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Seasonal Variability of Maize Yield on a Compacted Sandy Loam Soil in a Tropical Environment

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Abstract: The effect of weather changes on the yield of maize on a compacted sandy loam soil was investigated. The experiment was conducted in the teaching /research farm of the Rivers State University, Port Harcourt, Nigeria. The research started during the wet (rainy) season in October, through the dry season in February. Five experimental field plots were used in the study. The plots were subjected to different levels of compaction by routine tillage operations and wheel traffic, using a Massey Ferguson (MF) 260 tractor and an MF90 disc plough, before the maize seeds were planted. Field data of crop emergence, growth rate and crop yield were taken at regular intervals within the different seasons. Analysis of the results showed an inverse-proportional relationship between maize yield and compaction during the wet season and a direct-proportional relationship during the dry season up to a certain optimal compaction level, when a shift was noticed. It was, therefore, found that different optimum levels of compaction for increased maize yield exist for the wet and dry seasons, respectively. Furthermore, the compacted soil within the optimum limit had better yield during the dry season. On the whole, although the fields with lower bulk densities performed better at the beginning of the study, they were out-performed by those of higher bulk densities by the end of the experiment. Thus, while the plots of bulk densities of 1.17 and 1.23 g/mm^3 had better yield during the wet season, they were out-performed by the plots of bulk densities of 1.28 and 1.35 g/mm^3 during the dry season.

Keywords: Maize Yield, Seasonal Variability, Soil Compaction, Sandy-Loam, Tillage

1. Introduction

Soil compaction is essentially the densification of soil due to external forces; and has become a common and persistent problem in mechanized farming. Soil compaction has been attributed to several causes, both natural and man-induced. DeJong-Hughes et al [1] enumerated some of the causes of soil compaction as raindrops, tillage operations, wheel traffic and minimal crop rotation. But, in mechanized farming, most soil compaction is attributable to vehicular traffic [2].

When soils are compacted, soil physical properties are adversely affected either directly or indirectly. The soil bulk density, for instance, increases while the porosity decreases [3]. These effects due to the densification of the soil tend to increase the soil strength. High soil strength due to compaction reduces crop root growth [4], because the plant roots tend to exert greater pressure to penetrate the soil. However, Campbell and O'Sullivan [5] had stated that the soil resistance to penetration can be reduced with organic matter. But, it is notable that this role of organic matter in subduing compaction is more prominent and feasible in no-till lands, as their good effects may be eroded by vehicular wheel traffic on tilled lands [6]. Martinez [7] stated that crop roots tend to follow tortuous paths seeking out the path of least soil resistance since they are unable to penetrate pores narrower than their own diameter. The crop roots extract moisture from the soil and swell when physically impeded [8]. As roots extend into the soil, when they encounter restrictive layers, they spread horizontally/laterally and are unable to fully utilize moisture and nutrients below this layer, and this invariably limits the plant growth [9].

The state of soil physical conditions is generally determined by the prevailing weather conditions at the time and this in turn affects the growth performance of different crops differently. In other words, changing weather conditions between dry and wet seasons, for instance, alternately change the soil physical properties. Al-Kaisi [10] stated that when soil moisture is at or exceeds field capacity, there is an increased potential for soil compaction, particularly at topsoil depths. He explained further that the degree of soil wetness changes with proportional relationships of air (void spaces in the soil system) to water. The increase of one portion over another affects the rest of the soil's physical properties, such as bulk density, infiltration rate, and soil elasticity. The continual rainfall has the effect of filling voids with additional water. Al-Kaisi & Licht [11] were more graphic with the schematic in Figure 1, when they stated that actually maximum soil compaction occurs when soil moisture is at or near field capacity, because soil moisture works as a lubricant between soil particles under heavy pressure from field equipment.

