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Effects of Tractor Wheel Passes-induced Compaction and Organic Amendments on Soil Properties and Yield of Cowpea (*Vigna unguiculata* L. Warp) in an Alfisol of the Rainforest Zone of Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AS and AP designed the study, wrote the protocol, while authors AS, AP and FB wrote the first draft of the manuscript. Author OO managed the literature searches, analyses of the results and performed the field and laboratory analysis. Authors FB and OO managed the experimental process. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted to examine the effects of tractor wheel passes and organic amendment on soil physico-chemical properties and yield of cowpea (*Vigna unguiculata* L.) in an Alfisol of the rainforest zone of Nigeria. Varying degrees of penetration resistances were imposed on the seed bed via multiple tractorised wheel passes (4, 8 and 12) and the ploughed and harrowed only seed bed were imposed using Messy Ferguson tractor. Treatments which were laid out using split-plot design, consisted of 3 x 4 factorial combinations of tractor wheel passes and organic manure application and replicated 3 times on field plots of 60 x 12 m. The multiple tractor wheel passes increased soil strength (penetration resistance) and affected growth and seed yield of cowpea. The results show high soil strength was obtained within the plough layer and the active

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portion of crop root zone (10 - 30 cm) while there was increasing trends in values of soil strength from planting to crop maturity especially at depth (30 – 50 cm soil depth). Shoot biomass, pod and seed weight were lower for 8 and 12 tractor wheel passes compared with ploughed and harrowed seedbed and plots treated to 4 wheel passes. Application of organic manures ameliorated compaction effects on soil properties and enhanced growth and yield of cowpea. Organic amendment of the variously tractorized seedbed decreased bulk density thus alleviated the consequences of compaction especially within the plow layer on root development, growth and yield characters of cowpea. Close relationships among soil moisture status (content), mechanical impedance and cowpea seed yield characters obtained indicate strong interactions among soil moisture status, mechanical impedance and cowpea performance.

Keywords: Crop root zone; mechanical impedance; tillage; wheel traffic; yield.

1. INTRODUCTION

Cowpea (*Vigna uguiculata* L. Walp*)* is one of several species of the widely cultivated genus *Vigna* grown in the Semi-arid tropics covering Africa, Asia, Europe, United States and Central and Southern America. A drought-tolerant and warm weather crop, cowpeas are well adapted to the drier regions of the tropics, where other food legumes do not perform well. Cowpea's high protein, it's adaptability to different types of soil and intercropping system, it's resistance to drought and its ability to improve soil fertility and prevent soil erosion make it an important economic crop in many developing regions. It also has the useful ability to fix atmospheric nitrogen through its root nodules, and it grows well in poor soils with more than 85% sand and with less than 0.2% organic matter and low levels of phosphorus. Sub-Saharan Africa obtain low yields, estimated at about 350 kg per hectare (shelled seeds) due to low soil fertility and improper use of recommended technological packages such as use of manures – organic and inorganic. After harvesting, the pods are thoroughly dried and shelled either manually using mallet or mechanically. All parts of the cowpea are used as all are rich in nutrients and fiber. In Africa, humans consume the young leaves, immature pods, immature seeds and the mature dried seeds. The stems, leaves and vines serve as animal feed and are often stored for use during the dry season. Fifty-two percent of Africa's production is used for food, 13% as animal feed, 10% for seeds, 9% for other uses and 16% is wasted. Despite the importance of cowpea, declining yield per hectare is still currently experienced in West Africa; Agriculture in Sub-Saharan Africa is characterized by its poor productivity. Several factors related to soil fertility limit agricultural production and degradation of soil physical and chemical properties [1,2].

Soil compaction is an inevitable consequence of mechanized agriculture in the tropics and the main form of soil degradation which affects about 11% of the world total land area [3-5]. Degraded soils are also characterized by low organic matter content, superficial effective rooting depth, high bulk densities, compaction and exposed subsoil materials with hostile properties [6-8]. These degraded soils can be amended with commercial fertilizers, domestic refuse and farmyard manure. The commonest approach to soil fertility management in Nigeria is through the use of organic manure, but farmers can be discouraged due to associated problems like bulkiness, cost of transportation and application [9-12]. Also the attempt to improve production through the use of inorganic fertilizer is limited due to high cost of purchase, nutrient imbalance, soil acidification and loss of organic matter and leaching. However, the high cost of mineral fertilizers and environmental consequences involved in its use has awakened interest in the use of organic manures as nutrient sources. Manure from confined animal feeding lots is important for crop production and soil sustainability, in that it is a source of all essential nutrients. The manure also provides an excellent source of organic matter when added to the soils, restoring some of the organic matter depleted by agricultural crops.

Tractors and other heavy machineries have been used over the years on farms to reduce labour and remove drudgeries in farming operations. The use of tractorized equipment on farms in the intensification of cropping systems have produced significant increases in land area cultivated and crop yields [4]. However, over use of heavy machineries in agricultural operation and practices such as tillage, planting weed control and harvesting have been associated with soil compaction [3,7,13]. Tractors and other heavy machineries produce increased load on soil and subsequently compaction [4,5].

Compaction of agricultural soils produced degradation of soil quality parameters and reduces soil physical, chemical and biological properties and functions, hinder root development, promote soil water erosion and runoff losses, affects soil water and air relations and reduces crop yields and quality [8,14,15] .The force that is required to be applied to press the penetrometer into the soil as an index of shear resistance called the cone index. Cone penetrometer is used to estimate soil compaction in agriculture. Parameters such as cone index (CI), bulk density, porosity, runoff, erosion, root biomass, length, volume and density are indicators of compaction [4,15,16]. Soil compaction leads to increases in penetration resistance, bulk density, reduction in total pore space, air-water contents [8,12]. Ability of plant roots to penetrate the soil reduces as soil strength increases to a range of 2.5 MPa [13, 17]. Soil hard pan layer has soil strength of about 2 MPa. Critical limits of penetration resistance restrictions for root development within crop root zone within 40-50 cm soil depth [4,18,19]. Compaction reduces root development (lateral root number and sizes), growth and yields of crops [12,18,20-22].

