matter content of 1,192 kg ha^{-1}. Therefore, this research establishes that, with the agricultural practice of shifting cultivation, sandy loam soil in a humid tropical region requires a minimum level of tillage to achieve optimal yield of maize crop.

Key words: Maize, compaction, growth and yield, tilled soil, untilled soil, sandy loam.

INTRODUCTION

In agricultural production, the type and condition of soil are critical for the overall performance of the cultivated crops. Soil is one of the three major natural resources, alongside air and water; and is easily described as a natural body of loosed, unconsolidated materials several meters below, which are formed on the earth surface (Smith et al., 1999). Soils are formed from the weathering of rocks and are composed of four major components: minerals, organic matter, water and air (Patricia, 2003). Soils have pores and void volume between their aggregates. The amount of voids in any soil partly determines the behaviour of the soil and its support for plant growth. The level of tillage the soil is subjected to, or whether the soil is tilled or untilled influences the soil void. When soil is saturated, its pores are filled with water and constitute a bulk solution. The top layers of soil form the basis for plant growth and are referred to as agricultural soil, while the layer below the agricultural soil

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is referred to as engineering soil.

The cultivation of crops in agricultural soils may either be manually done for peasant farming or mechanized under intensive cultivation. Manual operations involve the use of raw human muscles or at best some labour-intensive crude implements (in a semi-mechanized bid), while mechanized farming involves the use of tractors and tractor-mounted implements. One of the preliminary cultivation operations on agricultural soil is tillage, which is aimed at pulverizing the soil, loosening its particles, in order to provide desired pore spaces in the soil for effective plant growth and yield. In mechanized cultivation, like tillage, the weight of the tractor and implements used impacts heavily on the soil by compacting its particles. So, while the tillage operation strives to prepare the soil by separating its particles, the machines used for the operation input the reverse effect of bringing the soil particles back together, by compacting them.

The phenomenon of compaction is currently viewed as an emerging serious problem affecting the yield of field crops globally. Compaction-induced soil degradation affects about 68 million hectares of land globally (Flowers and Lal, 1998). Soil compaction is the rearrangement of soil grains to decrease void space and bring them into closer contact with each other (Voorhees et al., 1986). According to Igoni and Jumbo (2019), soil compaction is the compressing of soil particles together by an external force, thereby eliminating the pore spaces and reducing the soil volume; and this bears serious consequences on the productivity of the soil and its environmental quality. The void space reduction occurs because the compaction stresses exceed the soil strength; the mineral and organic particles and the liquid fraction remain incompressible while being attached to the soil particles (Hillel, 1980). In such instances, crops may not be able to access the nutrients due to the compaction. Horn and Hartge (1990) had shown that changes in soil strength result from compaction due to a given load; and stated that compaction was dependent on the duration of loading. This implies that for tractors and other harvesting machinery that move relatively fast, soil compaction is worsened by their repeated re-compaction.

When soil is compacted, there are changes in its physical properties, such as soil structure, soil moisture and bulk density, which play an important role in the growth and development of plants (Sudduth et al., 2008). Out of these properties, the most direct consequence of soil compaction is increased soil bulk density. In fact, the "bulk density is an indicator of soil compaction" (United States Department of Agriculture, USDA, 2014). According to Panayiotopoulos et al. (1994), soil compaction being a microscopic rearrangement and bringing of the solid bulk particles closer to one another consequently means an increase in the soil bulk density. Therefore, it implies that the closer the soil solid particles, the higher the soil bulk density. Day and Holmgren (1958), in their work on the microscopic changes in soil structure during compression, concluded that soil aggregate strength increases inversely with moisture content but directly with bulk density; and Ohu et al. (1989) said that the capacity of soil to hold moisture is an important consideration in agricultural crop management practices.