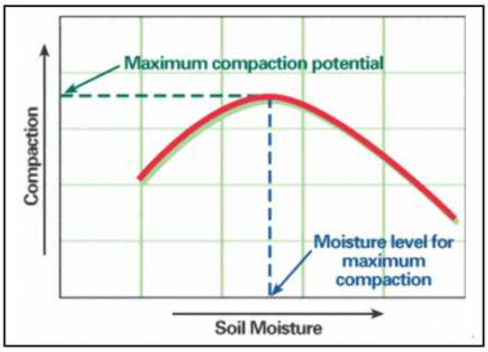

Figure 1. *Moisture-density curve for a medium-textured soil for a given compactive effort (Adapted from Al-Kaisi & Licht, [11]).*

The clear indication from Figure 1 is that soil compaction in the wet season would cause more damage to crop yield than in the dry season. According to McKenzi [12], in wetter than normal years, soil compaction can decrease soil aeration and lead to the increased loss of nitrate nitrogen by denitrification, which occurs when soils are in an anaerobic condition and soil pores are mostly filled with water. He stressed that reduced soil aeration can affect root growth and function, and lead to increased risk of crop disease. All these factors result in increased crop stress and yield loss. Accordingly, DeJong-Hughes [6] established a relationship between grain yield and compaction in wet and dry seasons, from studies in North America and Europe, as shown in Figure 2.

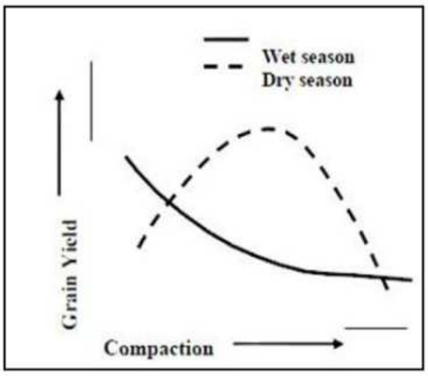

Figure 2. *Effects of weather on crop yield response to compaction levels (Adapted from DeJong-Hughes, [6]).*

From the Figure 2, grain yield increased gradually in the dry season with increasing soil compaction and got to a maximum point, after which the yield started decreasing even with increasing compaction. This clearly establishes an optimal compaction level for the soil in that season. However, the wet season witnessed its maximum grain yield at the lowest compaction level and a continuous decline with increasing compaction.

In Pakistan, Fayyaz-ui-Hassan & Ghulam [13] found that spring crops have superiority over autumn in terms of yield. However, they said autumn crops could be fitted well in the present cropping system of Pakistan to oversee the deficiency of edible oils. Emman & Nahed [14] investigated the effect of climatic seasonal change on the yield and composition of essential oil of *Achillea fragrantissima* and found that the percentage of the major compounds of the 25 components of the essential oil collected were obtained during the dry season (with α-cubebene - 17.1%, spathulenol - 1.54 and globulol - 5.2), while the wet season had fewer percentage components namely santolina alcohol - 5.31, camphor - 4.3 and cedrene - 9.01.

In a similar vein, during the dry season, most soils are loose, as their pore spaces are open, to allow higher water infiltration and greater plant root activity. Chen & Weil [15] observed higher root proliferation in the upper loose layer right above the compacted layer for rapeseed and rye. They reported that 80% of root mass was located within soil depth of 5cm. Grzesiak [16] reported that in drought periods, highly compacted soils affected the length of seminal adventitious roots, the number and length of lateral roots, which eventually aggravated the effect of drought in reducing the crop yield.

Butler and Centurion [17], on their work on variable soil densification, observed a decline in soybean yield beyond bulk density of 1.36 $g.mm^{-3}$ on soils without fertilizer amendment and 1.48 $g.mm^{-3}$ on soils amended with fertilizer. Also, Ishag et al [18] stated that when soils are compacted, the crop yields are reduced due to the increased resistance to root growth and decrease in water and nutrient use efficiencies. Furthermore, Oussible et al [19] observed that the grain and straw yield of wheat decreased by 12-23% and 4-20%, respectively when a clay loam soil was compacted to a bulk density of 1.52 $mg.m^{-3}$ from an initial density of 1.33 $mg.m^{-3}$. Lowery & Schuler [20] similarly observed that the height and mass of crop shoot were reduced in compacted soils when compared to those grown in non-compacted soils.

