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# Effect of Compaction Energy on Selected Physical and Hydraulic Properties of Soils Amended With Different Sources of Organic Matter

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## Abstract

Soil compaction has been recognized as a severe problem in mechanized agriculture and influences soil properties and processes. A study evaluated the effect of different energy levels on selected properties of Alfisols treated with different sources of organic amendments. The treatments consisted of soils with compost (10 pots), cow dung (10 pots), and control. These were laid out in a completely randomized design and replicated two times. All pots (soil ± amendment) were saturated and allowed to drain freely for 24 hours and 48 hours, respectively, and compacted to 0, 75, 150, 225, and 300 Joules of energy. Bulk density (BD), penetration resistance (PR), saturated hydraulic conductivity (Ksat), particle size distribution (PSD), gravimetric moisture content (GMC), and moisture retention (MR) was determined from treated plots. Results obtained indicated that the soil is sandy. BD and PR were highest in control, with mean values of 1.803 g cm-3 and 1.762 kg F cm-2, respectively. Treatment with compost improved the BD and PR with lower mean values of 1.320 g cm-3 and 1.283 kg F cm-2 respectively, compared to cow dung and untreated control. With increasing energy inputs, there was a highly significant difference amongst the studied soil properties at all the energies at $p<0.0001$. Minimum tillage is recommended to reduce the stress caused by heavy energy inputs on these soil properties. The organic matter will directly contribute to plant nutrients such as nitrogen, phosphorus, and micronutrients.

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## Introduction

Land preparation and other farming operations require the use of tractor-mounted implements for a particular cropping activity. Alfisols are a Northern Guinea Savanna soil order with a rich clay sub-soil and relatively high fertility. They have water content adequate for at least three consecutive months of the growing season. Northern Guinea savanna Alfisols have poor soil aggregation, are low in organic matter content with the tendency to seal and crust following rainfall and drying cycles respectively (Esu and Ojanuga, 1985; El-Swaify *et al*., 1987), and thus can easily be physically degraded by the use of heavy farm machinery especially in tillage operation. In recent decades, in agricultural production organized to meet the demands of an increasing population, the weight of agricultural machines has steadily increased, leading to soil compaction processes (Berisso *et al*., 2012).

Soil physical properties such as bulk density, aggregate stability, and penetration resistance are greatly affected by mechanical operations in cropping activities. Similarly, soil aggregate stability was reduced with increased use of heavy machinery, leading to a reduced soil moisture holding capacity.

The poor nature of savanna Alfisols further compounds this degradation in physical attributes. Since these mounted implements are of various sizes and weights, different energy levels (in terms of force) are exerted on the soil during field operations, causing varied levels of soil compaction. Compaction of the soil has been shown to significantly influence some physical properties such as bulk density, hydraulic conductivity, etc., because of the formation of hardpans (Curran *et al*., 2005; Berisso *et al*., 2012).

The addition of organic material, such as cow dung, poultry droppings, compost, etc., has been shown to reduce compaction and improve aggregation of soil, which is less stable. Soil compaction changes the ability of the soil to hold water, decreases infiltration rate and saturated hydraulic conductivity, and increases penetration resistance. Application of organic materials with a high carbon: nitrogen (C: N) ratio, such as cow dung (animal-source manure) and compost (plant-source); which would be used for this study, affects on the physical properties of soils by stabilizing soil pores (macro and micropores). These physical properties are responsible for how stable the aggregation of the soil is. Nevertheless, for the purpose of this study, bulk density, penetration resistance and saturated hydraulic conductivity will be focused on (Boyle *et al*., 1989; N'dayegamiye and Augers, 1990).

Soil compaction is emerging as a serious problem affecting the yield of field crops, leading to soil degradation worldwide. In Nigeria (especially in the Northern savanna), crust formation was cited as a major problem and is a significant factor in today's farm economy. Mechanization has also advanced to such a scale and intensity that compaction has become of worldwide importance (Monz *et al*., 2010).

Soil compaction is caused by the compression of soil by external forces that decrease the volume of pore space while increasing the soil density and reducing its porosity, associated with changes in the structure of the consequently, a reduction in hydraulic conductivity (Soane and Van Ouwerkerk, 1994). A thick compacted layer builds up in the root zone due to poor tillage practices, primarily due to the farmer failing to vary the depth of plowing over several years (Turšić *et al.*, 2008). The extent of the soil compaction problem is a function of soil type and water content, vehicle (tractor) weight, speed, ground contact pressure and several passes, and their interactions with cropping frequency and farming practices (Larson *et al.*, 1994; Chamen *et al.*, 2003).

