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Effect of Soil Compaction and Bulk Density on the Growth and Yield of Soybean (*Glycine max*) on Sandy Clay Loam Soil of the Semi-arid Region of Northern Nigeria as Influenced by Tractor Wheel Traffic

Abdu Dauda[1*] and Bukar Usman[2]

[1]Department of Agricultural and Environmental Resources Engineering, University of Maiduguri, Nigeria.
[2]Department of Civil and Water Resources Engineering, University of Maiduguri, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Soil compaction from farm machinery is an environmental problem. The effect of compaction on plant growth and yield depends on the crop grown and the environmental conditions that crop encounters. The effect of compaction from tractor traffic on soybean (*Glycine max*), variety TGX1448-2E, on a sandy clay loam soil in the semi-arid region of northern Nigeria was investigated for two growing seasons, 2015 and 2016. A randomized complete block design of the field of plots with treatments of 0,5,10, 15 and 20 passes of a tractor MF 390 was used. Each treatment was replicated three times. The soil bulk density, penetration resistance and soil moisture content for each applied load were measured and the yield from each treatment was determined. Agronomic treatments were kept the same for all plots in both 2015 and 2016. Results showed increased soil bulk density, penetration resistance and soil moisture content with increased tractor passes. Highest grain yield was obtained at 5 tractor passes with a mean bulk density of

**Corresponding author: E-mail: abdullahimiringa@gmail.com;*

1.76 Mgm^{-3}, penetration resistance 1.70 MPa and moisture content 13.37% with a mean yield of 2568 $kgha^{-1}$ and lowest was obtained from 20 tractor passes were 340 $kgha^{-1}$. Statistical models were used to predict yield as a function of bulk density, penetration resistance, moisture content, contact pressure, and a number of tractor traffic passes. Grain yield with respect to moisture content gave the best yield prediction (r^2 = 0.94).

Keywords: Tractor wheel traffic; soil compaction; bulk density; soil moisture content; plant growth; soybean.

1. INTRODUCTION

Soybean (Glycine max) is a species of ground nut, legume widely grown for its edible bean which has numerous uses. It has high quality and inexpensive protein (40%) and oil (20%). It has the highest protein content of all food crops and is second to ground nut species in terms of oil content amongst food legumes (Egwu, 2013).

The influences; of soil compaction from farm machinery on plant growth and yield have been investigated by many researchers (Dauda and Samari, 2002, Dauda et al.2011, Dauda et al; 2017 Dauda and Kachalla, 2017 Lipiec and Hatono; 2003, Lipiec et al, 1991). Soil compaction is of global concern due to its adverse effects on the environment (Akker and Canarache, 2001). Over use of machinery and inappropriate soil management leads to compaction, which affects soil properties such as porosity, bulk density, penetration resistance, hydraulic conductivity and plant available water(Hamza and Anderson, 2005; Passioura, 2002). Many studies have shown that soil compaction has adverse effects on crop growth and yield [1,2,3,4] Combolat et al., 2004; Ayub et al., 2010; Botta et al., 2008).

Ohu and Folorunso [1] investigated the effect of tractor traffic compaction on the yield of sorghum grown on a sandy loam soil and concluded that both the head weight and dry matter increased with increase in the number of tractors passes up to a point and then decreased with further increases in the number of passes. Bayhan et al. (2002) studied the effect of soil compaction on sun flower growth and yield. The compaction treatments were (i) pre-planting in entire plot area (pre-E), (ii) pre-planting intra rows (pre INTRA), (iii) post-planting-inter-rows (post-INTER) (iv) post posting inter-row (post INTRA), (v) post planting in entire plot area (post E) and (vi) control (C). During harvesting period, plant height, stem diameter, and yield were determined. Compaction caused by post E and pre E resulted in significantly lower sunflower yields than other treatments.

Arvidson and Hakansson [2] compared two compaction treatments on wheat yield. The treatments were zero compaction and compaction with 350 Mg of tractor wheel load. They reported that compaction caused a yield loss of 11.4%. There were 5.1% fewer plants in the compacted treatment than the control. Although compaction has an adverse effect on crop growth and yield, Ohu and Folorunso [1] had reported that not all levels of soil compaction are detrimental. They reported that 10 passes of tractor wheels gave the best yield of sorghum of 2.67 Mg/ha. Muni (2002) investigated the effect of soil compaction on the growth and seed yield of groundnut (*Arachis hypogea, Hordeum vulgare*). He reported that 5 passes of tractor wheels gave the best yield compared with 0, 10, 15 and 20 passes. Results of the investigation on the effects on soil compaction on the growth and yield of narrow-leafed lupine (*Lupinusangustifolius* L. Hordeum vulgare), spring oilseed rape (*Brassica napus* sp. *oleifera*Hertzg.), and spring barley (*Hordeumvulgare* L.). The field was compacted by a tractor of the weight of 4.84 Mg characterized by the tire to tire passing in a sandy loam soil, indicated that oilseed rape and narrow-leafed lupine grew more successfully on compacted soils than can barley (Truckman et al.,2008).

