Cowpea response to compaction and mulching on a sloping loamy sand soil in Southern Nigeria

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Abstract: Mulching the surface of soil after machinery traffic can offset some of the adverse effect of compaction of the soil caused by the machine. Thus, this study reported the response of cowpea (*vigna-unguiculata*) to compaction and mulching with elephant grass (*Pennisectum purpuereum*) on loamy sand soil in Southern Nigeria. A randomized split-block design of field plots with compaction levels as the main block and the mulching levels as the sub-block was used. The compaction treatment consisted of 0, 5, 10 and 15 passes of a tractor with a 31 kPa contact pressure while the mulching treatment consisted of 0%, 30%, 60% and 90% areal ground cover. The zero percent treatment served as control and each treatment was replicated twice. The soil dry bulk density, penetration resistance, soil moisture content and crop growth and yield parameters were measured. Results showed that compaction level significantly increased the dry bulk density, penetration resistance and reduced soil moisture content, crop growth and yield parameters; while mulching significantly increased soil moisture content, dry bulk density and reduced penetration resistance (P<0.05). The growth and yield parameter increased for 30% mulch cover and thereafter reduced for 60% and 90% mulch cover. Both the crop dry matter and grain yield had significant correlation (R^2 = 0.93 and 0.96, respectively) with mulch cover and compaction using surface response analysis. Multiple regressions showed that a ground cover of 40% will be optimum for cowpea production on uncompacted soil while up to 65% and 92% will be needed to complement the 5 and 10 passes of tractor to produce comparative yields respectively.

Keywords: cowpea, tractor traffic, mulch cover, yield parameters, dry bulk density, penetration resistance

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1 Introduction

The topography of many parts of Southern Nigeria is undulating with slopes varying from 2% to 5%, thus erosion is a common phenomenon in the region. Soil erosion removes the topsoil along with the organic matter and soil nutrients, causing varied changes in soil properties. Apart from the effect of erosion on soil physical properties, tons of nutrients are dissolved and transported with runoff sediments leading to lower yields (Oyedele and Aina, 2006).

Wheel induced soil compaction by agricultural machines is an ongoing concern in mechanized agriculture and has been a major problem in Nigeria probably because of the high runoff of the organic matter of the soil. Though it may reduce erosion on sloping land; compaction leads to lower infiltration and reduces soil water storage because of the aggravated surface runoff. This process usually creates moisture stress for shallow rooted crops as well as crops with weaker roots.

Soil compaction leads to increased dry bulk density, soil strength, reduced infiltration, reduced water movement within the root zone of plants and reduced nutrient uptake (Adekalu and Osunbitan, 2001; Czyz, 2004; Adekalu et al., 2006; Gao et al., 2014). These changes are more pronounced in the topsoil than in the

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subsoil (Onweremadu et al., 2012). Moderate compaction reduced corn yields by 37% while severe compaction reduced yields by 54% (Dauda and Samari, 2002; Humberto and Lal, 2008) other authors have shown crop yields to be very sensitive to compaction (Adekalu et al., 2006 and Sweeney et al., 2006). Mulching reduces surface runoff during and after rainfall event, increases infiltration and reduces soil loss (Adekalu et al., 2007). Ground cover slows down the runoff velocity, which increases the flow depth thereby providing a greater buffer for reducing the hydrodynamic impact forces of the raindrop on soil (Mutchler and Young, 1975). Bhatt and Khera (2006) reported that a 90% mulch cover reduces erosion by 33% though other modes of straw mulch application controlled soil loss better than an unmulched plot but with varying degree of effectiveness.

Cassol et al. (2004) reported that the average runoff and soil loss for different percent mulch covers were 17% of the applied rainfall and 8.40 tons/ha (3.4 tons/acre) respectively as compared to 30% of rainfall and 50.42 tons/ha (20.4 tons/acre) for unmulched plots. Many researchers (Doring et al., 2005; Li et al., 2004; Qin et al., 2006; Sarkar et al., 2007) have also evaluated the positive effect of mulching on crop yield and water use; though these studies were mainly carried out on flat terrains. In a simulated rainfall experiments, runoff and soil loss were observed to be reduced by increase in mulch cover (Osunbitan and Adekalu, 2000); while Adekalu et al. (2006) observed that mulching can increase infiltration in compacted soils.