The objective of this study was to investigate the effects of multiple tractor wheel passes and organic amendments on the soil physical and chemical properties and seed yield and yield components of cowpea.

2. MATERIALS AND METHODS

2.1 Experimental Site and Weather Conditions

A field experiment was carried out from June to September, 2012 at the Teaching and Research farm of the Federal University of Technology, Akure (Lat.7° 15 ^{1}N, Long 5° 10 ^{1} E) in the rainforest zone of Nigeria in order to determine the effects of multiple tractor passes and organic amendments on soil properties, and growth and yield of cowpea.

The results of the analysis of initial (Pre-planting) soil properties (0-15 cm bulked samples) at the site of the experiment are presented in Table 1.

2.2 Treatments

Treatments were 4 by 3 factorial combinations of tractor wheel passes and organic manure application arranged in a split-plot design using the Randomized Complete Block (RCB) design. The multiple tractor wheel passes constitutes the main plot while manure is split and randomized within the main plots as subplots. Tractor passes were plough and harrow alone, and 4, 8 and 12 passes while organic amendments consisted of soil application of 10t/ha sunshine organic fertilizer and farm yard manure and an unamended control. Treatments combinations were replicated three times on field. The size of the experimental plot was 60 by 30 m and was divided into 12 blocks of 4 by 12 m. There were 2 m guard rows between plots and 2 m between blocks. The experimental site was ploughed and harrowed once after which the degrees of compaction (penetration resistances) were imposed on the seed bed via multiple tractor-wheel passes using a 4 wheel drive tractor. The 4 wheel drive tractor was Mersey Fergusson – MF 275 Xtra 2Wd/4WD, 75 HP (55 Kw) 2200 Erpm, 2 WD) front and rear tires (8 x 16 – 8 30 x 16 PR) and tractor weight: 2360 kg weight).

The treatments were:

- T0: Plough+Harrow + zero manure (A0)
- T2: Plough+Harrow + 10tha^{-1} sunshine organic fertilizer (A1)
- T3: Plough+Harrow + 10tha^{-1} poultry manure (A2)
- T4: Four tractor passes + zero manure (B0)
- T5: Four tractor passes + 10tha^{-1} sunshine organic fertilizer (B1)
- T6: Four tractor passes + 10tha^{-1} poultry manure (B2)
- T7: Eight tractor passes + zero manure (C0)
- T8: Eight tractor passes + 10tha^{-1} sunshine organic fertilizer (C1)
- T9: Eight tractor passes + 10tha^{-1} poultry manure (C2)
- T10: Twelve tractor passes + zero manure (D0)
- T11: Twelve tractor passes + 10tha^{-1} sunshine organic fertilizer (D1)
- T12: Twelve tractor passes + 10tha^{-1} poultry manure). (D2)

2.3 Crop Management

Cowpea seeds which were obtained from Agricultural Development Programme (ADP) were planted at two seeds per hole at the spacing of 60 by 30 cm. Weeding was carried out manually at 2, 8, and 12 weeks after planting while pests were controlled via application of insecticides at 3 and 8 WAP.

2.4 Evaluations

The degree of compaction (penetration resistance or cone index) was measured using core penetrometer. The force that is required to be applied to press the penetrometer into the soil as an index of shear resistance called the cone index. Cone penetrometer is used to estimate soil compaction in agriculture. Soil moisture content was monitored by gravimetric method in which moist were oven-dried at 105℃ for 48 hrs. Soil moisture contents and penetration resistance were measured at planting and maturity (12 WAP). Weeding was carried out manually at 2, 8, and 12 weeks after planting while pests were controlled via application of insecticides at 3 and 8 WAP. Pre- planting soil samples were collected using core samplers and were analyzed for physical properties of bulk densities and textural class (percent of sand, silt and clay) using standard methods. The samples were subjected to particle size analysis by Bouyoucos (hydrometer) method using 50 g soil sample dissolved in water in a 200 ml beaker. Readings were taken at 40 seconds and 2 hours in the sedimentation cylinder. Bulk density values were obtained from the weight of oven dried soil samples and the volume of the soil corer while the total porosity was calculated from bulk density. Surface soil samples were collected, ten (10) from each site at start of experiment and at crop harvest from each treatment plot for chemical analysis. The soil samples were further analyzed in the laboratory for chemical properties – pH level, N, P, K, Ca, Mg and organic matter. Samples were analysed for pH using 1:1 water suspension by adding 10ml distilled water to 10 g of soil and read on the $_{P}$H meter. Organic matter content was determined by Dichromate Oxidation Method [23]. Nitrogen was determined by Micro-Kjeldahl apparatus [24]. Exchangeable K, was extracted using Ammonium acetate [24] and was determined on a Flame Photometer. Available Phosphorus byBray-P-1 extraction [25] and read on a Spectrophotometer. EDTA titration method was used for the determination of exchangeable Calcium and Magnesium. Measurements were also made on root and shoot biomass, plant height, yield and yield components (number of pods, seed weight per plant, 100 seeds weight and total seed yield.

2.5 Statistical Analysis

Data collected from the field and laboratory were subjected to analysis of variance and treatments means were separated using least significant design (LSD) at 5% level of probability.

3. RESULTS

3.1 Effects of Tractor Wheel Passes on Soil Physical and Chemical Properties

Tables 1a presents the results of soil analysis before the commencement and at termination of the experiments respectively. The results showed that soil of the experimental site is sandy loam. The effects of tractor wheel passes (TWP) were significant on soil physical properties measured as sand, silt and clay content, bulk density, porosity and soil moisture content (Tables 1). The 8 and 12 TWP had low silt, high clay content and addition to bulk density. It was also recorded that porosity reduced with increase in the number of tractor passes. The seedbed that was ploughed and harrowed once had best porosity (44%) which was significantly higher than value obtained (29%) for highly compacted plot (8 and 12 TWP). The results of the chemical analysis of surface soil at crop maturity are shown in Table 1b showed that there were significant differences in the magnitude of soil organic matter and organic carbon among the treatments. Soil organic carbon and matter content reduces with increase in the number of tractor passes. However, highest organic matter content was recorded in plot with low/minimal tractor passes (the plough + harrow treatment).