In Quebec, Raghavan et al [21] reported a 50% reduction in the height of crops planted in soils with some severe traffic treatments. From their research, the reduction in crops growth was found to be dependent on the number of passes and the contact pressure which the soil received. Similar research by Morris [22] showed reduction in crop height on compacted soils as compared to un-compacted soil. The extensive work of Raghavan et al [23] on traction and compaction problems, revealed that a minimal level of soil compaction is needed for optimum crop performance.

This implies that not all levels of soil compaction are detrimental to crop growth and yield. Some selected plants were reported by Soehne [24] to thrive best in their yield, in soils with porosity of around 40-50%. This means that at high porosity, crop growth and yield will be reduced. Thus, a level of soil compaction may be required to improve plant growth and yield. It also implies that when soils are compacted, the dry soil may be brought up to an optimum density to allow the soil to retain more moisture during periods of no rain. This invariably means that the ability of a soil to allow water to flow through it during the rainy periods is dependent significantly on the shape and size of the individual pores throughout the soil mass. Trouse & Humbert [25] agreed to this statement when they observed that a reduction in soil permeability affected ground water storage.

Following the natural variations in climatic and soil conditions of different parts, the major objective of this research work was to determine the seasonal weather condition and the associated level of compaction that is best suited for maize yield in a tropical rain forest climatic region.

2. Materials and Methods

2.1. Description of Study Area

The field investigation was conducted in the teaching and research farm of Rivers State University, Port Harcourt, Nigeria. The study area is of the tropical rainforest vegetation, with a rainfall depth of about 2400 mm and located at latitude 4°45' N and 4°55' N, and longitude 6°55' E and 7°05' E [26]. The area is characterized by high humidity (≥80%). The monthly minimum temperatures range from 18.32 to 23.14°C in rainy season (October - November), with a mean of 21.49°C, while the minimum temperature in dry season (December - February) range from 21.92 to 22.97°C with a mean of 22.40°C [27]

2.2. Materials

A 72 m^2 plot of land was used for the planting experiment. Other materials used for the experimental work include: Massey Ferguson (MF) 260 model tractor, MF90 disc plough, non-hybridized maize seeds, pesticide, core sampler, hydrometer, irrigation cans and grass mulch.

2.3. Methods

The experimental plot, fallowed for 24 months, was cleared manually. The plot was divided into 5 equal subplots of 9 m^2 each, with an inter-subplot furrow spacing of 1.5 m^2, for ease of administration of other field treatments and monitoring, like ensuring effective rainwater (rainy season) and irrigation water (dry season) distribution. The sub-plots were labelled 1-5. Plot 1 (the experimental control plot) was left in its original state, while plots 2-5 were ploughed using tractor mounted MF 90-disc plough. Plot 2 had no compaction treatment. Plots 3, 4 and 5 were given various tractor compaction treatments using MF 260 model tractor. Plot 3 had two tractor passes as its compaction treatment, while plot 4 had four passes as its treatment and plot 5 had six tractor passes as its compaction treatment.

After the compaction operations, soil samples were randomly taken at depths of 0.3 m below ground surface, respectively from each of the five sub-plots. The soil bulk density was determined using the core method. The soil particle size analysis was determined using the hydrometer method described by Forth [28]. From the results of the particle size analysis, the soil textural classes were determined using the United States Department of Agriculture textural triangle. The soil moisture content was determined using the gravimetric method described by the American Society of Agricultural Engineers standards [29].

