<u>Original Research Article</u>

Soil Compaction Effects on Soil Physical Properties and Soybean (*Glycine max*.) Yield in Ogbomoso, Southwestern Nigeria

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ABSTRACT

Compaction is one of the major threats to soil sustainability as it can have negative effects on soil physical properties. Therefore, field experiments were conducted at Ladoke Akintola University of Technology Teaching and Research Farm, Ogbomoso, Southwestern Nigeria, in 2015 and 2016 to evaluate the influence of soil compaction on selected soil physical properties, growth, yield and nutrient uptake of soybean (*Glycine max*.). The experiment was arranged in a randomized complete block design and replicated three times. There were four treatments which consisted of 0 (no pass of tractor wheel), 4, 8, and 14 passes of tractor wheel totaling 16 treatments. Soil physical properties determined were; bulk density, total porosity, macroporosity and saturated hydraulic conductivity. While data recorded on soybean were plant height, stem girth, number of leaves, biomass and grain yield. Data collected were subjected to Analysis of Variance and significant means were compared using Least Significant Difference at 5% level of probability. Although not significant, soil physical quality decreased with increased levels of soil compaction in both years of study. Growth of soybean was significantly reduced by soil compaction with 14 passes producing the shortest plant (91.46, 29.10 cm) compared to the control (103.96, 30.27 cm), respectively, for 2015 and 2016. Grain yield of soybean significantly decreased by 12, 27, and 44% respectively, for 4, 8 and 18 passes of tractor wheel. The study indicates that soil compaction as a result of tractor wheel passes should be minimized on agricultural fields to reduce the adverse effects on soil physical properties, soybean growth and yield.

Keywords: Soil Compaction, Physical Properties, Soybean Yield, Nutrient Uptake

1. INTRODUCTION

In modern agriculture, there has been an increased use of agricultural machinery for field operations. Though an integral part, farm machinery could result in the adverse effect of soil compaction [1]. The benefits of using heavy machinery to cover a larger area with more efficiency are evident. However, the steady increase in wheel load of agricultural machinery in the past few decades has caused agricultural soils to be susceptible to compaction in both the topsoil and subsoil [2], [3]. The frequency of wheel passes influences the stress transfer into the subsoil causing compaction [4]. It has been reported that there are 68 million hectares of compacted soil globally only because of the traffic of agricultural machinery [5].

In most recent times, soil compaction is considered one of the main threats to sustainable crop yield because of soil physical quality degradation [6], [7]. Soil compaction deforms the soil structure by crushing aggregates, increasing bulk density and decreasing total porosity and macroporosity. These have cascading negative effects on water storage and transport through the soil profile, soil aeration, root growth and nutrient availability, eventually affecting overall crop yields [8], [9]. Another consequence of soil compaction is an increase in energy demands of soil tillage, which adversely affects the germination of cultivated crops [8]. Compaction also has consequences on the direct and indirect losses of farmers' profits. Losses of crops, fertilizers, and additional fuel consumption constitute the direct losses while indirect profit losses occur over time with an accumulation of compaction and are associated with flooding, erosion and soil sealing [3].

Indicators for measuring soil compaction include bulk density, porosity, moisture content, plant growth, development and yield [10]. Reports have shown varying effects of soil compaction on soil properties and crop growth. [11] noted that machine traffic of four passes of the tractor increased the bulk density and decreased the total porosity for all layers above 30 cm depth. They also noted that the grain yield of soybean had a strong negative response to compaction. In the contrary, [10] observed that the grain yield data of corn and soybean crops showed no significant difference between compacted and non-compacted rows. The highest soybean yield was observed in plots cultivated with chisel plough (3.47 Mg ha^{-1}) and disc plough (3.46 Mg ha^{-1}), producing a 10% higher yield than no-till plots with wheat cover (3.15 Mg ha^{-1}) [11]. In an experiment by [12], the effect of three different tillage regimes on soil compaction and for corn yield was analysed. High soil compaction levels in direct sowing tillage system decreased yield by 15% compared to the other two tillage systems.