Population increase has resulted in high pressure on the soil to boost food production to support the teeming populace. The use of heavy machinery is necessary to carry out most farm operations on big lands, which have led to soil problems such as compaction, erosion, death of beneficial soil biota, etc. A study in Samaru showed the impact of varying energy levels on soil compaction and tested some selected physical properties. Although several studies have shown organic matter to improve the physical attributes of soils, few studies have focused on the effect of different types or sources of organic matter on soil compaction and other soil physical properties. This study will be carried out to see the effect of organic amendments from different sources on compaction and selected physical properties of the soil. The general objective of this study is to see the effect of compaction energy on selected physical and hydraulic properties of soils amended with different sources of organic matter. The specific objective is to determine the effect of five varying energy levels 0, 75, 150, 225, and 300 Joules on selected physical and hydraulic properties of Alfisols treated with compost and cow dung. Also aimed at determining the influence of moisture on selected physical and hydraulic properties of the organic matter-amended soils when compacted at varied energy levels.

## Materials and methods

### Site Description

The study was conducted at the Institute for Agricultural Research (IAR) Farm Samaru, Zaria. Zaria area falls into the Northern Guinea Savanna zone, on Latitude $11^0$ 10' 30.40''N and Longitude $007^0$ 36' 42.9''E at an altitude of 700 m above sea level. Samaru in Zaria is marked by a tropical continental climate with an annual temperature of about 24.9 $^0$C and rainfall averaging 1050 mm. The driest month is January, with zero mm of precipitation; and an average of 273 mm of the highest precipitation in August as there is alternating wet and dry seasons.

The area comprises an open sub-humid broad-leaved savanna weed land with a well-developed short to medium grass layer. As a result of a combination of several factors such as bush burning, cultivation, tree felling, and urban development, the characteristic vegetation now noticeable in the area is one of open shrub woodland in various stages of growth. The predominant soil type in the area is mainly Alfisols (Garba, 2010).

### Sample Collection and Preparation

Soil samples were randomly collected from S2 plot at IAR farm which has been under fallow for four years at 0-15 cm depth. The organic material (cow dung) for the experiment was obtained from the National Animal Production Research Institute (NAPRI) Shika, Zaria; while compost was obtained from the Department of Soil Science, Ahmadu Bello University Zaria. Then, the soil and organic matter samples were air dried under standard conditions and room temperature for two weeks, after which the samples were thoroughly mixed, ground, and sieved through a 6 mm sieve, followed by storage in cartons with appropriate labels in a screen house. The chemical properties of soil and organic matter are presented in Table 1.

**Table 1. Chemical properties of soil and organic amendments chemical properties**

| | | CP | CD | SS |
|---|---|---|---|---|
| **Chemical Properties** | | | | |
| pH(water) | | 7.02 | 7.40 | 6.31 |
| pH($CaCl_2$) | | 6.71 | 6.72 | 5.98 |
| Organic carbon (%) | | 2.29 | 3.07 | 0.91 |
| Total Nitrogen (%) | | 0.64 | 0.46 | 0.20 |
| Total P (mg/kg) | | 1954.57 | 2045.48 | 409.10 |
| Exchangeable bases (cmol/kg) | K | 5.73 | 10.74 | 0.29 |
| | Na | 2.43 | 3.83 | 0.69 |
| | Mg | 10.15 | 5.83 | 0.40 |
| | Ca | 37.60 | 21.60 | 3.80 |

CP= Compost + soil, CD= Cow dung + soil, SS= Soil sample only

### Treatment and Experimental Design

Thirty experimental pots containing sieved topsoil samples (1.5 kg) were used. Twenty pots were mixed with organic materials (cow dung and compost) flat rate of 5 t/ha, and then put into 10 plastic pots respectively. While the remaining 10 pots were without organic amendments, which serve as control were kept in the screen house of the Department of Soil Science, Ahmadu Bello University Zaria. The amount of amendment to use for each pot was calculated by finding the area of the pot (using $\pi r^2$ by measuring its diameter, which was 0.182 m and then dividing by 2 to get the radius. The area was found to be 0.026 $m^2$ after calculation). If 5 tons (5,000 kg)/ha of compost and cow dung were the recommended rate per hectare (10,000 $m^2$); then for a 0.026 $bm^2$ area pot, the rate will be 1.3 kg of the amendment.