Two non-hybridized maize seeds were planted at 0.05 m depth with an inter-row spacing of 0.25 m x 0.75 m. Manual method of weed control was adopted for the experiment and the experimental plots were irrigated as at when due with equal volume of water per plot. The evaporative moisture control method adopted was the grass mulch system. At the ninth week of growth, the field was treated with Karate 0.8% ULC pesticide as a pest control measure.

The plant heights were measured at weekly intervals from the third week of growth using soft measuring tape. The crops viability was noted and the leaf area also determined. After fifteen weeks of growth, the crop wet root mass for each plot was determined. The yield was determined through the cobs above ground matter. These cobs were oven dried for a 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 & Gomez [30]

3. Results and Discussion

The results obtained from the field and laboratory experimentations are presented in Table 1 and graphically related one to another using the charts in Figures 3 to 8.

3.1. Particle Size Analysis

Table 1 shows the results of particle size distribution of the different experimental plots.

Table 1. *Results of Soil Analysis.*

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

The results show that all the experimental plots had a uniform soil type. Soils in plots 1-5 all fall within the sandy loam classification, using the United States Department of Agriculture textural triangle.

3.2. Moisture Content and Bulk Density

Figures 3 and 4 establish relationships between the soil bulk density and moisture content with respect to the different experimental plots numbered 1-5.

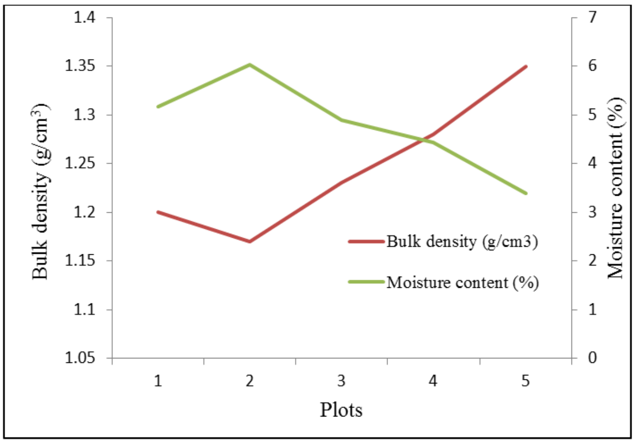

Figure 3. *Relationship between bulk density and moisture content on the various plots with varying tractor compaction treatments.*

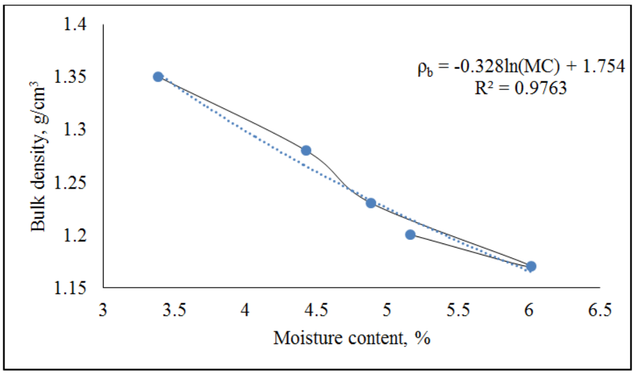

Figure 4. *Relationship between soil moisture and bulk density.*

Considering the bulk density (Figure 3), the chart shows a fall from a high value on the untilled plot (plot 1) to a low value on the tilled but un-compacted plot (plot 2). Thereafter, the rising curve on the right side of the depression shows a continuous increment in bulk density for plots 3 to 5, corresponding to their various levels of compaction treatment. This trend does not only indicate that the soil bulk density is directly proportional to the level of compaction, but that, despite the extent of tillage done on a field, compaction will increase the bulk density beyond the level of the untilled field and neutralize or nullify whatever effect the tillage would have had. This was why Duiker [31] advised that the fact of tillage should not make farmers to neglect the "important principles of soil compaction avoidance". On the overall, the variations in the field results agree with the work of Gupta and Jangid [32] on the effect of bulk density on emission behaviour of soil at microwave frequencies. In their work, they concluded that bulk density increases with soil strength and densification.