There are still limited studies on the interactive effect of compaction and mulching on crop yields and soil properties especially on tropical humid soils where the soils are exposed to high intensity rainfall and temperature variations. In southern Nigeria, elephant grass is a potential mulching material because it grows naturally on fallow lands. Cowpea is one of the most important crops planted in the late planting season in Nigeria. It is a major source of plant protein in the local diet and enhances the nutrient content of the soil. This study therefore describes research into field studies on the effectiveness of mulching with elephant grass in improving yields of cowpea on compacted sloping land in southern Nigeria.

2 Materials and methods

The experiment, a 4×4 factorial design laid out in randomized split-block design, was carried out in the late growing season of 2014 at the Obafemi Awolowo University Teaching and Research Farm at Ile-Ife, Nigeria. The soil is an *alfisol* on a slope of 3%, with 80.4% sand (63 μm to 2 mm), 4.7% silt (63 to 2 μm) and 14.9% clay (<2 μm) determined by the pipette method (Gee and Bauder, 1986). The land has been left fallowed for 3 years. The independent variables were compaction level (0, 5, 10, 15 passes of tractor; equivalent to no compaction, low, medium and severe compaction levels respectively) and percent areal ground covered by mulch (0, 30, 60 and 90). This gave 16 experimental treatments and there were two replications of each treatment. The compaction level constituted the main block while the mulching the sub plot. Each sub plot measured 8 m×8 m with 2 m spacing between adjacent plots. A graded trench was constructed at the high end of the area and in-between sub plot after the compaction operation to drain out runoff from the experimental site.

Soil compaction, imposed before mulching and planting following the studies of Dauda and Samari (2002), was achieved using a Massey Ferguson (MF 165 D 2WD) tractor with rear tyre dimensions of 0.43×0.7 m and a weight of 43.3 KN resulting in a ground contact pressure of 31.0 kPa (the ratio of load to contact area). The tractor forward speed was kept constant at a speed of 6 km h^{-1} for all the treatments. The plots were ploughed using three-bottom disc plough at an average depth of 20 cm on June 20, 2014, which produced an average dry bulk density of 1.41mg m^{-3} in the top 20 cm soil depth. The compaction was done the following day with whole plot area being completely covered with the wheeling at average moisture content of 9.6%; less than the optimum moisture content of 13.2% for the compaction of the soil (Adekalu and Osunbitan, 2001).

The amount of elephant grass mulch needed for a given mulch cover was estimated using the following equation derived by Gregory (1982):

$$MR = -\frac{\ln(1-MC)}{A_m} \qquad (1)$$

where, *MR* is the mulch rate in tons/ha; *MC* is the fraction of ground covered by mulch, and A_m is the area covered per unit mass of the mulch type. The A_m value of 0.38 derived by Ozara (1992) for grass was used. This gave mulch application rate of 0.94, 2.41 and 6.1 tons/ha for 30%, 60% and 90% mulch cover, respectively. The mulch was applied by spreading evenly at crop emergence.

Cowpea (*vigna unguiculata*) variety VITA was planted manually at 3 seeds per hole on an 8 m×8 m area of each sub plot at the recommended spacing of 30 cm on rows and 60 cm apart. Thinning was done seven days after planting. Weeds and insect pest were controlled using recommended procedures (Onwueme, 1978).

Soil dry bulk density, penetration resistance, soil moisture content, plant height and leaf area of each sub plot were determined at the following crop stages (i) crop emergence (ii) flowering (iii) pod-filling (iv)harvesting. The soil dry bulk densities were determined from the top 20 cm soil depth using soil cores 7 cm in diameter and 7.8 cm high, (Gee and Bauder, 1986). The penetration resistance was measured using a hand-pushed Proctor spring-type soil cone penetrometer with a cone base diameter of 12.8 mm and cone angle of 30°. The cone was hand-pushed into the soil at a uniform rate of 1829 mm min^{-1} as recommended (ASAE, 1984). Four random penetration resistance measurements were made in each treatment over the entire depth from the soil surface to 20 cm. At maturity, the crops were harvested and the grain and dry matter yield were determined.