Furthermore, 500 $cm^3$ of water was added into each of the 30 plastic pots, and allowed to drain off freely (treatments 1-5 for each replicate were allowed to drain off for 24 hours while treatments 6-10 for each replicate were allowed to freely drain off for 48 hours), after which moisture contents at the varying energy levels were determined. Five energy levels were imposed and were achieved by allowing a load of 1.5 kg to freely fall from a height of 1 m on the soil samples in each plastic pot using 0, 5, 10, 15, and 20 drops. This is to obtain energy values of 0, 75, 150, 225, and 300 Joules, respectively by multiplying mass, acceleration due to gravity, the height of fall, and each number of drops.

Penetration resistance was determined using a pocket penetrometer, and soil core samples were taken at 0-5 cm depth of each experimental pot as the fresh weights were taken using a weighing balance for moisture content determination. The bulk density, surface penetration resistance saturated hydraulic conductivity of the soil were determined for each pot, and comparisons were made from the replicates treated with cow dung to that treated with compost and to that with no organic inputs. The experiment was a factorial arranged in a completely randomized design (CRD).

## Soil physical properties

Soil particle size was determined using the Bouyocous Hydrometer method involving the use of Sodium hexa-metaphosphate (Calgon) as a dispersing agent to disperse the soil (Gee and Bauder, 1986). The gravimetric moisture content was determined by measuring the fresh weight of the soil samples using a weighing balance and then oven drying it at 105 $^0$C for 24 hours. Soil bulk density was determined according to the method of Blake and Hartge (1986). Saturated hydraulic conductivity ($K_s$) was determined using the constant head permeameter method of Black *et al*. (1965).

## Moisture retention

The pressure plate apparatus was used to determine the moisture retention characteristics of the soils at different suction points (0, 0.3, 1, 5 and 15 bars respectively). Field capacity and permanent wilting point were considered due to their importance in determining water availability.

## Surface penetration resistance

The surface penetration resistance was determined using a pocket penetrometer. The penetrometer rubber head was inserted into the soil sample and pressure was gently applied until the penetrometer head entered and became properly leveled with the soil surface. The pressure applied is then maintained as the penetrometer cone index reading is taken. Multiple penetrometer readings were taken per sample to maximize accuracy, as readings were then recorded in kg F $cm^{-2}$.

## Data Analysis

Data on moisture content from the experiment was analyzed using Analysis of Variance (ANOVA) by General Linear Model (GLM) with *Statistix version 10.0* statistical software. Means that were significantly different were separated using Least Significant Difference (LSD) at $p < 0.05$ and $p < 0.001$. Data from the pressure plate apparatus was used to plot soil moisture retention using the Microsoft Office 2010 Excel program (Microsoft Inc. 2010) to obtain the best treatment.

## Results and discussion

## Chemical properties of soil and organic amendments

From the results obtained in Table 1, the routine analysis for organic carbon showed that cow dung had the highest organic carbon value because it is made up of digested grass and grain. The pH was weakly acidic and slightly alkaline as it was lower in water because it displaces a higher proportion of hydrogen ions compared to

$CaCl_2$ which is the best containing solution. pH was, however highest in the treatment with cow dung and lowest in the control as cow dung raised the pH. Total Nitrogen for compost was higher due to the pronounced effect of fresh leaves and materials in the compost pile. Similarly, Total P was highest in the treatment with compost and lowest in the treatment without amendments because Alfisols are low in P due to P-sorption. Soils treated with cow dung had high values of exchangeable bases because it is more porous than compost and taking into cognizance that organic matter increases the cation exchange capacity of the soils.

**Effects of soil amendments, sampling days and energy levels on soil physical properties**

Results of the effect of soil amendments, sampling days and energy level on physical properties are presented in Table 2. From the result, the textural class of all the treatments was sandy-loam and good for arable farming. Since soil texture is an inherent property, the soil amendments more or less did not affect the textural class. The soil bulk density was highest in the treatment not amended, while cow dung had the lowest bulk density value which implies that it improved bulk density the most. Its value, however reduced on the second sampling day because moisture drainage was more after 48 hours. Penetration resistance increased considerably with an increase in energy levels. The means of the data for the penetration resistance using compost and cow dung were statistically the same at $p > 0.05$ because they were followed by the same letters, likewise the energies at 0 and 75 Joules, respectively.