3.2 Effects of Organic Amendments on Soil Properties

Effects of organic fertilizers on soil physical properties is shown in Table 2a. Application of organic fertilizers at 10t/ha significantly (P=0.05) reduced bulk density and produced remarkable increase in total porosity. The results showed that soil amended with poultry manure had lower bulk density with increased porosity and silt content. In Tables 2a and b are presented the summary of the effects of organic amendments on soil chemical properties. Application of manure improved significantly the values soil pH, exchangeable bases potassium, calcium, organic carbon and organic matter over non-amended plot. Poultry litter substrates recorded higher values of these soil nutrients compared to soil amended with sunshine organic fertilizer at 10 $t.ha^{-1}$.Within the organic fertilizers, poultry manure application produced lower bulk density and higher porosity compared with plot amended with sunshine organic fertilizers at 10 $t.ha^{-1}$. However, among level of compaction and manure treatments, non-compacted plus 10 $t.ha^{-1}$ of poultry manure followed by plot with minimal number of tractor passes (4 tractor passes), in combination with 10 $t.ha^{-1}$ of poultry manure, and then 8 tractor passes amended with 10 $t.ha^{-1}$ poultry manure recorded the lowest bulk density and highest values for porosity than plot ploughed and harrowed alone.

3.3 The Effects of Tractor Wheel Passes and Organic Amendment on Soil Physical and Chemical Properties

Soil nutrients contents in amended compacted and non-compacted plots were higher than un-amended plots (Table 3b). Compaction alone reduced the values of organic matter, total nitrogen, available phosphorus and exchangeable potassium, calcium and magnesium contents, whereas, application of manure at 10 t/ha significantly increased ($P = 0.05$) values of these parameters at crop maturity. The fertility of the soil with minimal compaction level of four tractor passes amended with 10 $t.ha^{-1}$ poultry manure recorded the highest values while non-compacted without amendment recorded the lowest values of soil chemical properties measured. Total nitrogen in both experiments decreased with increase in the number of tractor passes (Table 3b).

3.4 Effects of Tractor Wheel Passes and Organic Amendments on Growth and Yield of Cowpea

Table 4 presents the responses of growth and yield parameters of cowpea to soil compaction. The adverse effects of multiple tractor passes influenced cowpea growth responses, better growth were produced by plots with zero or low tractor pass induced compaction. The number of heavy tractor passes significantly influenced plant height, number of leaves and number of branches produced per plants. Heavily compacted plots recorded lower value of these growth parameters compared to non-compacted plot.

Manure application improved growth components of cowpea over un-manured plot and there were significant ($P < 0.05$) treatment difference for most of the parameters. The plot with high values of exchangeable K, available N, soil organic carbon and organic matter improved significantly some yield parameters of cowpea. All amendments increased biomass yield, significantly higher growth were produced by poultry manure at 10 $t.ha^{-1}$ over sunshine organic fertilizer. The values of plant height, leaves and branches numbers were close under application of organic fertilizers at 10 $t.ha^{-1}$.

The results showed that manured plot improved significantly ($P < 0.05$) values of leaves and branches number produced over un-amended plots (Table 4). The results also showed that soil compaction influenced plant height, number of leaves and branches produced as severely compacted plots of eight and twelve tractor passes consistently produced the lowest values of growth characters. Application of manure (poultry manure and sunshine organic fertilizer) at 10 $t.ha^{-1}$ to non-compacted plot produced highest values of plant height and number of leaves and branches produced. Seedlings survival and growth were similar between plots that were ploughed alone and plots with low tractor passes. The adverse effects of high soil strength on cowpea growth, improvements in growth were obtained from soil amended with poultry manure over sunshine organic fertilizer at 10 $t.ha^{-1}$. The lowest root and shoot weight was recorded in heavily compacted plot with twelve heavy tractor passes. Multiple tractor wheel passes had negative on pod weight, seed weight, root and shoot weight as the values of these parameters decrease with increases in the number of tractor passes. Plot with no or zero number of tractor passes recorded the highest grain yield followed by plot with low (four tractor passes) compaction level (Table 4).

Table 1a. Physical and chemical properties of soil before experiment

Soil properties	Values
Sand	71
Silt	4.0
Clay	25
Total nitrogen (%)	0.26
Organic matter (%)	11.47
Organic Ca (%)	0.8
Exchangeable cations (cmol/kg)	4.0
Exchangeable Mg (cmol/kg)	1.20
Exchangeable K (cmol/kg)	0.54
Exchangeable Na (cmol/kg)	0.50
Available P (mg/kg)	11.47
pH (1:2 water)	5.84

Table1b. Effects of tractor passes on soil physical properties at crop maturity

Tractor wheel passes	Bulk density ($g.cm^{-3}$)	Porosity (%)	Moisture content (%)	Sand (%)	Silt (%)	Clay (%)
Plough+ Harrow	1.06^{d}	44.34^{a}	26.56^{d}	70.13^{a}	7.67^{a}	15.87^{b}
Four tractor Passes	1.41^{c}	37.71^{b}	28.56^{c}	72.80^{a}	9.67^{a}	16.20^{b}
Eight tractor Passes	1.58^{b}	33.88^{c}	30.89^{b}	73.47^{a}	10.33^{a}	18.87^{a}
Twelve tractor Passes	1.74^{a}	28.78^{d}	33.33^{a}	74.47^{a}	11.00^{a}	19.53^{a}