In Nigeria, soil compaction is an increasing problem because farmers are adopting mechanized farming to produce on large scale to meet the ever-increasing population. Soil compaction becomes imperative on agricultural soil, especially in the subsoil layer below the arable topsoil. Therefore, this work aimed to determine the influence of tractor wheel pass on selected soil physical properties, growth and yield of soybean.

2. MATERIAL AND METHODS

2.1 Site Description

A field experiment was carried out from 2015 to 2016 at the Teaching and Research Farm of the Ladoke Akintola University of Technology, Ogbomoso, (8°10'06" N and 4°16'12" E) in Nigeria. The mean annual precipitation is 1000 mm, while annual temperature ranges from a low of 28°C tohigh of 33°C, with a relative humidity of about 74%. The soil of the area is an Alfisol according to the United States Department of Agriculture (USDA) Taxonomy [13]. It is moderately well-drained, ferruginous, tropical soil with sandy loam texture.

The experimental field (48 m^2) was ploughed once and after two weeks was ploughed again with the aid of a mold board disc plough. After the second plough, the land was leveled manually, and the compaction treatments were imposed with the use of tractor wheel model Massey Ferguson (MF 435) with specifications in Table 1. The experiment was a Randomized Complete Block Design with four replications. There were four treatments which consisted of 0 (no pass of tractor wheel), 4, 8, and 14 passes of tractor wheel, totaling 16 plots. Each replicate measured 4 by 2 m which gave a plot size of 8 m^2.Soybean seeds (*Glycine max)* sourced locally were planted manually on the field. Three seeds were sown in rows 50 cm apart and within row spacing at 25 cm. Thinning of seedlings to two plants $stand^{-1}$ was carried out at 2 weeks after sowing. This gave 80,000 plants per hectare.

Table 1. Specification of the tractor used for compaction of the soil

Specification	Unit
Model	Massey Ferguson (MF 435)
Engine type	Perkin 4000 Effective power: 54 kW

Rated Engine Speed	2200rpm
Number and type of cylinder	i = 4p Firing order: 1-3-4-2
Stroke to bore ratio, (S/D)	127 mm/100 mm Injection sequence: 1-3-4-2
Maximum power at rpm	ISO14396 – cv: 72kW @ 2200rpm
Maximum torque at rpm	ISO14396 – Nm: 267 @ 1400 rpm
Mechanical efficiency	86%

(Source: Massey Ferguson owner's manual)

2.2Data Collection and Analyses

Undisturbed soil samples were taken from each plot at 0–15 and 15–30 cm soil depth for the determination of soil dry bulk density (BD) using the core method (5 cm height × 5 cm diameter) as described by [14]according to equation 1.

$$BD = \frac{Soil\ Mass\ (Oven\ Dried)}{Soil\ Volume}\ (Mgm^{-3})\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$Volume\ of\ soil\ sample\ =\ Volume\ of\ the\ core\ = \frac{\pi D^2 h}{4}$$

Where:

$BD\ = Bulk\ density;\ h = Height\ of\ the\ core\ (cm); D\ = Inner\ diameter\ of\ the\ core\ (cm)$

Total porosity (TP) was calculated from the relation of soil dry bulk density and particle density (assumed as 2.65 gcm^{-3}) as represented in equation 2.

$$TP\ = \frac{1\ - \rho_b}{\rho_s}\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where:

$TP = Total\ porosity;\ \rho_b = Bulk\ density;\ \rho_s =\ Particle\ density.$

Macroporosity (MP) was determined according to [15] and was calculated as:

$$q_w = \frac{W_w}{V_w}$$

Where

$q_w =\ Macroporosity;\ W_w =\ Different\ wet\ and\ dry\ soil;\ V_w =\ Volume\ of\ the\ core\ used.$

Saturated hydraulic conductivity (ksat) was obtained using method described by [16].