The objective of this study was to determine the effects of tractor traffic on the growth and yield of soybean in a sandy clay loam soil in a semi-arid region of Nigeria.

2. MATERIALS AND METHODS

2.1 Experimental Site

This study was carried out at Miringa (Latitude 10.44N and Longitude 12.15 E.East, northern Guinea Savanna), Biu Local Government Area, Borno State, Nigeria. Borno state is located in the North Eastern sub-region of Nigeria. The soil of the research farm is sandy clay loam. The soil has a sandy clay loam texture and made up of 21.6% silt, 24.5% clay, and 53.9% sand. The study was conducted during the rainy seasons of 2015 and 2016.

2.2 Experimental Design and Treatments

The treatments consisted of a 0, 5, 10, 15 and 20 passes of the tractor tire at 31.0 kPa imposed before seeding following the studies of Ohu and Folorunso [1], Mamman and Ohu, [4] and Dauda and Samari, (2002). A Massey Fergusson MF 165D 2 wheel drive tractor with rear tire dimension of 0.43 m x 0.7 m with a weight of 43.3 kN and a resulting ground pressure of 31.0 KPa was used to impose the treatments. Forward tractor speed was kept constant at a speed of 6 kmh^{-1} for all the treatments.

The plots (10 m x 10 m) were plowed using a three bottom disc plough at an of an average depth of 200 mm on the 16 July 2015 and 23 July 2016, which produced an average bulk density of 1.57 Mgm^{-3} in the top 20cm of the soil. On 23 July 2016, the plots received the specific passes of the tractor, as described above. The whole plot area was covered completely with the wheeling at an average soil moisture content of 102 g/kg less than the optimum moisture content (i e 125 g/ kg) less than the optimum moisture content for compacting the same type of as reported by Ohu et al. (1989). Manual planting of soybean variety TGX1448-2E, seeds were carried out on 17 July, 2015 in a 10 m x 10 m of each plot, by placing four seeds in rows 50cm apart with row spacing of 25 cm. Thinning was carried out 14 days later to 2 stands per hole. In the second year of the experiment (2016), the same operations were carried out as in 2015 on the same plots. The plots were ploughed to an average depth of 200 mm on 23 July 2016 which produced an average bulk density of 1.54 Mgm^{-3} in the top 20m of the soil. On 24 July 2016, the plots received the same tractor passes as in 2015 at average moisture content of 97 g/kg. On 24 July, 2016, the planting operation was carried out exactly like that of the previous year.

2.3 Soil and Plant Measurements

Soil dry bulk density, penetration resistance and soil moisture content of each plot were determined at the following stages 1. Crop emergence, 2.Flowering and 3. Harvesting, following the method of Dauda and Samari (2002). The dry bulk densities were determined using core sampler method as described by Blake [5]. The dimensions of the soil core were 7cm diameter x 7.8 cm height. The penetration resistance was measured using a manually operated soil cone penetrometer (ASAE, 1984) with a cone base diameter of 12.88 mm and cone angle of 30^{o}. The cone was hand pushed into the soil at a uniform rate of 1829 mm/min (as recommended by ASAE [6] immediately after the seeding operation. Three random penetration resistance measurements were made in each treatment over the entire depth from the soil surface to 20cm. At 7 weeks after emergence, plant height, plant moisture content and stem diameter were determined.

2.4 Statistical Methods

All the data collected were subjected to statistical analysis of variance using the statistical software, Statistics Version 8.0.They were separated using Duncan's Multiple Range Test (DMRT). Regression analysis was also carried out using the same package. It was meant to formulate different statistical models in order to relate soil bulk density, penetration resistance, soil moisture content, plant height and traffic intensity to yield of soybean.

3. RESULTS AND DISCUSSION

3.1 Soil Parameters

Tables 1 and 2 show the mean values of dry soil bulk density, penetration resistance and moisture content for each treatment at the stages of crop emergence, flowering, and harvesting for the growing seasons of 2015 and 2016. Dry bulk density, penetration resistance, and moisture content increased with increased number of tractor pass at all the three stages of crop growth.