The difference in the mean bulk density values of the interactions between the treatments and energy levels and also days and energy levels were highly significant at $p < 0.001$. In the same vein, the mean penetration resistance values of the interaction between the treatments and energy levels had a significant difference $p < 0.001$ while the interaction between the days and varying energy levels was not statistically different ($p > 0.05$).

**Table 2. Effect of soil amendments, sampling days and energy levels on soil physical properties**

| | BD | PR | PSD | | |
|---|---|---|---|---|---|
| | | | % Clay | % Silt | % Sand |
| Treatments | | | | | |
| **SA** | | | | | |
| Compost | 1.320 **b** | 1.283 **a** | 6 | 26 | 68 |
| Cow dung | 1.340 **c** | 1.320 **a** | 4 | 24 | 72 |
| Control | 1.803 **a** | 1.762 **b** | 10 | 34 | 56 |
| SE | 0.0264 | 0.0298 | | | |
| **SD (hours)** | | | | | |
| 24 | 1.628 **a** | 0.993 **b** | | | |
| 48 | 1.546 **b** | 1.250 **a** | | | |
| SE | 0.0211 | 0.0243 | | | |
| **EL (Joules)** | | | | | |
| 0 | 1.456 **c** | 0.733 **d** | | | |
| 75 | 1.436 **c** | 1.052 **c** | | | |
| 150 | 1.636 **b** | 1.128 **bc** | | | |
| 225 | 1.723 **a** | 1.220 **b** | | | |
| 300 | 1.785 **ab** | 1.475 **a** | | | |
| SE± | 0.0355 | 0.0385 | | | |
| **Interactions** | | | | | |
| SA * SD | ** | ** | | | |
| SA * E | *** | *** | | | |

| | | | | | |
|---|---|---|---|---|---|
| SD * E | *** | *** | | | |
| SA * SD * E | NS | NS | | | |

BD = Bulk density, PR= Penetration resistance, PSD = Particle Size Distribution, SA= Soil Amendments, SD = Sampling Days, EL= Energy Levels, SE = Standard Error, * = significant difference at $p < 0.05$, *** =highly significant difference at $p < 0.001$, NS= No significant difference at p>0.05, mean values followed by same letters are not significantly different at p≤0.05.

**Effect of soil amendments, sampling days and energy level on soil hydraulic properties of treated soils**

From the results obtained in Table 3, the amendments improved the soil hydraulic properties through their high mean values. The interactions were also mostly significant or highly significant at $p < 0.001$. The mean values for saturated hydraulic conductivity were statistically not the same and compost had the highest $K_s$ while the unamended soil had the lowest value hence the need to augment for the limiting moisture, thereby increasing productivity through the addition of organic materials is necessary (Mbagwu, 1992). The hydraulic conductivity was also considerably reduced on imposition of high compaction energies due to stress and compression on the soil pores.

The gravimetric moisture content also increased with soil amending, while the addition of soil amendments reduced the moisture retention at PWP and increased it at FC and was statistically different at $p < 0.001$. The $K_s$ values for the interaction between treatments and sampling days, treatments and energy inputs were highly significant at $p < 0.001$.

Higher energy activities can break down soil aggregates, reducing pore space and increasing soil density (Six *et al.*, 2000). This can decrease water infiltration rates and increase surface runoff (Soane and van Ouwerkerk, 1994). Energy levels can impact soil bulk density, altering water movement. High-energy activities like compaction increase soil bulk density, reducing pore spaces and limiting water movement (Pagliai *et al.*, 2004). This can decrease water infiltration rates and increase surface runoff (Lal, 1998). High-energy activities can decrease soil porosity by compacting soil particles and reducing pore space available for water storage (Nimmo and Landa 2005). Decreased porosity limits water retention capacity and can increase the potential for waterlogging or poor drainage (Hillel, 2003).