One of the primary objectives of tillage in loosening the soil is to permit adequate moisture movement and effective aeration in the soil; and control soil temperature. All these are required by crops for proper root formation and penetration in the soil; although, at the same time, a compact soil is required to firmly grip the plant and support its continued growth without bending and being eroded from the soil by wind or water. With effective soil pulverization: "soil water tends to occupy thin films around soil particles and the smaller pores leaving the larger pores filled with air" (Wolkowski and Lowery, 2008). According to Lipiec and Hatano (2003), poor aeration alongside increased densification may restrict root growth, which especially affects the uptake of nutrients and subsequently crop yields. Thus, this is one of the most serious environmental problems caused by conventional tillage (Mc-Garry, 2005). These effects of soil compaction on water movement and redistribution in the soil profile is mostly achieved through changes in hydraulic properties (Walczak et al., 1997) and indirectly done through influences on soil mechanical resistance and aeration status in relation to crop root growth and uptake of soil moisture (Horton et al., 1994).

In a research on growth and yield of maize as affected by soil moisture with surface and subsurface compaction, Johnson et al. (1990) observed that maize yields were consistently reduced at high compaction. It has also been established that maize (*Zea mays*) performs better on well drained sandy loam or loamy soil (Sangakkara et al., 2004) and grows on soils with a pH range of about 5.0 - 7.0. If the soil pH is outside of this range, then the result may be a deficiency of soil nutrient and mineral toxicity, which in turn would retard the growth and yield of the maize. Furthermore, the depth of planting depends on the moisture level of the soil (United States Department of Agriculture, USDA, 2004). A depth of 2-3 cm is adequate for moist soil and 5-10 cm is recommended for dry planting. Maize has shallow, fibrous roots that can grow to a depth of about thirty centimetres or more and they possess aerial, adventitious roots that form at the nodes at the base of the stem (Arsyid et al., 2009; Mosaddeghi et al., 2009).

Nigeria is the tenth largest producer of maize in the world and the largest producer in Africa (FAO, 2013). As at 1992, annual production of maize in Nigeria was estimated at about 5.6 million tonnes (Central Bank of Nigeria report, 1992). The production capacity of the country had increased tremendously over the years, such that, despite a reported 8.0 million tons per annum production of maize in 2017, which positioned the country as the large producer of maize in Africa (Abba, 2017), before the end of 2017, the country recorded maize production capacity of 12, 107, 580 tonnes (NAN, 2018).

Maize is a very important staple food item in the menu of most persons in the tropics, especially Nigeria. FAO (2013) reported that it is a major cereal crop in Nigeria and actually the second most important cereal crop in Nigeria after sorghum; and is "grown in the rain forest and derived savannah zones of Nigeria" (Olaniyi and Adewale, 2012). According to Iken and Amusa (2004), many agro-based industries depend on maize as raw material. Therefore, maize is a veritable product for both food and industrial raw material.

In spite of the place of maize in domestic, commercial and industrial utilization, its production is somewhat inhibited by certain extraneous factors. Ojo (2000) opined that capitalization, price fluctuation, pest and disease, poor storage facilities and inefficiency of resource utilization are some of the limiting factors to maize production. It had earlier been shown that maize production is also affected by soil type and further by the degree of compaction of the soil. Furthermore, Igoni and Jumbo (2019) showed that the extent of soil compaction itself is depended on the level of soil tillage. This ultimately implies that the growth and yield of maize would be affected differently on tilled and untilled soils. Therefore, the aim of this study was to determine the appropriate combination level of soil tillage and compaction that would result in optimum maize crop yield.