For the water content of the soil (Figure 3), the indication is that plot 2 (tilled but without compaction) had the highest level of moisture (with moisture level of about 6.02%). This was followed by plot 1 (untilled and un-compacted) with moisture level of about 5.17%). Thereafter, there was a continuous reduction in moisture content on plots 3 to 5, also corresponding to their various increasing levels of compaction. This, therefore, shows that as the soil compaction level increases the soil moisture level reduces. A distinct relationship between the soil bulk density and moisture content is shown in Figure 4 and described by a logarithmic function as in equation (1).

$$\rho_b = -0.328[\ln(MC)] + 1.754 \qquad (1)$$

Where: ρ_b - Bulk density

MC - Moisture content

These variations might be related to the changes in pore sizes due to the compaction treatment given to the soil. The applied water tends to infiltrate into the soil at a slow rate, giving rise to ponding on the soil surface. Furthermore, there would also be more evaporation of the applied irrigation water, which was observed as black streaks on the soil surface. These conditions were worsened by the high temperature of the region during the dry season as compared to the low temperature recorded during the wet season. The variation existed irrespective of the fact that equal amounts of rainfall and irrigation water were applied at all times. These observed irregularities in moisture distribution level of the soil will affect the maize crop growth and yield, since nutrients are mostly available to crops through moisture extracted by the crops roots. These results were in conformity with the work of Rezaee et al [33], where the researchers estimated the soil water retention from soil particle size distribution using the Arya and Paris model for Iranian soils.

From Figure 3, it was further observed that an equilibrium was established between the moisture content of the soil and the soil bulk density. This point of intersection was observed at about 1.275 $g.cm^{-3}$ for the bulk density and 4.5% for the soil moisture content. This point of equilibrium was just around plot 4 (with 4 tractor passes as its compaction treatment). This result tends to correlate the findings of Meek et al [34]. Meek and his research team worked on the bulk density of sandy loam soil after some tractor traffic and irrigation was given to the soil as treatments and reported that, after tillage, settling and trafficking of a soil results in rapid changes in the physical condition of the soil until an equilibrium was reached. This equilibrium point tends to establish the minimum compacted soil requirement for optimum plant performance.

3.3. Maize Crop Height

The variation of maize crop height and the time of growth in weeks after planting is shown in Figure 5.

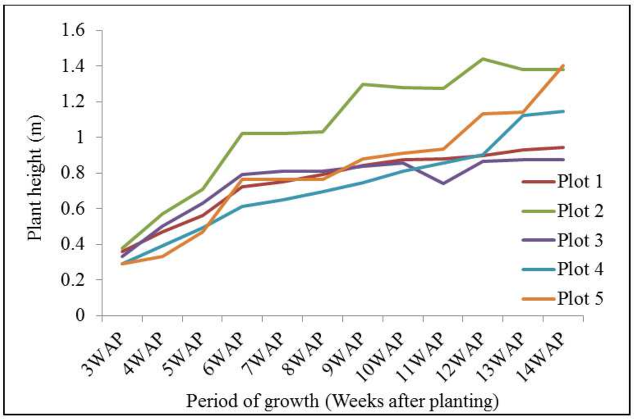

Figure 5 *Relationship between plant height (m) and time of growth (weeks after planting).*

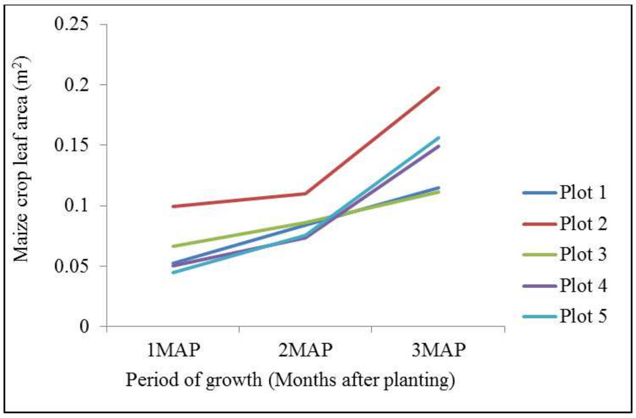

Figure 6. *Plot of Maize crop leaf area (m^2) against period of growth (months after planting).*