$$Ksat = \frac{QL}{(L + h)\cdot A(T)}$$

Where

$Q = Quantity\ of\ water\ equilibrium\ flow;\ L = Length\ of\ core\ used\ (cm);$

$A = Area\ of\ the\ core\ (cm^2);\ T = Time\ interval\ (minutes);\ h = Height\ of\ the\ core\ (cm)$

To evaluate the effect of soil compaction on soybean growth and yield, the following measurements were taken. Plant height, stem girth, and the number of leaves were monitored at 2 week intervals for 12 weeks, but only data for 12 weeks after sowing (WAS) were reported. The number of pods at 10 and 12 WAS were recorded for 2016 only while total biomass and grain yield (kg ha^{-1}) were obtained for 2015.

2.3Data Analysis

All data collected were subjected to analysis of variance (ANOVA) using SAS (SAS Institute), version 9.4. The significant means were separated using least significant difference(LSD) at 5 % level of probability.

3. RESULTS

3.1 Soil Physical Properties

The Influence of soil compaction on selected soil physical properties at 0-15 cm and 15-30 cm soil depths are presented in Table 2 and 3.

At both soil depths of soil sampling, soil compaction as a result of tractor wheel pass did not show any significant effects on the soil bulk density in both years of study. However, bulk density increased with an increase in the number of tractor wheel passes. Bulk density ranged from 1.24 Mgm^{-3} on no pass to 1.43 Mgm^{-3} on 14 passes at 0-15 cm depth. Corresponding soil bulk density ranged from 1.27 to 1.42 Mgm^{-3} at 15-30 cm soil depth.

Similarly, soil compaction had no significant effect on total porosity in both years at the two depths of soil sampling. The value ranged from 46.04% on 14 passes of tractor wheel in 2015 to 53.21% in 2016 at 0-15 cm depth, while at 15-30 cm depth, total porosity ranged from 46.22% on 14 passes to 52.08% on no tractor wheel pass.

Soil macroporosity (MP) showed no significant difference among tractor wheel passes at 0-15 and 15-30 cm soil depths for both years. MP was highest on no pass (0.17 and 0.99 m^{3}m^{-3}) and least on 14 tractor wheel passes (0.12 and 0.69 m^{3}m^{-3}) respectively, for 2015 and 2016, at 0-15 cm. MP ranged from 0.08 to 0.16m^{3}m^{-3} at 15-30cm depth.

Saturated hydraulic conductivity followed a similar trend as other physical properties. Ksat also decreased with an increase in tractor wheel pass at 0-15 and 15-30 cm in both years. Ksat ranged from 6.13 to 13.65 for 0-15 cm and 2.85 to 7.05 at 15-30 cm soil depth.

Table 2. Influence of soil compaction on selected average soil physical properties at 0-15 cm soil depth, total porosity, macroporosity and saturated hydraulic conductivity in both years of study

Number of tractor wheel pass	Bulk Density (Mgm^{-3})		Total porosity (%)		Macroporosity (M^{-3}M^{-3})		Ksat (cmhr^{-1})	
	2015	2016	2015	2016	2015	2016	2015	2016

0 (control)	1.24	1.34	53.21	49.43	0.17	0.99	6.73	13.65
4	1.26	1.35	52.45	49.04	0.15	0.77	6.53	13.60
8	1.29	1.39	51.32	47.44	0.14	0.73	6.46	7.80
14	1.30	1.43	50.94	46.04	0.12	0.69	6.13	7.20
LSD (0.05)	0.09	0.20	10.15	7.78	0.25	0.26	10.25	8.79

Table 3. Influence of soil compaction on selected average soil physical properties at 15-30cm soil depth