MATERIALS AND METHODS

Description of research area

The research was carried out in the Teaching and Research Farm of the Rivers State University, Port Harcourt, Nigeria. Port Harcourt is the capital city of Rivers State in Niger Delta, Nigeria. The region has huge deposit of oil and gas and blessed with one of the world's largest wetlands with arable land for agriculture; and has the capacity to become a domestic and international provider of agricultural produce (The Guardian Newspaper Online, 14 November, 2017). The lands of the Niger Delta are very fertile, such that there may not be need for the use of artificial fertilizers for crop production (Igoni, 2018). Geographically, Port Harcourt is found in latitude 04° 47' 30" N and longitude 06° 59' 30" E (Fubara-Manuel et al., 2017) and is characterized by high humidity (80%) and moderately high temperatures of between 25 and 30°C; and heavy rainfall, with total annual rainfall ranging from 2000 to 2500 mm, occurring mostly in the months of June through September. The soil colour ranges from light to dark brown and the soil texture ranges from sandy loam to sandy clay loam with the soil becoming more clayey as the depth increases (Edori and Iyama, 2017).

Experimental design

The research experimentation included field and laboratory investigations of different aspects of the work. The field work was carried out in the Teaching and Research farm of the Rivers State University, Port Harcourt, Nigeria, while the laboratory investigation was conducted in the laboratory of the Department of Soil and Crop Sciences of the University. The experimental field, measuring 72 m^2, was left fallow for about two years before this research. The plot was sub-divided into five experimental subplots of 3 × 3 m (9 m^2) each, with a furrow of 0.5 m between respective plots and round the perimeter of the whole plot. The furrow was adopted for irrigation purposes. The plots were numbered and marked 1 to 5. The first plot was left in its original fallow (untilled) state, while plots 2 to 5 were ploughed (tilled) 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.

Soil treatment, planting and growth response data collection

Preceding soil compaction treatments, soil samples were taken randomly at five different points from the un-compacted plot. After the compaction of the plots, soil samples were taken randomly at five different points on each subplot, at a depth of 0.3 m. This was used for the determination of the soil bulk densities of the different plots, 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 soil particles were determined based on the readings obtained and the soil textural classes were then determined using the United States Department of Agriculture (USDA) textural triangle. Measurements of soil moisture contents were carried out on the soil samples from the various subplots, using the gravimetric method prescribed by the American Society of Agricultural Engineers standards, ASAE (1984).

The research lasted for four months, beginning from October and ending in January. Maize seeds were manually planted at a depth of 0.05 m, with intra-row and inter-row spacing of 0.25 and 0.75 m respectively (AGRORAF, 2017; Ibirogha, 2018); and weeding was also manually done to keep the field constantly free from weed. The maize seeds were the non-hybridized type. Apart from a few late rains, the major source of water was through furrow irrigation method, which was manually applied using watering cans. Equal amounts of water were applied during the irrigation. Moisture loss control was done using grass mulch. At the 9th week, the plots were treated with KARATE 0.8% ULV pesticide to prevent pests' infestation.

Plant heights were measured at weekly intervals from the third week after emergence, using a soft measuring tape. A number of viable plants were recorded and the area of the leaves determined by tracing on graph sheets. 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. These procedures were originally reported in Douglas (2002).

RESULTS AND DISCUSSION

Soil classification

Using Table 1 and the textural triangle shown in Figure 1, the soil type was determined as sandy loam. The results further showed that the field had fair distribution of soil particles. Tueche et al. (2013) proposed that these proportions of sand, silt and clay can significantly

Table 1. Results of particle size distribution.

Plots	Tractor passes	% sand	%silt	% clay	Soil types
1	0(untilled)	57.7	25.1	17.2	Sandy loam
2	0 (tilled)	58.2	23.4	18.1	Sandy loam
3	2	57.8	24.1	18.1	Sandy loam
4	4	57.2	23.8	20.0	Sandy loam
5	6	57.6	20.6	21.8	Sandy loam