Means followed by the same letters along column are not significantly different at 5 % level of probability

Table 1c. Effect of tractor wheel passes on soil chemical properties at crop maturity

Tractor wheel passes	pH (1:2 water)	Organic C (g/kg)	Soil organic matter (g/kg)	N g/kg)	P (mg/kg)	K (cmol/kg)	Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)
Plough+ Harrow	5.58^{b}	1.35^{d}	2.33^{d}	0.11^{c}	2.54^{d}	0.42^{c}	4.07^{b}	1.20^{b}	0.43^{c}
Four tractor Passes	5.59^{b}	1.86^{a}	3.21^{a}	0.12^{c}	3.32^{c}	0.50^{a}	4.37^{a}	1.70^{a}	0.49^{a}
Eight Tractor Passes	6.01^{a}	1.56^{b}	2.70^{b}	0.13^{b}	4.85^{b}	0.49^{bc}	4.23^{ab}	1.37^{b}	0.44^{bc}
Twelve tractor Passes	6.15^{a}	1.46^{c}	2.21^{c}	0.16^{a}	6.37^{a}	0.46^{b}	4.40^{a}	1.90^{a}	0.46^{b}

Means followed by the same letters along column are not significantly different at 5 % level of probability.

Table 2a. Effect of organic amendment on soil physical properties

Manure types	Bulk density ($g.cm^{-3}$)	Porosity (%)	Moisture content (%)	Sand (%)	Silt (%)	Clay (%)
Control	1.73^{a}	33.02^{c}	32.83^{a}	70.55^{c}	8.7^{b}	19.70^{a}
Sunshine organic fertilizer	1.36^{b}	36.18^{b}	30.0^{b}	73.05^{b}	9.75^{ab}	16.45^{b}
Poultry manure	1.25^{c}	39.33^{a}	26.67^{c}	74.55^{a}	10.5^{a}	16.70^{b}

Means followed by the same letters along column are not significantly different at 5 % level of probability

Table 2b. Effect of organic amendment on soil chemical properties

Manure types	pH (1:2 water)	Organic C (g/kg)	Soil organic matter (g/kg)	N (g/kg)	P (mg/kg)	K (cmol/kg)	Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)
Control	5.61 [b]	1.40 [c]	2.41 [a]	0.12 [b]	2.14 [c]	0.15 [b]	4.28 [a]	1.23 [b]	0.44 [a]
Sunshine fertilizer	5.85 [a]	1.52 [b]	2.64 [a]	0.13 [b]	3.05 [a]	0.45 [b]	4.25 [a]	1.65 [a]	0.47 [a]
Poultry manure	6.03 [a]	1.76 [a]	3.03 [a]	0.15 [a]	7.62 [a]	0.48 [b]	4.28 [a]	1.75 [a]	0.47 [a]

Means followed by the same letters along column are not significantly different at 5 % level of probability

Table 3a. Effect of tractor wheel passes and organic amendment on soil physical properties

Treatments	Bulk density ($g.cm^{-3}$)	Porosity (%)	Moisture content (%)	Sand (%)	Silt (%)	Clay (%)
Ploughed + Harrow	1.42	40.3	28.7	70.8	3.0	26.2
Organic fertilizer (OF)	0.93	45.0	26.0	71.8	11.0	17.2
Farmyard Manure (FYM)	0.83	47.7	25.0	75.8	9.0	15.2
4 wheel passes	1.65	34.0	30.0	71.8	13.0	15.2
4 wheel passes + OF	1.35	37.5	29.0	74.8	9.0	16.2
4 wheel passes + FYM	1.22	41.6	26.7	76.8	7.0	16.2
8 wheel passes	1.81	31.4	32.7	67.0	12.0	20.2
8 wheel passes + OF	1.53	34.2	31.0	72.0	10.0	17.2
8 wheel passes + FYM	1.41	36.0	29.0	69.0	11.0	19.2
12 wheel passes	2.03	26.3	40.0	71.8	11.0	17.2
12 wheel passes + OF	1.63	28.0	34.0	72.8	12.0	15.2
12 wheel passes + FYM	1.55	32.0	26.0	75.8	10.5	16.2
LSD (0.05)	0.08	1.39	4.09	2.46	4.79	4.4

Table 3b. Effect of tractor wheel passes and organic amendment on soil chemical properties

Treatments	pH (1:2 water)	Organic C (g/kg)	Soil organic matter (g/kg)	N (g/kg)	P (mg/kg)	K (cmol/kg)	Na (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)
Ploughed + Harrow	5.91	1.21	2.08	0.10	1.87	0.44	4.0	1.0	0.44
Organic fertilizer (OF)	5.97	1.32	2.28	0.11	9.33	0.36	4.2	1.0	0.39
Farmyard Manure alone (FYM)	6.14	1.53	2.63	0.13	3.34	0.47	4.0	1.6	0.46
4 wheel passes	5.26	1.74	3.04	0.14	3.50	0.58	4.3	1.6	0.5
4 wheel passes + OF	5.63	1.61	2.77	0.14	3.34	0.41	4.5	1.5	0.5
4 wheel passes + FYM	5.85	1.02	1.75	0.09	3.11	0.50	4.3	2.0	0.48
8 wheel passes	5.30	1.65	2.84	0.14	1.48	0.58	4.4	1.2	0.46
8 wheel passes + OF	5.51	1.42	2.44	0.12	3.11	0.41	3.9	1.8	0.39
8 wheel passes + FYM	5.96	1.62	2.81	0.14	3.04	0.48	4.4	1.1	0.47
12 wheel passes	5.98	1.49	2.58	0.13	1.71	0.45	4.4	1.1	0.46
12 wheel passes + OF	6.28	2.68	4.62	0.23	14.7	0.48	4.4	2.3	0.46
12 wheel passes + FYM	6.18	1.42	2.44	0.12	2.72	0.45	4.4	2.3	0.46
LSD (0.05)	0.22	0.66	1.16	0.06	5.21	0.08	0.3	0.63	0.04