The curve shows that the crop height varied directly as the period of growth. The crop growth measurement commenced at the third week after planting. This period fell under the wet season of the year. At the third week after planting, the crops in plot 2 (tilled and un-compacted plot) experienced better growth compared with the crops planted in other plots. This might be attributed to the ease with which the crop roots penetrated the soil and extracted moisture, since the plot was not given any form of compaction after the tillage operation. Plot 1 (neither tilled nor compacted) ranked second in terms of crop growth at the third week, while plot 5 performed the least at the third week of growth. This poor performance by plot 5 (with the highest level of compaction) can be linked to the reduction in soil pore sizes due to the densification from the tractor traffic. Similar trend on some row crops were observed by Gaultnery et al [35], who reported that an impeded plant height during the crop growth was due to compaction problems.

At the fourteenth week of growth, which fell within the dry season of the year, it was observed that the compaction had beneficial effects on the plant performance. The crops at plot 5, which had the least crop height during the wet season, now has the best growth with crop height of about 1.402 m in the dry season. This performance can be linked to the ability of the compacted soil to retain the moisture that the plant used for its growth. This result agrees with the conclusion of Zlatko et al [36], who stated that maize crops performance may not be negatively affected by compaction.

Apart from measurement errors encountered in this research work, the observed soil-plant relations are primarily due to the level of applied external pressure on the soil by tractor traffic treatment.

3.4. Maize Crop Leaf Area

The relationship between the maize crop leaf area and the level of compaction applied on the different plots is shown in Figure 6.

At first month after planting, which fell under the wet (rainy) season of the year, it was observed that best maize crop leaf area was from crops on plot 2 (plot that was tilled but without compaction treatment). The least maize crop leaf area recorded at that same period was from crops on plot 5 (with the highest level of compaction). This observation corroborates the findings of Lipiec et al [37], who stated that increase in compaction reduces the crop leaf area. In the third month after planting, which fell into the dry season of the year, it was observed that, though the crops on plot 2 still retained the best leaf area, it was now followed by the crops on plot 5, which had the least leaf area during the rainy season. This rapid change can be linked to the ability of the densified soil to retain the applied moisture for crop use. This observation agrees with the conclusion of Odjugo [38], that: retained soil moisture can positively impact crop leaf area. The observation indicates that crops on plots 2 and 5 will have more active photosynthetic activities when compared with the other crops. Also, these crops with higher leaf area would have better yield compared to other plots, provided equal treatments of moisture and nutrient are applied to them.

3.5. Maize Crop Wet Root Mass

The United States of America National Research Council [39] stated that when the bulk density of soil increases to a critical level, root penetration is restricted and root distribution is reduced. Beyond the critical level, roots are unable to penetrate the soil and root growth and distribution is prevented. These changes affect the productivity of the plant and can lead to lower yield and higher cost of production. This assertion was confirmed by Jacques [40], that excessive soil compaction can impede root growth and, therefore, limits the amount of soil explored by roots, thus reducing the plant's ability to take up nutrients and water. Figure 7 shows the variation of wet root mass with the level of compaction given as soil treatment.