Data was subjected to analysis of variance (SAS, 1992) to test mean effect of the treatments on the soil dry bulk density, penetration resistance, soil moisture content, plant height, leaf area, grain and dry matter yield and their interactions. Also, surface response analysis was done using linear, quadratic and cubic multiple regression relationships between the yield and the independent variables (mulch cover and compaction level).

3 Results and discussion

The analysis of variance as shown in Table 1 indicated that compaction and mulch cover had significant effect (P<0.05) on all the dependent variables measured except plant girth and height. There was a significant interaction (P<0.05) between mulch cover and compaction for dry matter and grain yields, leaf area and soil moisture content. The mean values of soil dry density, penetration resistance and moisture content at the stages of crop emergence, flowering, pod filling and harvesting for the compaction and mulch levels respectively are as shown in Tables 2 and 3.

Table 1 Analysis of variance

Treatment	DF	F values							
		Seed yield	Dry matter	Plant girth	Leaf area	Plant height	Soil penetration resistance	Soil moisture content	Soil bulk density
Mulch	3	132.4^{xx}	129.6^{xx}	2.5^{NS}	31.2^{x}	5.13^{NS}	25.6^{x}	48.1^{x}	22.3^{x}
Compaction	3	140.7^{xx}	138.2^{xx}	26.2^{x}	22.7^{x}	30.8^{x}	60.3^{x}	40.5^{x}	42.6^{x}
Mulch & Compaction	9	43.4^{x}	41.9^{x}	0.43^{NS}	15.5^{x}	0.83^{NS}	2.78^{NS}	14.6^{x}	2.55^{NS}

Note: ^{x} Significant at 0.05, ^{xx} significant at 0.01, NS – Not significant.

Table 2 Mean values of soil dry density (Bd in mg m^{-3}), penetration resistance (Pr in MPa) and soil water content (Mc in %) at 0-20 cm depth at four growth stages for different tractor passes

Treatment (Tractor passes)	Crop emergence			Flowering			Pod-filling			Harvesting		
	Bd	Pr	Mc	Bd	Pr	Mc	Bd	Pr	Mc	Bd	Pr	Mc
0	1.43_a	0.62_a	9.7_a	1.48_a	0.56_a	12.9_a	1.47_a	0.55_a	12.9_a	1.45_a	0.60_a	11.6_a
5	1.47_a	0.85_b	9.6_a	1.52_b	0.81_b	12.5_b	1.53_b	0.80_b	12.7_a	1.50_b	0.83_b	11.3_b
10	1.56_b	1.10_c	9.5_a	1.61_c	0.92_c	11.8_a	1.60_c	0.94_c	10.8_b	1.60_c	0.93_c	11.2_b
15	1.67_c	1.20_d	9.2_b	1.68_d	1.04_d	11.7_c	1.67_d	1.04_d	10.6_b	1.66_d	1.05_d	11.0_b

Note: Values in a column that are followed by dissimilar letters are significantly different at P<0.05 using Duncan multiple range test.

Table 3 Mean values of soil dry density (Bd in mg m^{-3}), penetration resistance (Pr in MPa) and soil water content (Mc in %) at 0-20 cm depth at four growth stages for different mulching rates

Treatment (Mulching rates, %)	Crop emergence			Flowering			Pod-filling			Harvesting		
	Bd	Pr	Mc	Bd	Pr	Mc	Bd	Pr	Mc	Bd	Pr	Mc
0	1.48 a	1.16 a	9.0 a	1.52 a	1.10 a	11.0 a	1.48 a	1.12 a	9.40 a	1.51 a	1.14 a	10.2 a
30	1.50 b	1.12 b	9.2 a	1.55 a	0.86 b	11.6 b	1.53 b	0.95 b	10.9 b	1.53 a	0.99 b	10.7 b
60	1.53 c	0.86 c	9.5 b	1.59 b	0.79 c	12.5 c	1.61 c	0.77 c	13.1 c	1.57 b	0.80 c	12.0 c
90	1.58 d	0.66 d	10.2 c	1.64 c	0.61 d	13.2 d	1.67 d	0.60 d	13.4 d	1.62 c	0.63 d	12.2 c

Note: Values in a column that are followed by dissimilar letters are significantly different at $P<0.05$ using Duncan multiple range test.