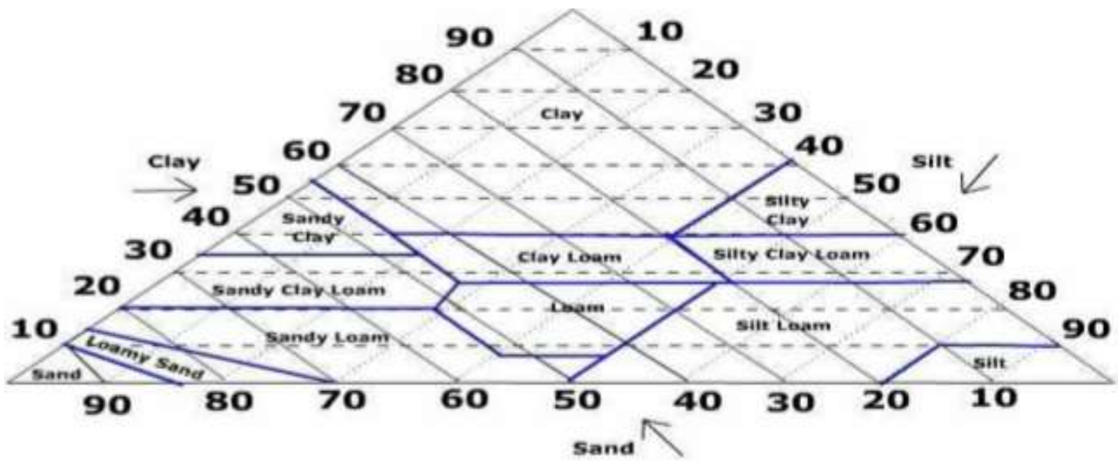

Figure 1. United States Department of Agriculture (USDA) textural triangle.
Source: Hillel (1980).

correlate diversely with maize crop yield.

Soil bulk density and moisture content

The effects of the compaction treatments on the soil bulk densities and moisture contents of the different experimental plots are shown in Figure 2. The results indicate that the bulk density of the soil on the plots varies directly with the number of tractor wheel passes on the plots; especially, while the untilled sub-plot (1) had a bulk density of 1.20 g cm^{-3}, the tilled and un-compacted sub-plot (2) had 1.17 g cm^{-3}. Further analysis on the results showed that a significant relationship exists between the bulk densities of the soil and the level of the soil compaction using the 95% confidence interval and the reasonable overlap observed in the Figure 2. The length of the error bars revealed that the concentration of values used in the analysis is high and thus the average value is certain. These results corroborate the findings of Hakansson and Lipiec (2000) and Sun et al. (2018), where the researchers concluded that soil bulk density increases with compaction and decreases when the soil is pulverized.

On the other hand, there is an inverse proportionality relationship between the soil moisture content and the level of soil compaction. The tilled and un-compacted sub-plot (2) had the highest moisture content of 6.02%. This is followed by the un-tilled and un-compacted soil (sub-plot 1) with 5.17%, while that of the other sub-plots (3-5) declined with increasing level of compaction. Odjugo (2008) stated that soil moisture can impact positively or negatively on crop yield and emergence. Thus when the moisture becomes higher or lower than required, crop emergence and yield would be poor. Furthermore, it is easily observable that on sub-plot (5), with the highest level of soil bulk density of 1.35 g cm^{-3}, the irrigation water, rather than infiltrate into the soil for plant use, resulted into runoff water from the soil surface, thereby making it to have the lowest moisture content of 3.89%. The estimated justification for this occurrence is the reduction in pore sizes of the soil in the sub-plot due to the heavy compaction treatment.

Notably, the unavailability of water in the top soil, which is the root zone of the plant, will starve the plant of soil moisture and the accompanying soil nutrients, thus inhibiting plant growth and yield. Also, high temperatures caused by solar radiation, occasioned by the absence of sufficient moisture and inadequate soil aeration would not only cause excessive evaporation of the un-infiltrating irrigation water, but heat-up and destroy the plant root system, resulting in poor growth and yield. Further