Number of tractor wheel pass	Bulk Density (Mgm^{-3})		Total porosity (%)		Macroporosity ($M^{-3}M^{-3}$)		Ksat ($cmhr^{-1}$)	
	2015	2016	2015	2016	2015	2016	2015	2016
0 (control)	1.27	1.27	52.08	51.98	0.16	-0.10	5.49	7.05
4	1.27	1.32	52.08	50.18	0.16	-0.08	4.52	6.45
8	1.31	1.32	50.56	50.18	0.15	0.08	4.55	5.85
14	1.34	1.42	49.43	46.22	0.15	0.08	2.85	5.40
LSD (0.05)	0.12	0.19	4.14	7.40	5.19	2.59	3.81	2.10

3.2Soybean Growth and Yield

Generally, the growth of soybean was influenced by soil compaction (Table 4). Plant height of soybean decreased with an increased number of tractor passes. The taller plants (103.96, 30.27 cm) were under the control while the shorter plants were recorded on 14 tractor wheel passes (91.46, 29.10 cm), respectively for 2015 and 2016.

Soil compaction had a significant influence on the stem girth of soybean plant. Tractor no pass recorded the thickest stem for both years and was significantly higher than 14 tractor wheels pass in both years.

The number of leaves followed the trend observed for stem girth in 2015. The number of leaves for soybean plants was significantly higher under no pass (118) than 14 tractor wheels pass (110). However, in 2016, the number of leaves was highest under 4 tractor wheels pass and decreased significantly with an increasing number of wheel passes.

The number of branches followed the same trend as the number of leaves in 2016. However, the differences were not significantly different. The number of branches ranged from 13 (14 passes) to 24 (4 passes).

Table 4. Influence of soil compaction on soybean growth at 12 weeks after sowing

Number of tractor wheel pass	Plant height (cm)		Stem girth (mm)		Number of leaves		Number of branches	
	2015	2016	2015	2016	2015	2016	2015	2016
0 (control)	103.96	30.27	1.72	1.47	118	54	-	18

4	101.67	33.72	1.59	1.42	115	73	-	24
8	96.25	34.27	1.21	1.40	112	66	-	22
14	91.46	29.10	1.13	1.30	110	39	-	13
LSD (0.05)	3.61	6.53	0.12	0.13	2.54	3.25	-	11

Total biomass and grain yield of soybean as influenced by the degree of soil compaction are presented in Table 5. In 2015, no data were collected on biomass and grain yield of soybean because of logistic reasons on the field. However, in 2016, number of pods per plot showed that there was no significant difference among wheel passes. There was a significant decrease in total biomass and grain yield of soybean with increased levels of soil compaction.

Table 5. Influence of soil compaction on number of pods, biomassand grain yield of soybean in 2016

Number of tractor wheel pass	Number of pods	Total biomass	Grain yield
		← $Kgha^{-1}$	→
0 (control)	17	0.29	1.58
4	19	0.24	1.38
8	15	0.16	1.15
14	9	0.10	0.88
$LSD_{(0.05)}$	8.54	0.05	0.16

3.3Nutrient Uptake

The effect of soil compaction on uptake of N, P, and K was not significantly different among compaction levels. However, N, P, and K decreased with an increase in the number of tractor wheel passes in both years. The uptakes by soybean grown on soil subjected to 18 tractor wheel pass relative to 0 (no pass), respectively, for 2015 and 2016 were N (8%, 1%), P (26%, 3%) and K (15%, 3%).

Table 6. Influence of soil compaction on nutrient uptake of soybean at harvest

Number of tractor wheel pass	N (%)		P (%)		K (%)	
	2015	2016	2015	2016	2015	2016
0 (control)	0.75	3.07	0.19	1.02	0.69	0.36
4	0.74	3.03	0.18	1.00	0.64	0.36
8	0.73	3.04	0.17	1.00	0.61	0.35
14	0.69	3.03	0.14	0.99	0.59	0.35
LSD (0.05)	0.27	0.13	0.18	0.12	0.29	0.02

Regression graph in Fig. 1 shows significant relationship (R^2= 0.9683) from bulk density and total biomass and Fig. 2 shows significant relationship (R^2= 0.9693) from bulk density and soybean grain yield both at 0- 15 cm soil depth.