Compaction significantly affected the parameters ($P<0.05$). Penetration resistance and dry bulk density increased while soil moisture content reduced with increased number of tractor passes at the four stages of crop growth. The highest mean value of dry bulk density was at 15 tractor passes with a mean value of 1.67 mg m^{-3}. Dry bulk density decreased with increasing values of moisture content from crop emergence to harvesting. Penetration resistance increased with increasing number of tractor passes but decreased with increase in soil moisture content. These results agreed with those obtained by Dauda and Samari (2002), though they obtained higher moisture content with increasing number of tractor passes. This may be because their studies were carried out on a fairly flat terrain. The lower moisture content and higher yield shows that there is higher aeration of the upper horizon and hence better crop growth with increasing number of tractor passes. Ideally, the soil water storage on a sloping land is generally low due to high runoff rates. However, the mulch cover served as a buffer to moderate the flow of runoff and thereby increase infiltration. The increased infiltration however does not lead to surface water ponding as it is the case on compacted flat terrain. Under a flat, compacted/ untilled terrain, the top soil is usually flooded after a rainfall event. Most of the water is therefore subsequently lost to evaporation which does not contribute directly to plant growth (Adekalu and Okunade, 2006).

Mulching also significantly affected the parameters ($P<0.05$). Penetration resistance reduced while dry bulk density and soil moisture content increased with increasing rates of mulching. The decrease in penetration resistance and increased dry bulk density might have resulted from increase in soil moisture content by the mulch cover due to reduced runoff. Mulching increased infiltration and decreased runoff (Adekalu et al., 2007). Li et al., (2007) reported a slight increase in dry bulk density of soil on a flat terrain with mulching. Similar increase in dry bulk density and decrease in penetration resistance with increasing moisture content on bare-compacted soils were reported by Dauda and Samari (2002); Adekalu et al., (2006). The increase in dry bulk density with increasing moisture level was however less pronounced in this study despite higher rainfall intensity, probably because of the cushioning effect of the mulch cover against the impact of the rainfall. Soil dry bulk density increased with increasing moisture content because the soil was further compacted under the influence of the rainfall intensity. It has been shown generally that soil bulk density increases with increasing moisture content under compaction up to a predetermined optimum level. The optimum moisture content for the soil type has been found to be 13.6% (Adekalu and Osunbitan, 2001). All the moisture contents observed on the field were less than the optimum for the soil.

The effect of compaction and mulch treatments on plant height, leaf area and plant girth is as shown in Tables 4 and 5. Compaction had significant effects on plant height ($P<0.05$). The average plant height varied from a maximum of 28.2 cm at zero traffic to a minimum of 14.7 cm at 15 passes of the tractor. This was consistent with the findings of Dauda and Samari (2002) who reported similar decrease in cowpea height with increase in traffic wheel. The plant stem girth however increased with increase in tractor passes. This probably resulted from less root development and penetration as suggested by Dauda and Samari (2002). The leaf area and crop yields also decreased with increased number of tractor passes ($P<0.05$).

Table 4 Mean values of plant height (Ph in cm), plant girth (Pg in cm), leaf area index (La) at four growth stages for different tractor passes

Treatment (Tractor passes)	Crop emergence			Flowering			Pod-filling			Harvesting		
	Ph	Pg	La	Ph	Pg	La	Ph	Pg	La	Ph	Pg	La
0	1.6^{a}	0.2^{a}	0.29^{a}	7.1^{a}	0.3^{a}	0.96^{a}	16.2^{a}	0.6^{a}	2.48^{a}	28.2^{a}	0.7^{a}	1.54^{a}
5	1.5^{ab}	0.2^{a}	0.26^{b}	6.4^{b}	0.4^{a}	0.92^{b}	14.8^{b}	0.7^{a}	2.37^{b}	24.6^{b}	0.8^{a}	1.50^{b}
10	1.4^{bc}	0.3^{a}	0.24^{c}	5.3^{c}	0.6^{b}	0.90^{b}	11.4^{c}	0.9^{b}	2.12^{c}	18.5^{c}	1.0^{b}	1.45^{c}
15	1.3^{ac}	0.4^{a}	0.23^{c}	4.5^{d}	0.8^{c}	0.72^{c}	9.6^{d}	1.1^{c}	1.78^{d}	14.7^{d}	1.3^{c}	1.30^{d}

Note: Values in a column that are followed by dissimilar letters are significantly different at P<0.05 using Duncan multiple range test.