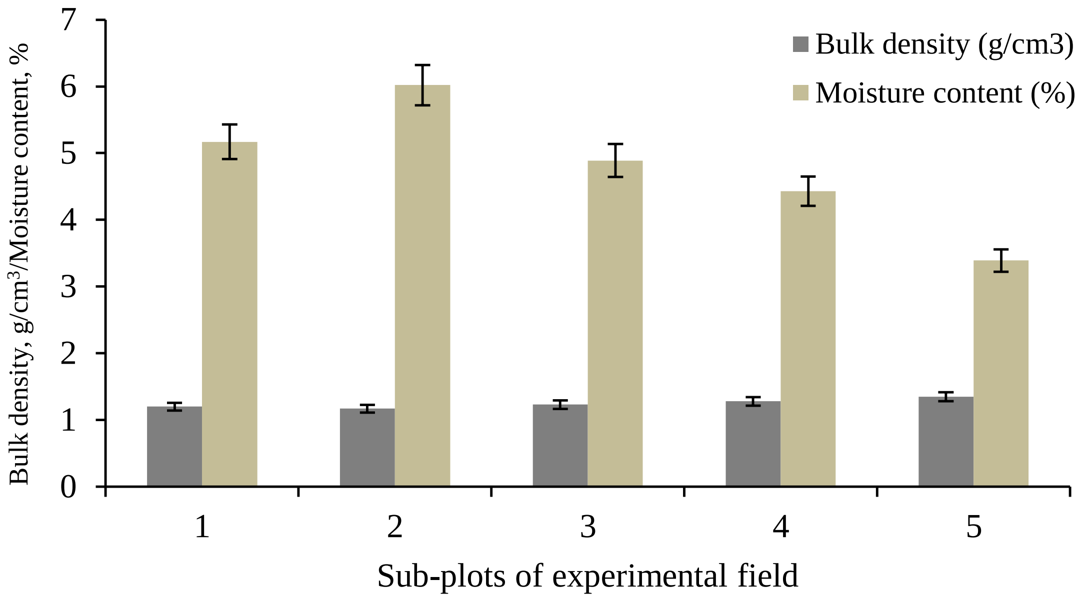

Figure 2. Effects of compaction treatments on the soil bulk density and moisture content of the different sub-plots.

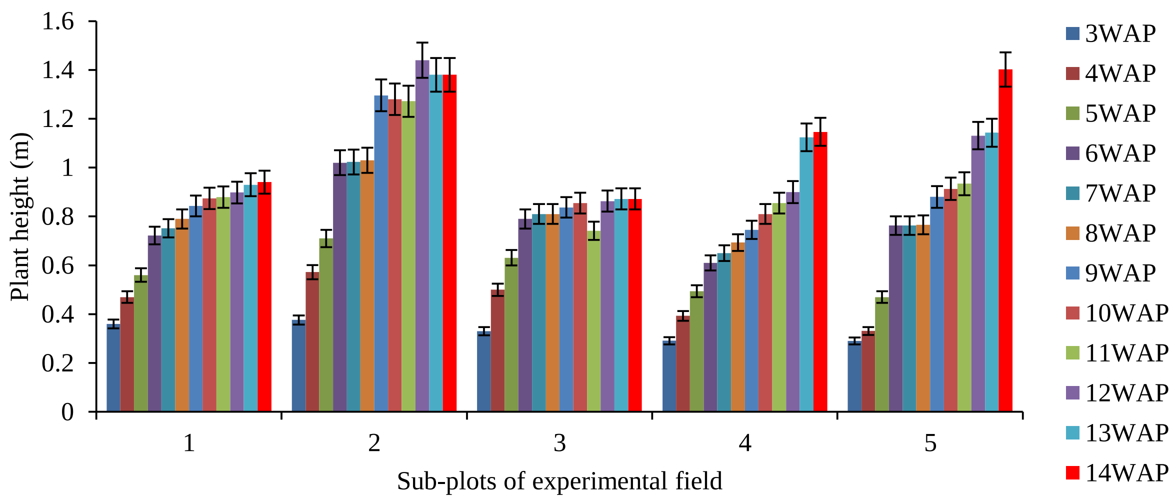

Figure 3. Variation of maize plant height with number of weeks after planting (WAP) at various levels of compaction treatment on the different sub-plots.

studying of the results using the 95% confidence interval showed that no overlap exists between sub-plot (2), which is tilled and un-compacted, and the other subplots. Reasonable overlap was observed in Figure 2 between the other subplots except subplot (2). This is also indicative of a significant effect in the results, since $p < 0.05$.