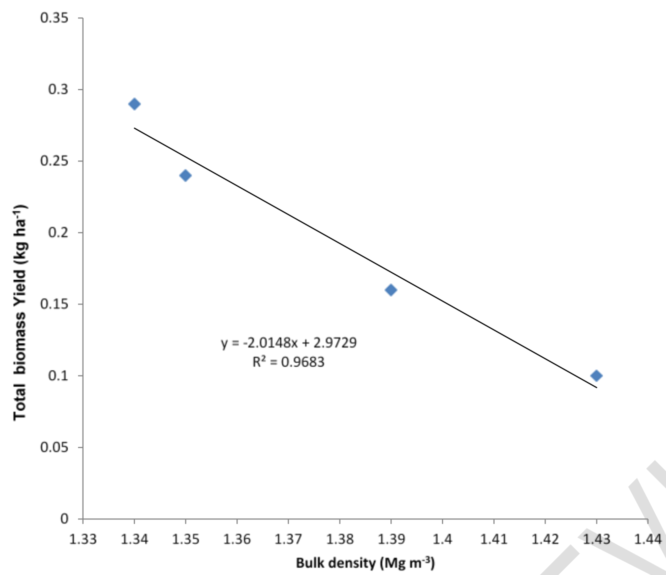

Fig. 1.Relationship between bulk density and total biomass yield at 0 -15 cm depth in 2016 cropping season.

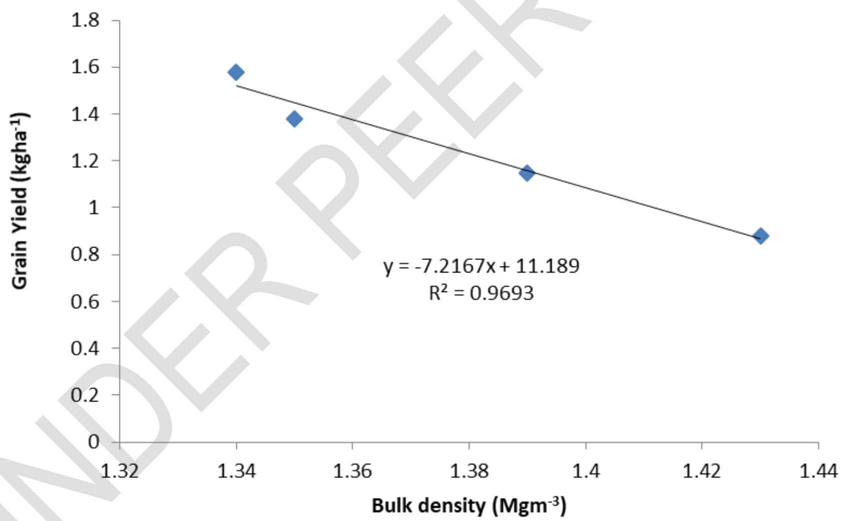

Fig. 2. Relationship between bulk density and grain yield at 0 -15 cm depth in 2016 cropping season.

4. DISCUSSION

The result of the effect of soil compaction on soil bulk density in this study revealed that the compression of soil led to the highest bulk density observed on 14 tractor wheel passes. An increase in soil compaction causes an increase in bulk density, as compacting forces squeeze the volume of soil by eliminating pore spaces. External stress (high axle load) reduces aggregate stability of the soil, thus increasing the bulk density of soil [17]. This may limit crop growth by reducing infiltration of water into the soil, causing mechanical impedance for root growth. Similar reports by [19] and [20] suggested that bulk density due to soil compaction can lead to degradation of the soil's physical environment for plant roots. Averaging over treatments, the bulk density was found to be greater at wheel trafficking treatment than the control at all measured depths [20]. [21] found that increasing the number of passes increased the density of the soil and eventually led to soil compaction [22] reported that bulk density could be increased up to 20% due to multi-wheeling.