Table 4. Effects of soil compaction and amendments on growth and yield of cowpea

Treatments	Root weight (g)	Shoot weight (g)	Date of 50% flowering	Pod weight (g)	Seed weight (g)	100 seed weight (g)	Seed yield (t/ha)
Ploughed + Harrow	21.02	196	50	3.63	2.4	14.33	2.0
Organic fertilizer (OF)	22.10	221	51	4.27	3.0	15.0	2.5
Farmyard Manure (FYM)	24.06	242	53	4.83	4.27	15.0	3.56
4 wheel passes	19.2	174	45	2.20	1.47	16.33	1.22
4 wheel passes + OF	19.7	202	47	3.07	1.93	16.67	1.61
4 wheel passes + FYM	20.1	211	48	4.40	3.17	17.0	2.64
8 wheel passes	18.4	165	45	2.07	1.23	16.67	1.17
8 wheel passes + OF	19.0	184	46	2.17	1.57	17.0	1.3
8 wheel passes + FYM	19.3	193	46	3.20	2.4	17.3	2.0
12 wheel passes	17.3	143	44	1.53	1.1	17.0	0.92
12 wheel passes + OF	18.1	164	45	2.03	1.53	16.67	1.27
12 wheel passes + FYM	18.5	178	46	3.27	2.33	17.0	1.94
LSD (0.05)							

At the commencement of experiment (late august), penetration resistances (soil strength) ranged from 1.42 to 1.53 and 1.44 to 1.55 MPa at 10 and 30 cm while at crop maturity, values ranged from 1.46 to 1.56 280 to 400 and 1.49 to 1.55 MPa at the respective at 10 and 30 cm depths (Fig. 1a). Manuring decreased soil strength from 1.36 to 1.46 and 1.37 to 1.48 MPa at the respective at 10 and 30 cm depths (Fig. 1b).

Soil moisture contents (on dry weight basis) ranged from 15 to 14% and 14 to 12% while manuring enhanced soil moisture contents (15 to 14% at commencement to termination of experiment: Fig. 2a and b). Soil moisture were lower for tractor wheel passes alone (11.5, 12.8 and 14.7% for 12, 8, and 4 wheel passes) and increased under organically amended wheel passes treatments (11.5, 12.8 and 14.7%). The low rainfall amount and consequently decreases in soil moisture contents at the commencement of experiment (late August) associates with increases in soil resistance (mechanical impedance) (Figs. 2a and b). The declining trends in rainfall amount and consequently reductions in soil moisture contents from commencement of experiment (late August) to crop maturity appeared to have provoked the increases in soil resistance (mechanical impedance) at crop maturity.

The time course of changes in mechanical impedance (penetration resistance) and moisture contents showed that penetration resistances decreased as soil moisture contents increased. In general, the depth wise trends in mechanical impedance (penetration resistance) and soil moisture were 1.48, 1.52 and 1.55 MPa and 11.5, 12.8 and 14.7% at 10, 30 and 50 cm depths are presented in (Figs. 1a and b and 2a and b respectively). The results show high soil strength within the plough layer and the active portion of crop root zone (10-30 cm) and declining trends in values of soil strength beyond crop root zone depths (40- 60 cm), however, patterns observed for soil moisture contents differed (Figs. 2a and b). The results show high soil strength was obtained within the plough layer and the active portion of crop root zone (10-30 cm) while there was increasing trends in values of soil strength from planting to crop maturity especially at depth (30 – 50 cm soil depth). Organic amendment alleviated the consequences of multiple tractorized wheel passes-enhanced compaction especially within the plow layer and high moisture contents within crop root zone and consequently enhanced root development, growth and yield characters of cowpea.

The application of organic manures alleviated the consequences of compaction especially within the plow layer, increased moisture contents within crop root zone and enhanced root development, growth and yield characters of cowpea. The results show that mechanical impedance is a major limitation to root elongation and crop performance in the soils of the study area (tropical Alfisol) even under moderately wet conditions.

Root development in compacted soil was generally limited by a combination of mechanical impedance and soil moisture status. Root biomass was typically reduced by half under 8 – 12 multiple tractor wheel passes with penetrometer resistance 1.55 MPa and soil moisture contents of 11% especially in the absence of organic amendment. The likelihood of each factor constituting limitations to root development and cowpea seed production is dependent on the soil strength characteristics of arable soils. This suggests that mechanical impedance is often a major limitation to root development even under moderately wet conditions, and is important to consider in breeding programmes for compaction resistance in arable crops.

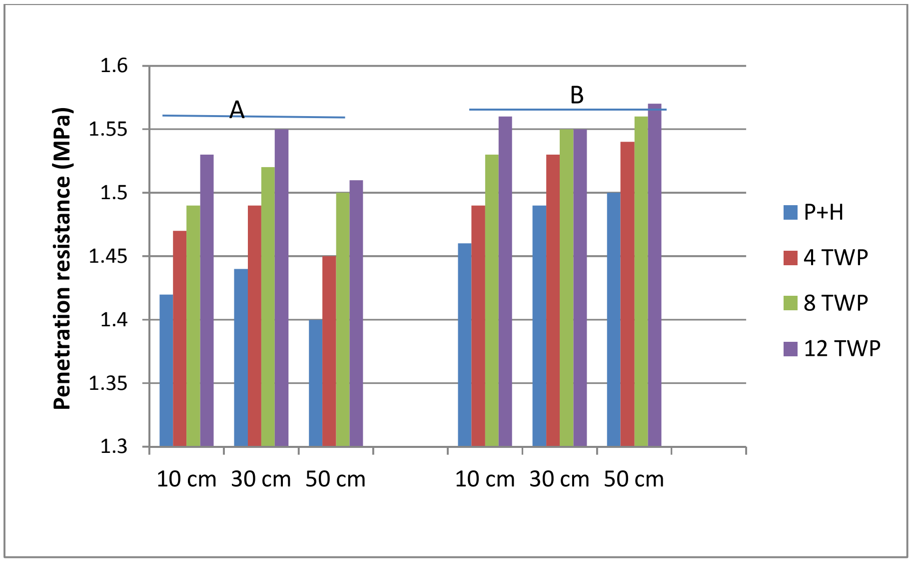

Fig. 1a. Effect of tractor wheel passes on soil strenght within soil depth
TWP (Tractor Wheel Passes) A: @ planting, B: @ crop maturity