Maize crop performance

The assessment of the performance of the maize plant was based on its growth and yield. The growth rate of the maize crops was examined using its height and leaf area, while the yield was based on its dry matter.

Maize crop height

The results of maize crop heights on the tilled and untilled plots at various levels of compaction treatment, after several weeks of planting, are shown in Figure 3. On the untilled and un-compacted subplot (1), the crops

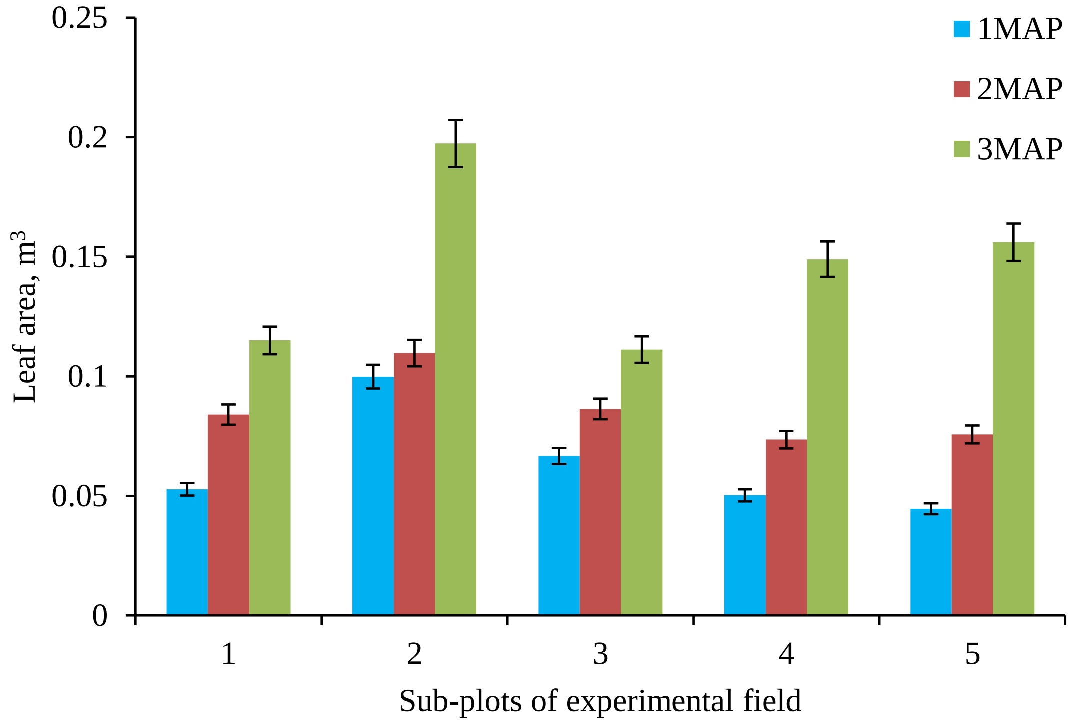

Figure 4. Variation of maize plant leaf area with the number of months after planting at various levels of tractor compaction treatment for the different sub-plots (MAP = Months After Planting).

experienced a relatively poor growth rate attaining a maximum height of 0.94 m after fourteen weeks of planting. This may be due to the inability of the plant roots to extract moisture and nutrients from the soil, despite the applied irrigation water. The soil also may have undergone some level of consolidation for the over two years of its being fallow, in addition to gradual compaction arising from animal and human movements, thus reducing its porosity. The overall effect of these is increased soil bulk density, which limits root penetration and accessibility to nutrients. The tilled and un-compacted subplot (2) recorded a high growth rate of 1.44 m in the same time period, although some measurement errors were observed in the recorded data. This high growth rate can be attributed to the pulverized nature of the soil, which allowed easy penetration of crop root into the soil. The plot recorded the least bulk density and high moisture content after irrigation, although it was unable to retain the moisture for a longer period.