The effect of tractor passes on soil bulk density was significant ($P>0.05$). The highest mean value of dry bulk density was 1.72 Mgm^{-3} at 20 tractor passes with a moisture value 15.01 g/kg^{-1}. Bulk density increased with increasing value of moisture content. Treatments had significant effects on height ($P>0.05$).

Dry bulk density, penetration resistance, and soil moisture content increased with increased number of tractor pass at all the three stages of crop growth. The effect of a number of tractors passes on soil bulk density was significant ($P < 0.05$). The highest mean value of dry bulk density obtained was 1.68 Mg m^{-3} at ·20 tractor passes with a moisture content value of 14.9 gkg^{-1}. Bulk density increased with increasing value of moisture content. Penetration resistance increased with increasing number of tractor passes, while it decreased with increase in soil moisture content. These results agree with those obtained by Soane [7], Ohu et al. [3], Mamman and Ohu [4] and Dauda and Samari (2002). The effect of the number of tractors passes on penetration resistance was significant ($P < 0.05$). Therefore, penetration resistance depends on applied load (compaction) bulk density and moisture content among other properties.

With increased tractor passes, the· soil moisture content increased significantly ($P < 0.05$). The soil moisture content in 2016 was higher than 2015. This could be attributed to the fact that the amount of total rainfall was more in 2016 than in 2015. The total rainfall amount for 2015 and 2016 were 1067.4 and 911.8 mm, respectively, in the area of the research plot.

3.2 Crop Response

Tables 3 and 4 show the mean values of plant height, plant stem diameter, and plant moisture content at 7 weeks after planting.

Treatments had significant effects on plant height ($P < 0.05$). The average plant height (2015 and 2016) varied from a maximum of 30.4 cm with zero traffic to a minimum of 22 cm for 20 passes of tractor traffic, a decrease in height of 25.6%. However, there was no significant difference ($P < 0.05$) in height between the plants grown on plots with zero and five tractor traffic passes. Similar results have been reported by Ngunjiri and Siemens [8] who found that wheel traffic significantly decreased maize height. The plant stem diameter increased significantly with increased tractor passes ($P < 0.05$). This result is probably a consequence of less root development in the compact soils as suggested by Ohu et al. [9]. Liptay and Gier [10] reported an increase in stem diameter of tomato *Lycopersicon esculentwnMills)* seedlings which was attributed to variations in the compression of the soil in the vertical profile. Mamman and Ohu (1997) also reported that with increased compaction over a soil surface, the stem diameter of millet *(Pennisetum glaucum* L.) plants also increased.

There was a significant difference ($P < 0.05$) in plant moisture content between treatments. The average maximum plant moisture content value obtained was 40.4% from plots with 20 tractor traffic passes compared to 28.8% in the zero traffic plots, a decrease of 11.67%.

A grain yield of 984.5, 1067.5, 1276.5, 775 and 555 kg ha^{-1} were obtained for the 0, 5, 10, 15, and 20 tractor traffic passes, respectively.

Five (5) passes of tractor traffic passes giving the highest significant yield value ($P < 0.05$). For all the treatments, the greater grain yield in 2015 than in 2015 was probably due to additional rainfall.

Correlations between grain yield and soil bulk density, penetration resistance, soil water content and the product of contact pressure and number of tractor passes were established ($r2$ = 0.87 for Bd; r^2 = 0.75 for Pr; r^2 = 76 for MC;r^2 = 0.92 *)*. A multiple regression equations was established as follows:

$$Yg = 92265 + 5643Bd - 1381Pr + 614MC - 45.7\mu, \quad (1)$$

where Yg is the grain yield (kg^{-1}), Bd the bulk density ($Mg\ m^{-3}$), Pr the' penetration resistance (MPa), MC the soil water content (gkg^{-1}), *t* the number of tractor passes, and μ the contact pressure (kPa).