Table 5 Mean values of plant height (Ph in cm), plant girth (Pg in cm) and leaf area index (La) at four growth stages for different mulching rates

Treatment (Mulching rates, %)	Crop emergence			Flowering			Pod-filling			Harvesting		
	Ph	Pg	La	Ph	Pg	La	Ph	Pg	La	Ph	Pg	La
0	1.5^{a}	0.3^{a}	0.26^{a}	6.6^{a}	0.4^{a}	0.90^{a}	14.8^{a}	0.7^{a}	2.37^{a}	22.3^{a}	0.9^{a}	1.52^{a}
30	1.5^{a}	0.2_{a}	0.27^{a}	6.8^{a}	0.6^{b}	0.98^{b}	15.5^{b}	0.8^{b}	2.50^{b}	26.5^{b}	1.0^{b}	1.61^{b}
60	1.4^{a}	0.3_{a}	0.25^{b}	5.0^{c}	0.6^{b}	0.83^{c}	11.7^{c}	0.8^{b}	2.04^{c}	19.2^{c}	1.0^{b}	1.43^{c}
90	1.4^{a}	0.3_{a}	0.24^{b}	4.9^{c}	0.6^{b}	0.79^{d}	10.1^{d}	0.8^{b}	1.92^{d}	18.0^{c}	1.0^{b}	1.22^{d}

Note: Values in a column that are followed by dissimilar letters are significantly different at P<0.05 using Duncan multiple range test.

Mulching on the other hand had significant effects on leaf area and crop yield but no significant effects on stem girth and crop height (P<0.05). The 30% mulch cover gave the highest grain yield of 2243 kg ha^{-1} while the 90% gave the lowest grain yield of 1822 kg ha^{-1} among the mulched plots. This may be because of the high soil moisture content under the 60% and 90% mulch cover since cowpea has been shown to be sensitive to excessive water (Gumbs and Lindsay, 1993). Generally, the yields were high and compared favorably with the range of yield reported in literature for cowpea around the world despite the sloping terrain of the field. Grain yield were quite adequate as they compared well with global average grain yield of cowpea given as 1.2-1.80 t ha^{-1} (IITA, 2005). The grain yield was far above that obtained by Dauda and Samari (2002) on a compacted flat terrain under similar climatic and soil conditions (Table 6). Since mulching has a moderate effect on the physical properties of the surface 20 cm soil depth and it has been observed that compaction has the most severe effects on the same top 20 cm (Schäfer-Landefeld et al., 2004), it is expected that mulching of sloping land will affect the yield on all shallow-rooted crops especially in the tropical region. Mulching of sloping land with elephant grasses has been shown to effectively reduce erosion and increase infiltration up to a land slope of 9% and rainfall intensity of 100 mm hr^{-1} (Adekalu et al., 2007; Gao et al., 2014).

Table 6 Mean grain yields at different levels of tractor passes

Number of tractor passes	Observed grain yield, kg ha^{-1}	Grain yield, kg ha^{-1} (Dauda and Samari, 2002)
0	1997	980
5	530	1050
10	1378	1200
15	906	750
20	-	550