Furthermore, the plots with varying levels of compaction treatments experienced reduced growth, excepting subplot (5) that recorded a somewhat relatively higher growth between the ninth and the tenth week after planting. This may be attributed to the ability of the soil to retain the little amount of moisture that got into it for a longer period, even though a greater amount of the irrigation water disappeared as surface runoff. Thus, the crops had constant access to nutrients, as long as the moisture was retained. This result correlates with the work of Aikins et al. (2012), in their study of the effect of compaction with tillage practices on soil, where they stated that compaction may improve crop performance. A further analysis of the results using the 95% confidence interval showed that overlaps exist between and within the sub-plots. These reasonable overlaps observed in Figure 3 indicate a significant effect in the results at $p< 0.05$.

Maize crop leaf area

The relationship between the maize plant leaf area and the various compaction treatments of the various sub-plots are shown in Figure 4. From the chart of Figure 4, the leaf area increased for all the plots with increase in the number of months, excepting the variation that exists in the monthly incremental rate. On the untilled and un-compacted subplot (1), there appeared to have been a fairly constant incremental amounts in the leaf area per month, at an average of 0.312 m^2, but the inter-monthly incremental rate varied from 59.4% in the first month to 36.9% in the second month, indicative of a declining rate of increase in leaf area on the untilled plot with increasing number of months. It is possible that the early increase in the leaf area on this plot may have facilitated evapotranspiration and subsequently exhausted available

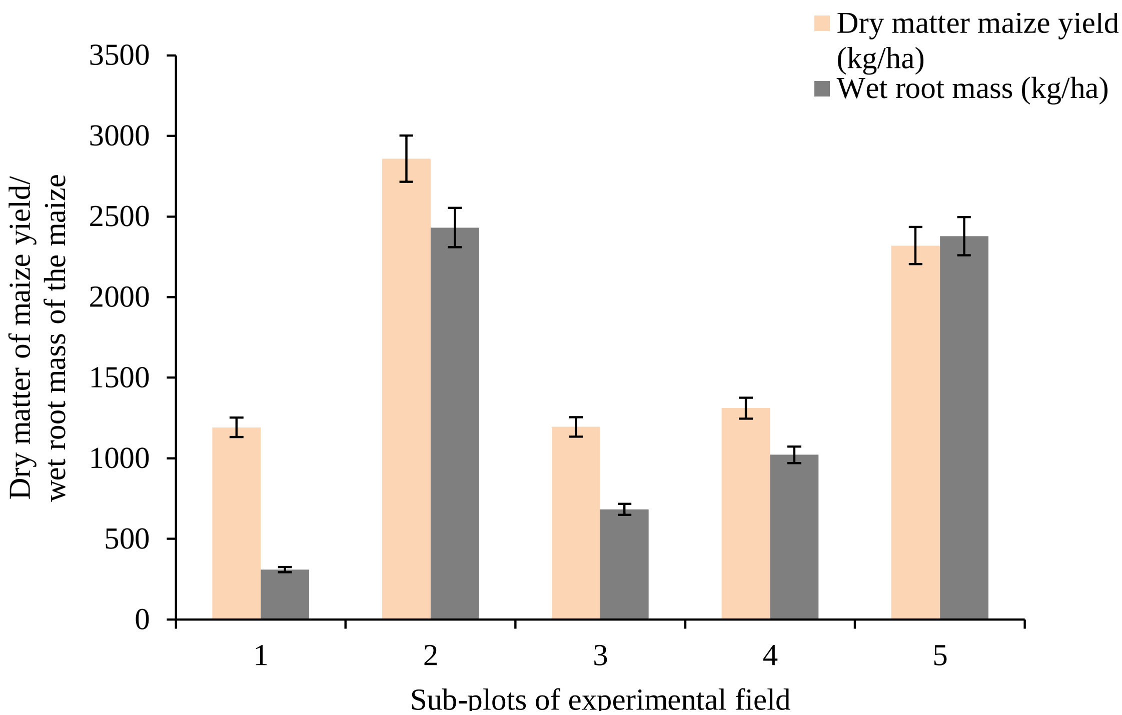

Figure 5. Dry matter of maize yield and wet root mass of the maize crops at various levels of tractor compaction treatments on different experimental sub-plots.