Table 1. Mean values at 20 cm depth soil dry bulk density (Bd) in MGM^{-3} penetration resistance in MPa and soil moisture content (MC) in gkg^{-1} at crop emergence, flowering, and harvesting in a sandy clay loam at Miringa, Nigeria for 2015[a]

Treatment	Crop emergence			Flowering			Harvesting		
	Bd	Pr	MC	Bd	Pr	MC	Bd	Pr	MC
0 Pass	1.22c	1.1d	12.2e	1.32e	1.4e	12.8c	1.3d	1.45e	11.2.0e
5 Passes	1.72b	1.53c	13.4d	1.83d	1.76c	14.3c	1.96c	1.97d	13.6d
10 Passes	1.79b	1.77bc	14.5c	1.93c	1.89bc	15.5b	1.98c	2.34c	14.2c
15 Passes	1.83b	1.85b	15.5b	2.04b	2.45b	16.6a	2.52b	2.46b	15.3b
20 Passes	2.62a	2.372a	16.0a	2.68a	2.78a	18.9a	2 .75a	2.69a	16.77a

a Values are means of three replicates.
b Values followed by the same letter down the column do not differ significantly at P=0.05 using Duncan's multiple range analysis.

Table 2. Mean values at 20 cm depth soil dry bulk density (Bd) in MGM^{-3} penetration resistance in MPa and soil moisture content (MC) in gkg^{-1} at crop emergence, flowering, and harvesting in a sandy clay loam in Miringa, Nigeria for 2016a

Treatment	Crop emergence			Flowering			Harvesting		
	Bd	Pr	MC	Bd	Pr	MC	Bd	Pr	MC
0 Pass	1.20c	1.06d	12.06e	1.28e	1.36e	13.5c	1.3d	1.41e	11.06e
5 Passes	1.69b	1.51c	13.1d	1.78d	1.72c	14.20c	1.80c	1.87d	12.8d
10 Passes	1.75b	1.75bc	14.1c	1.82c	1.82bc	14.4b	1.91c	2.12c	14.03c
15 Passes	1.80b	1.83b	14.96b	1.98b	2.33b	16.6a	2.46b	2.15b	14.98b
20 Passes	2.56a	2.18a	15.97a	2.36a	2.45a	17.9a	2.65a	2.45a	15.8a

a Values are means of three replicates.
b Values followed by the same letter down the column do not differ significantly at P=0.05 using Duncan's multiple range analysis.

Table 3. Mean values" of plant height, plant stem diameter, plant moisture at 7 weeks after plant emergence and grain yield at harvest for the year 2015[b]

Treatment	Plant height (cm)	Plant stem diameter (cm)	Plant moisture (g kg-^{1})	Grain Yield (kg ha-^{l})
0 Pass	90.52 e	0.68 e	30.3a	1987 c
5 Passes	92.32 d	0.72 d	36.2b	2568 b
10 Passes	68..32 c	0.76 c	36.3b	1200 a
15 Passes	56.7 b	0.85 b	37.4c	750 d
20 Passes	22.30 a	0.94 a	41.4a	340 e

[a] Values are means of four replicates.
[b] Values followed by the same letter down the column do not differ significantly at P = 0.05 using Duncan's multiple range analysis.

Table 4. Mean values" of plant height, plant stem diameter, plant moisture at 7 weeks after plant emergence and grain yield at harvest for the year 2016[b]

Treatment	Plant height (cm)	Plant stem diameter (cm)	Plant moisture (g kg-^{1})	Grain Yield (kg ha-^{l})
0 Pass	86.2 a	0.64 c	30.1 e	1923 c
5 asses	91.41 a	0.70 cb	35.7 d	2460 b
10 Passes	64.3 b	0.78 ab	36.5 c	1786 a
15 Passes	50.8 c	0.82 b	37.75 b	745 d
20 Passes	21.4 c	0.96 a	40.6 a	356 e

[a] Values are means of three replicates.
[b] Values followed by the same letter down the column do not differ significantly at P = 0.05 using the Duncan's multiple range analysis.

From the results presented, it is evident that in a sandy clay loam soil under the condition investigated, 5 passes of tractor traffic soil compaction can be beneficial to the soybean production. Similar investigations on other crops support this report although with different number of tractor passes [11,12,1,13,4] Dauda and Samari (2002) and Dauda et al (2017).

4. CONCLUSIONS

This study showed that dry bulk density, soil moisture content, and penetration resistance increased with increased tractor traffic passes. Significant differences in grain yield, plant moisture, and plant stem diameter and plant height were obtained from tractor passes. Maximum cowpea grain yield was obtained at 5 tractor traffic passes. The need for an appropriate selection of machine weight, tire size and traffic timing programme for agricultural production efficiency and profitability is indicated from the results obtained. It can, therefore, be concluded that although excessive soil compaction is detrimental to crop growth and yield, an optimum level of machinery traffic is beneficial to crop production. It is, therefore, necessary to achieve an optimum level of soil properties to give maximum yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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