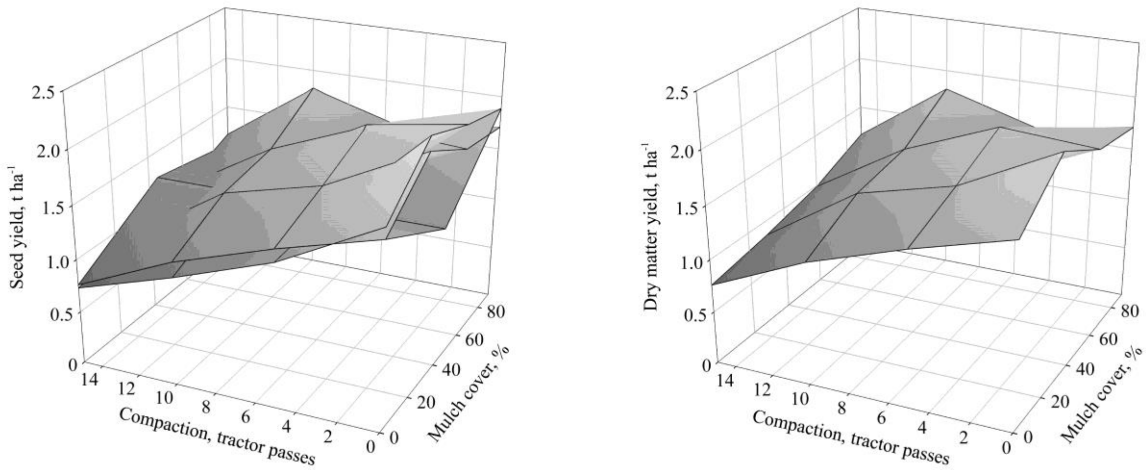
Figure 1 shows the surface response analysis of the crop yield against mulching and compaction levels. The crop yield increased to a maximum of 2.243 t ha^{-1} at 30% mulch cover and decreased with further mulching.

The computed surface response models for grain and dry matter yield are as follows:

$$Y_g = 1865.29 + 7.356M - 148.78C + 0.12MC + 5.76E-02M^2 + 8.87C^2 - 1.57E-03M^3 - 0.265C^3 - 1.05E-03MC^3 - 9.79E-05CM^3 - 6.74E-04M^2C^2 + 5.02E-05C^2M^3 - 2.19E-06M^3C^3 (R^2 = 0.96) \quad (2)$$

$$Y_d = 5222.76 + 26.20M - 52.57C + 2.53MC - 5.62E-02M^2 - 24.01C^2 - 2.93E-03M^3 + 0.977C^3 - 1.44E-02MC^3 - 5.85E-04CM^3 - 1.17E-03M^2C^2 + 1.34E-04C^2M^3 - 4.45E-06M^3C^3 (R^2 = 0.93) \quad (3)$$

where, Y_g is the grain yield in t ha^{-1}; Y_d is the dry matter yield in t ha^{-1}; M is the areal ground cover by mulch in %, and C is the number of tractor passes. The equations show linear, quadratic and cubic functions of the independent variables and combination of interactive terms.



a. Seed yield b. Dry matter yield

Figure 1 Cowpea yield response as influenced by different levels of mulch cover and compaction

Some of the multiple power interaction terms were eliminated without significantly altering the fit of the model to the data. The regression coefficients indicated that about 96% and 93% of grain yield and dry matter respectively were accounted for by the independent variables. The equation gave comparative high yields response to compaction and mulch cover at level of 30% mulch cover and 5 passes of compaction level. This is evident of mulch ground cover and compaction interaction. Also when either mulch rate or compaction increased, the relative response of the independent variables sharply increased or decreased. From Figure 1, it could be observed that there was a shift of optimal degree of compaction for maximum yield with increasing mulch cover. This shows the stabilizing ability of mulch for affecting soil compaction on soil properties. Thus, as the compaction level increases, the soil must be mulched comparatively to obtain good yield. This is because the higher the compaction, the higher the mulch level is needed at maximum yield. This may not be the case on a flat terrain as the field tends to be ponded at higher levels of tractor passes leading to reduced yield.

4 Conclusions

Compaction by machine traffic on sloping land increased the dry bulk density, penetration resistance and decreased soil moisture content, while mulching decreased penetration resistance and increased the dry bulk density and soil moisture content. Significant differences in grain and dry matter yield, plant stem diameter and height were obtained from the treatments. Maximum cowpea grain and dry matter yields were obtained with 30% mulching and zero traffic passes, followed by 60% mulching and 5 tractor passes, while the least yield was obtained by 0% mulching and 15 passes of tractor traffic. Thus appropriate selection of machine weight, tyre size and traffic timing should be complemented with adequate mulching for efficient yield production and profitability on a sloping land. Although compaction is detrimental to crop growth and yield on sloping land, adequate mulching of the compacted land would help to give good yields.

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