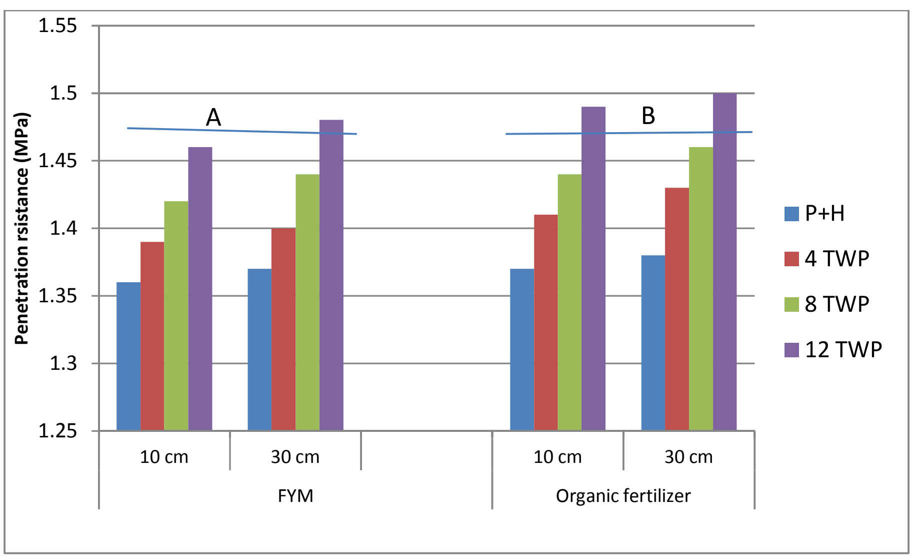

Fig. 1b. Effect of tractor wheel passes and manuring on soil strenght within soil depth
TWP (Tractor Wheel Passes). A: @planting, B: @crop maturity

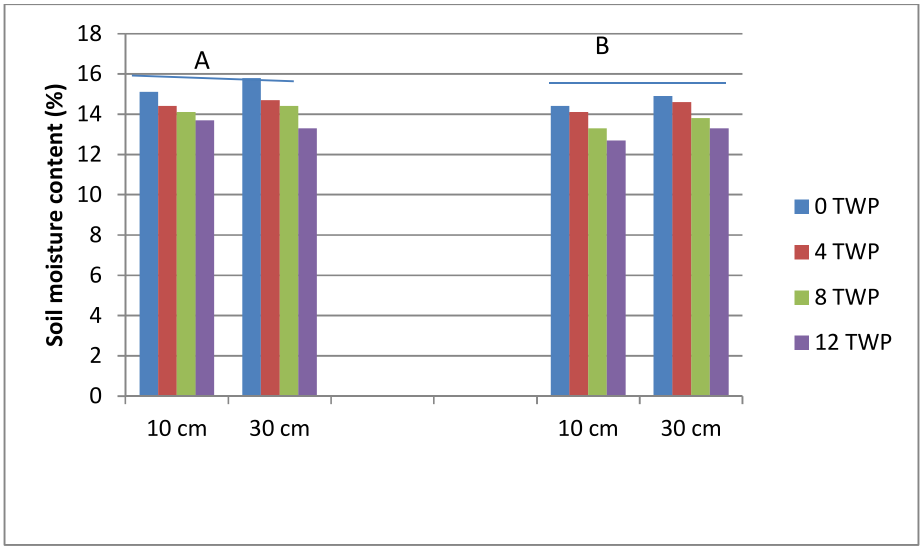

Fig. 2a. Effect of tractor wheel passes on soil moisture content within soil depth
TWP (Tractor Wheel Passes). A: @planting, B: @crop maturity

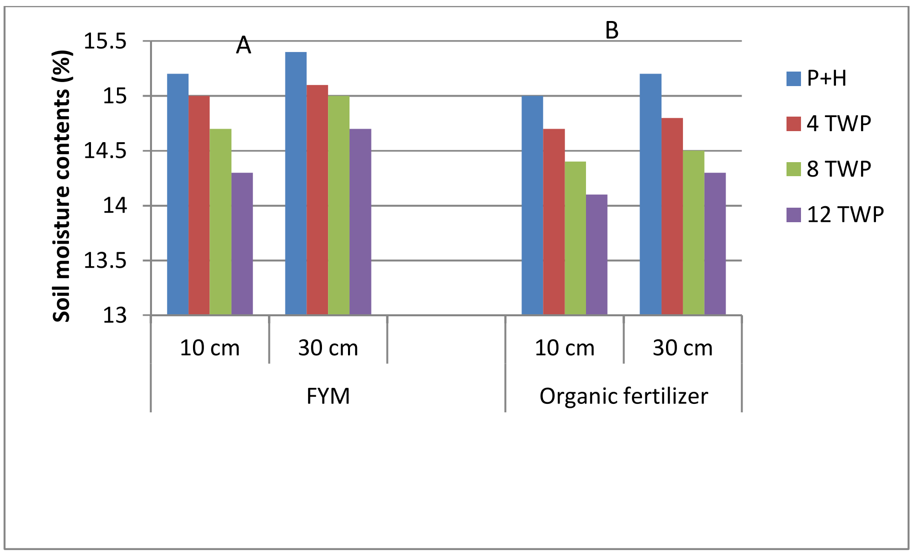

Fig. 2b. Effect of tractor wheel passes and manuring on moisture content with soil depth
TWP (Tractor Wheel Passes). A: @planting, B: @crop maturity

Organic amendment alleviated the consequences of compaction especially within the plow layer and increased moisture contents within crop root zone and consequently enhanced root development, growth and yield characters of cowpea.