**Table 3. Effects of soil amendments, sampling days and energy levels on soil hydraulic properties**

| | **K**s (mm sec$^{-1}$) | ϴg (%) | FC ϴv (%) | PWP ϴv (%) |
|---|---|---|---|---|
| Treatments | | | | |
| **SA** | | | | |
| Compost | 3.311 **ab** | 18.107 | 0.295 **b** | 0.258 **b** |
| Cow dung | 2.790 **b** | 14.894 | 0.211 **c** | 0.168 **c** |
| Control | 2.775 **a** | 14.592 | 0.137 **a** | 0.277 **a** |
| SE± | 0.2961 | 0.3366 | 6.8470 | 8.5180 |
| **SD (in hours)** | | | | |
| 24 | 3.482 **a** | 18.421 | 0.291 **a** | 0.242 **a** |
| 48 | 3.102 **a** | 13.308 | 0.271**b** | 0.226 **b** |
| SE± | 0.2417 | 0.2749 | 7.9060 | 6.9550 |
| **EL (in joules)** | | | | |
| 0 | 2.624 **b** | 16.098 | 0.231 **b** | 0.196 **b** |
| 75 | 3.802 **a** | 16.748 | 0.341 **b** | 0.205 **b** |
| 150 | 3.451**ab** | 15.822 | 0.316 **a** | 0.266 **a** |

| | | | | |
|---|---|---|---|---|
| 225 | 3.118 **bc** | 15.530 | 0.305 **a** | 0.256 **a** |
| 300 | 3.065 **ab** | 15.123 | 0.310 **a** | 0.246 **a** |
| SE± | 0.2633 | 0.4346 | 0.0125 | 0.0110 |
| **Interactions** | | | | |
| SA * SD | *** | | *** | *** |
| SA * E | *** | | * | *** |
| SD * E | *** | | * | * |
| SA * SD * E | NS | | NS | NS |

Ksat= saturated hydraulic conductivity, ɵg= gravimetric moisture content, FCɵv= volumetric moisture content at field capacity, PWP ɵv= volumetric moisture content at permanent wilting point, SA= Soil Amendments, SD = Sampling Days, EL= Energy Levels, SE =Standard Error, * = significant difference at $p < 0.05$, *** = highly significant difference at $p < 0.001$, mean values followed by same letters are not significantly different at $p < 0.05$.

## Effect of soil amendments on moisture retention

Results of soil amendments on soil compaction showed that the moisture content of the soil not amended was higher from low to high pressure, while the moisture retention curve for compost was higher than that of cow dung. The volumetric moisture content also reduced progressively irrespective of the energy level as moisture tended towards PWP from FC (Table 4).

**Table 4. Soil moisture retention curve of the soil amendments at various suction points**

| Organic matter | Volumetric moisture content (KPa) | | | | |
|---|---|---|---|---|---|
| | 0 | 0.3 | 1 | 5 | 15 |
| compost | 0.48 | 0.295 | 0.277 | 0.267 | 0.258 |
| cow dung | 0.356 | 0.211 | 0.182 | 0.172 | 0.168 |
| control | 0.584 | 0.337 | 0.296 | 0.283 | 0.277 |

Results of compaction energy levels on moisture retention (Table 5) showed that moisture was retained more for 150-300 joules of energy while moisture was less retained from 0-75 joules of compaction energy as moisture was tending from field capacity to permanent wilting point.

**Table 5. Soil moisture retention curve of the different energy levels for various matric suction**

| Energy level | Volumetric moisture content (KPa) | | | | |
|---|---|---|---|---|---|
| | 0 | 0.3 | 1 | 5 | 15 |
| 0 | 0.4283 | 0.2317 | 0.21 | 0.2017 | 0.1967 |
| 75 | 0.4883 | 0.2417 | 0.2217 | 0.21 | 0.205 |
| 150 | 0.5067 | 0.3167 | 0.2867 | 0.2717 | 0.2667 |
| 225 | 0.47 | 0.305 | 0.2767 | 0.265 | 0.2567 |
| 300 | 0.4733 | 0.31 | 0.2633 | 0.255 | 0.2467 |

## Conclusion

The soil physical properties of Alfisols respond easily to energy impacts caused by high energy input. This could be caused either by heavy animal trampling or vehicular traffic. Soil bulk density, surface penetration resistance, saturated hydraulic conductivity, and moisture content were adversely affected by the impact of energy inputs. The effects of soil compaction could be minimized if agricultural operations are performed with little or no energy impacts so as to improve soil bulk density, surface penetration resistance and saturated hydraulic conductivity through minimum tillage. Moisture retention even though low at no energy input would infiltrate better through the soil profile than at higher energy inputs which would retain more water but have poor infiltration due to compression of soil pores. Therefore, this study recommends that organic amendment be incorporated in the soil before tillage to improve soil properties. Also, mechanized agriculture should be controlled to reduce stress on soil factors.

## Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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