soil moisture that would have sustained future growth. Hence, on the average, this plot recorded the least observed leaf area. This finding is in tandem with the work of Tueche et al. (2013), where they stated that leaf area at harvest were significantly lower in no-till soils, when compared with tilled soils.

Still from Figure 4, the incremental pattern was different on the tilled and un-compacted subplot (2), which had the highest leaf area at the third month after planting. On this plot, although there was only a marginal increment in leaf area between the first two months after planting, the incremental rate of the leaf area rose from 10% in the first month to 80% in the second month. This observation is attributable to the ease with which the plant roots penetrated and extracted moisture and nutrients from the soil, due to the pulverization and reduced compaction of the soil on the plot. A similar finding had been reported by Lipiec et al. (1990), when the researchers posited that the degree of compactness of soil particles affects the leaf area of the crops. Further investigation of the results using the 95% confidence interval showed that no overlap exists between the maize crops intra or inter subplots and thus indicates a significant effect in the results obtained.

Maize crop yield

The maize crop yield, which was evaluated on the basis of its dry matter and wet root mass, is presented in Figure 5. From the Figure 5, the best yield of maize was obtained from the tilled and un-compacted subplot (2), with a dry matter and wet root mass of 2,859 and 2,431 kg ha^{-1} respectively, followed closely by subplot (5), compacted with 6 tractor wheel passes, with dry matter of 2,320 kg ha^{-1} and wet root mass of 2,378 kg ha^{-1}. On the other hand, the least yield was obtained from the untilled and un-compacted subplot (1), with dry matter of 1,192 kg ha^{-1} and wet root mass of 309 kg ha^{-1}. The indication from these results is that the crops on subplot (2) easily accessed moisture and nutrients due to the tilled nature and perhaps the reduced bulk density, only occasioned by the self-weight of the soil. Therefore, the crops on subplot 2 developed an extensive rooting system to access the soil moisture and nutrients. Trouse (1977) as cited by Abu-Hamdeh (2003) stated that optimum crop yields are dependent on optimum root growth; and when soil is in good condition, root systems are large, deep, and expansive.

Using the 95% confidence interval for the dry matter yield (shown in Figure 5), it was observed that no overlap exists for plots 2 and 5, but reasonable overlaps were observed for plots 1, 3 and 4. For the wet root mass, no overlap was observed for plots 1, 3 and 4, but overlap was seen in plots 2 and 5. These observations indicate a significant effect on the results at $p< 0.05$. Therefore, tillage of a sandy loam soil would provide a conducive soil structure for the cultivation of maize for optimum yield in tropical regions. This conclusion finds similarity in the report of Jagdish and Hadda (2015), when the researchers stated that, though minimal compaction is needed for optimal maize crop performance, higher compaction of the subsoil layers decreases crop yield.

Conclusion

The state of sandy loam soil, before and after tillage, in a humid tropical region affects the growth and yield of maize crop differently. The growth and yield of maize on a tilled sandy loam soil in the humid tropics, especially in terms of its dry matter content and wet root mass, is more than twice its performance on a fallow untilled soil. Although soil tillage is essential for optimal maize growth and yield, it is pertinent to check the extent of soil compaction induced by the tractor wheel passes, which should not exceed 1.17 g cm^{-3}. This is so because the maize crop yield is affected adversely by soil compaction, exceeding this value, induced by tractor wheel passes, but performs better on pulverized sandy loam soils.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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