4. DISCUSSION

The results of this study confirmed that multiple tractor wheels passes affected soil physical and chemical properties and the resultant compaction of the soil exerted negative effects on measured soil properties. This observation implies that with increase in tractor passes, soil particles are continually pressed together and consequently destroying the soil structure [4,19]. The bulk density of the ploughed and harrowed soil was lower and porosity higher compared to soils subjected to multiple tractor passes. It appeared that in the case of high compacted soils, pores were pressed tight (squeezed out) which would prevent soil water infiltration into the root zone of crops. Water infiltrates non-compacted soils much faster than compacted massive structure [16,18,19]. Thus much of the rainfall would not be available for crop uptake in particular, during growing season when soil moisture may be inadequate, hence yield is reduced.

The results showed that bulk density of the soil subjected to 8 – 12 tractor wheel passes ranged from 1.41 – 1.74 g/cm^3 compared to slightly compacted soil (plough + harrow alone) (1.06 g/cm^3), this in turn produced significant decline in soil porosity. The negative effects of compaction were the remarkable decline in soil porosity. In general, bulk density increased while porosity and moisture content decreased with increase in the number of tractor passes. This may be as a result of the densification of the soil resulted from the pressure exerted by the tractor wheel on the soil particles [16]. The higher bulk density produced under multiple tractor wheel passes could be due to decreases in soil volume as soil particles are pressed together and pore space reduced [4,9].

Yield reductions are commonly found with soils subjected to compaction by vehicle traffic (tractor) due to reduced pore space and increased soil bulk density. In this study, effects of compaction was negative on cowpea growth and yield such as number of leaves reduced significantly with increase in the level of compaction. Kaspal et al. [26] found that wheel traffic significantly reduced corn root growth in the upper 30/cm as compared to the un-trafficked side of the row, in other words, plants roots exerts more force to grow in this compacted soil environment. Gaultney et al. [20] and Reeves [6] among others, found 50% corn yield reductions with severe compaction. The results showed that cowpea planted into high tractor traffic (8 and 12 passes) soil declines rapidly in growth because of two factors namely: insufficient macro porosity which results in poor drainage and aeration, and high bulk density which impeded root movement through the soil. This is consistent with the reports of [1,14] who investigated application of repeated traffic of 1, 5, 10 and 15 passes and found yield reductions of 40 – 50% with higher contact pressure and multiple passes. It was observed that soil that was ploughed and harrowed alone (topsoil) produced highest pod and seed weight, and higher root weight, root development also increased with decrease in number of tractor passes while the lowest number of branches was obtained from severely compacted soils. Low cowpea yield obtained from plots with higher multiple tractor passes is suspected to result from reduction of volume available for air and water as the soil mineral components are pressed together.

Application of poultry manure and sunshine organic fertilizer to compacted plots adopted in this study maintained a relatively lower bulk density and increased porosity, which in turn cowpea growth and yield performance [11]. This investigation showed that soil properties influenced cowpea growth and yield as the performance of cowpea improved significantly under soils with low bulk density and increased porosity. The widely reported influence of manure application on the soil physical conditions has been attributed to the enhancement of soil organic matter and possible improvement in soil porosity and structure [11, 19]. The decreased in porosity and hence deterioration of soil structure could explain the adverse effects of soil compaction on cowpea growth and yield performance. However, organic amendment reduced bulk density and reduced total porosity possibly due to improved soil properties in particular, increases in the proportion of soil macro aggregates [4]. At twelve tractor passes, amended soil produced significant higher values of bulk density and porosity compared to un-amended soils. The results showed that soils across the range of multiple tractor passes examined, poultry manure or sunshine organic fertilizer amended soils had lower bulk density and porosity. The plot with no amendments had 1.25 and 1.30 g.cm^{-3} bulk density for eight and twelve tractor passes respectively, which was reduced significantly to 1.13 and 1.15 g.cm^{-3} when amended with poultry manure at 10 t.ha^{-1}. The low soil bulk density produced by this treatment could be attributed to the aggregates stability and high water holding capacity of the organic fertilizers [10,27]. According to Lal and Shukla [4] and Agele [10], organic matter plays important role in maintaining physical and chemical properties of the soil and yield. Agele [8] also reported that manure is the major source of organic matter, also beneficial in improving physical properties in compacted soil. Rivenshield and Bassuk [11] observed a decrease of 2.0 g.cm^{-3} in bulk density and 11.8 kPa in soil strength of a sandy loam following application of 10 t.ha^{-1} of green leaf manure to a compacted soil.

In terms of soil chemical properties, increases in compaction further compressed the soil with consequent deterioration in its physical and chemical properties which are essential for growth of plant. The results of this study showed that compaction influenced the chemical properties of the soil. There was a decline in soil pH of compacted plots and the decline could be attributed to loss of organic matter and CEC. Another possible factor for decrease in pH for multiple tractorized plots may be due to exposure of soil to erosion and leaching of base elements [11,19]. Incorporation of organic fertilizers (sunshine organic fertilizer and poultry manure) at 10t/ha into top plough and harrowed, and compacted soils reduced bulk density and enhanced porosity compared with un-amended soils. However, application of farm yard manure (poultry manure) produced improvements in soil physical conditions and status of soil nutrient compared to sunshine organic fertilizer, presumably due to their high content in N. Combination of farm yard manure and minimal tractor wheel passes (4 tractor passes) gave higher values of soil nutrients (pH, N, P, Ca and Mg) contents, growth and seed yield of cowpea compared with other treatments (8 and 12 wheel passes with or without organic fertilizer amendments).