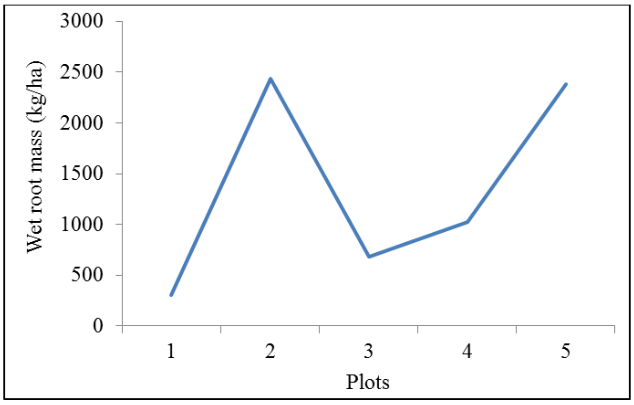

Figure 7. *Wet root mass (kg/ha) versus plots with varying levels of tractor compaction.*

From the curve of Figure 7, it was observed that the highest wet root mass, 2859 kg/ha was obtained from plot 2 (plot tilled but no compaction given). This was closely followed by plot 5 (plot with highest level of compaction) with wet root mass of 2320 kg/ha. This improvement recorded in plot 5 can be related to the fact that the wet root mass was obtained at the point of harvest, which fell within the dry season of the year. Thus at that level of compaction, the crop roots at plot 5 were able to extract the moisture retained by the soil due to compaction. It is worthy of note that, for the plants to be able to extract the retained soil moisture from the compacted soil (plot 5), the critical level of compaction that may be detrimental to maize crop growth and yield was not exceeded.

3.6. Maize Crop Dry Matter Yield

Figure 8 is a plot of the variation of maize dry matter yield (kg/ha) on the plots, with varying levels of tractor compaction treatments.

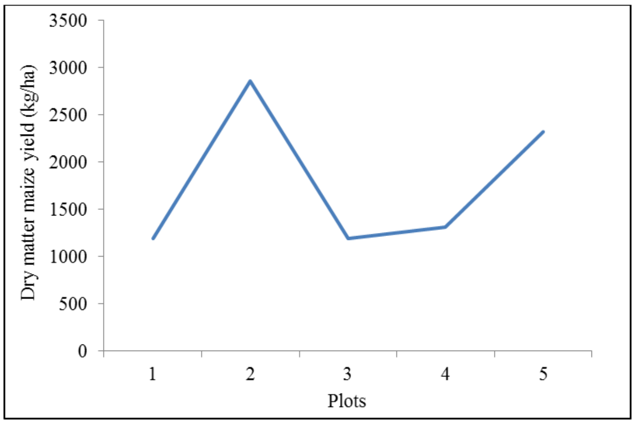

Figure 8. *Variation of maize dry matter yield (kg/ha) on plots with varying levels of tractor compaction.*

The yield recorded is a summation of the responses of the plants from the wet (rainy) season when the crop was planted to the dry season when it was harvested. From the chart, it was observed that crops on plot 2 had the best yield. This was closely followed by crops on plot 5 with reduction in yield of 18.85% when compared with crops on plot 2. The yield can be attributed to the crops accessibility to moisture, nutrients and the crop leaf area. The result obtained from plot 5, with the highest level of compaction, contradicts the findings of Gysi et al [41], who stated that compaction significantly reduces grain yield. It rather corroborates the work of Ohu et al. [42], who worked on groundnut production in a sandy loam soil and concluded that a moderate amount of soil compaction is needed for optimum yield.

4. Conclusion

This work has established that soil compaction effect on the growth and yield of maize on a sandy loam soil in a humid tropical environment is dependent on the season of the year in which the compaction is operational. In the Port Harcourt metropolis, Rivers State, Nigeria where this work was carried out, the compaction effect on the maize growth and yield was more favourable in the dry season than in the (wet) rainy season, as the compacted fields that were performing poorly during the wet season would eventually improve and even outperform the un-compacted fields during the dry season. Notably, the varying seasons of the year alongside the compaction on the soil had no effect on the soil textural class. So, it is concluded that soil compaction has beneficial effects on maize growth and yield during the dry season when moisture is not readily available. However, it is recommended that this research be continued with more field plots and increased levels of compaction, to be able to establish the optimal compaction level of the soil beneficial to the maize crop during the dry season.

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