Total porosity has an inverse relationship with bulk density. This study shows that with an increase in compaction levels, the total porosity decreased by 15% on 14 passes relative to no pass of the tractor wheel. A reduction in total porosity will lead to fewer pores spaces for water and air which can limit crop growth. [23] noted that due to vehicular traffic, compaction increases soil bulk density and decreases porosity.

The decrease in macroporosity due to compaction revealed that macropore which are majorly responsible for aeration and drainage were reduced in size. Therefore, air and infiltration of water into the soil decreases with an increase in the number of tractor wheel passes. The heavy use of farm implements enforces high axle load and ground pressure on soil, causing shrinkage in pores, and consequently, the volume of pores decreases. [17] noted that the alteration in pore size distribution due to compaction could result in increased runoff, decreased infiltration, and high erosion losses. In a similar experiment, a smaller macroporosity and number of pores were recorded in a trafficked treatment compared with the non-trafficked control [23]. These authors noted that severe compaction may decrease preferential water flow by reducing macropore continuity. In another study by [24], who examined the effect of repeated wheeling on the pore size distribution and pore volume, they noted that no visible macropore were observed in highly compacted zones. The destruction effect of a compacted zone has also been reported by [25], who pointed out that a compacted zone negatively affects macropore volume and air permeability of the topsoil (0.05–0.1 m and 0.18–0.23 m) and subsoil (0.4–0.45 m) layers.

Saturated hydraulic conductivity (Ksat) decreased with compaction levels in both sampled depths. However, 15-30 cm had lower Ksat than 0-15 cm depth. This can be attributed to more compaction at the subsoil layer than the surface soil. This is however in contrast with the findings of [26] who noted that saturated hydraulic conductivity was found lower in topsoil than in subsoil at the same bulk density, which may be due to differences in soil structure. It is also a known fact that soil compaction has more effect on large pores, whereby large pores diminish and thus reduce the hydraulic conductivity of soils.

[27]observed that compaction reduces the saturated and near-saturated hydraulic conductivity of the soil. Similarly, [28]reported that hydraulic conductivity was lower for the soil with several tractor passages compared with no passage. Furthermore, [29] reported that compaction decreased Ksat in both the topsoil and upper subsoil of medium-and fine-textured soils. [23] also found out that compaction significantly decreased Ksat at the wheel trafficked treatment compared to the control. They noted that it was consistent with the reduced macroporosity and connected porosity.

The reduction of growth and yield of soybean as was generally observed in plant height, stem girth, number of leaves, number of branches, biomass and grain yield, was evidence of less favourable soil physical condition for the soybean plant. The growth and development of aboveground crop plants depend on the performance of the belowground part (root); however, root performance is majorly governed by soil conditions in the root rhizosphere. Soil compaction results in a significant reduction in soil porosity and soil aeration; therefore, roots show stunted growth and poor root proliferation which could have reduced water and nutrient uptake by the plants. A decrease in macropore could also result in the development of anoxia conditions, thus interfering with crop growth and development [17]. The increase in soil bulk density might have led to unfavourable soil physical conditions for plants that resulted in yield losses. Similar results have been reported for soybean[7], [30], [31],wheat and maize [32].

The result of the effect of soil compaction on uptake of N, P, and K suggested that the uptake of these nutrients was adversely affected with the highest level of soil compaction.

The regression equations in 2016 cropping season, revealed that the relationship of total biomass and grain yield decreased with increased bulk densities which is an indicator of soil compaction.

5. CONCLUSION

An experimental study was conducted on theeffect of soil compaction on soil physical properties and Soybean (*Glycine max*.) yield. The experiment showed thatthenumber of tractor passages affects soil compaction. Generally, the higher the number of tractor wheel passes, the higher the soil compaction. Soil compaction led to; 5-12% increased soil bulk density, decreased range of; 4-11% total porosity, 2- 30% macroporosity, and 9- 48% saturated hydraulic conductivity. There was also a reduction in soybean growth, yield and N, P and K uptake with increased compaction levels.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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