Potter et al. [28] reported that wheel traffic greatly reduced the rate of water infiltration. The authors used a controlled traffic system to raise crops on wide beds and found that the trafficked row middles functioned as conduits for surface run-off. Hemlett et al. [29] concluded that soil moisture near the surface was reduced by vehicle traffic, therefore reduced from available moisture was available for plant growth, and plant roots are therefore forced to grow in compacted soil environment suffer due to increased mechanical impedance [13]. Amendments of compacted soil with poultry manure and organic fertilizers at 10t/ha in this study improved soil nutrients, increased porosity and reduced bulk density significantly.

Although soil compaction and it's deleterious effects can be mitigated with the addition of soil amendments [30], several experiments have questioned the need for soil amendments. Mosaddeghi et al. [19] reported that yields were no significantly improved following the addition of manure, suggesting that little or no amelioration effect of manure. In general, the authors concluded that compaction did not significantly decrease yield when compared to farmer's check and manure did not "ameliorate" negative effects of compaction. However, in this study distinct differences between amended and un-amended soils in terms of growth of cowpea were obtained as a result of pressure caused by tractor wheel movement, wheel passes of the heavy tractor change the soil physical and chemical characteristics.

The results has shown that cowpea growth characters were affected were adversely affected by soil compaction, probably because smaller volume of soil were exploited by roots in compacted soil which results in a smaller water reservoir available to the plant. Modification of the soils with organic fertilizers could be expected to reduce root impedance, and increase soil aeration and drainage [11]. This investigation showed that bulk density and porosity of a disturbed sandy loam was enhanced through amendment with organic fertilizer or manure. One could hypothesize with this result that with increases in soil porosity and decreases in bulk density, cowpea roots would establish more readily, with resultant improvement in growth. The results also suggest that amendment of soil with sunshine organic fertilizers did not produce improvement in physical and chemical properties as much as poultry manure amendment.

The ploughed plus harrow and 4 wheel passes provided higher values of number of branches, shoot weight and 100 seed weight. The plot overridden four tractor wheel passes, produced improvement in soil chemical properties,(highest values of organic carbon, soil pH, organic matter and Magnesium) compared with 8 and 12 passes. Four tractor passed plots also produced significantly high number of leaves compared to un-compacted soil, after which, yield decreased with increase in compaction (8 and 12 passes). Organic amendment of compact 8 – 12 multiple tractor wheel passes for example, severely reduced cowpea performance (leaf development and seed yield even under organic amendment. At this level of compaction, an organic amendment seems to be ineffective at twelve tractor pass.

Treatment effects on cowpea growth and yield in this study were in agreement with previous findings of [12,31] which suggest that soil compaction does not always decrease crop yields. Bouwran and Arts [32] also reported that slightly compacted soil can speed up the rate of seed germination possibly due to the close contact between the seeds and soil in compacted soils. It can thus be inferred that there the minimum levels of compaction tolerable one crop specific under a given soil and climatic conditions. In other words, yield begins to decrease with increase in compaction level above the minimum (threshold) level of compaction tolerable by crops.

It is evident from the result that when soil is compacted, regardless of the source, the magnitude and pattern of changes in physical and chemical properties depends on the extent or level of compaction (axle load) and soil management practices adopted such as manure application, this is because soil compaction renders the soil vulnerable to structural disintegration, nutrient depletion and run-off. Lowest bulk density and porosity recorded from non-compacted plots could be adduced to minimum or no soil disturbance. Close interactions among root development and seed yield, soil moisture contents and mechanical impedance (penetration resistance) had been reported [21]. In the present study, cowpea growth and seed yield reduced with increased compaction compared with the lesser soil disturbance under plough + harrow alone. Hence it is found that slight or low compacted soil amended with poultry manure at 10 $t.ha^{-1}$ gave the most productivity in soil fertility, growth and yield of cowpea.

5. CONCLUSION

Results of this study demonstrated negative effects of multiple tractor wheel passes (TWP) on soil strength (penetration resistance) and other soil properties. Increases in tractor wheel passes (from 4, 8 and 12 tractor passes brought about increases in bulk density and decline in porosity. Multiple tractor wheel passes and amendments with organic fertilizer affected soil physical and chemical properties, while the observed changes in soil properties appeared to have mediated soil conditions required for optimum growth and yield of cowpea. The results show high soil strength was obtained within the plough layer and the active portion of crop root zone (10-30 cm) while there were increasing trends in values of soil strength from planting to crop maturity especially at depth (30 – 50 cm soil depth). In general, depth wise trends in mechanical impedance (penetration resistance) and soil moisture were 1.48, 1.52 and 1.55 MPa and 11.5, 12.8 and 14.7% at 10, 30 and 50 cm depths respectively. These findings attest to the positive effects of organic amendment on soil quality and productivity as organic fertilizer application reduced effects of high soil strength on soil and cowpea productivity especially at 4 and 8 tractor passes. However, 12 tractor passes brought about reductions in yield of cowpea. Organic amendment with 10 $t.ha^{-1}$ of poultry manure or sunshine organic fertilizer alleviated compaction effects thus possibly creating environment more conducive for root growth, though poultry manure was marginally effective at lowering bulk density and increases in porosity. Close relationship were obtained among root biomass, soil moisture content and porosity, these relationship revealed strong interactions between soil physical and chemical properties and cowpea performance. These relationships revealed strong interactions among soil moisture status (content), mechanical impedance and cowpea performance. The time-course changes in soil strength show increases in soil compaction within the plough layer from time of planting to crop maturity. Organic amendment appeared to have alleviated the consequences of compaction especially within the plow layer and increased moisture contents within crop root zone and consequent enhancement of root development, growth and yield characters of cowpea. Root and shoot biomass and seed yields of cowpea were strongly affected by soil moisture contents and mechanical impedance (penetration resistance). The results show that mechanical impedance is a major limitation to crop performance in the soils of the study area (tropical Alfisol) even under moderately wet conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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