Compaction characteristics and penetration resistance of poultry-litter-amended agricultural soils

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Abstract. Compaction characteristics and penetration resistance of five southwestern Nigeria agricultural soils amended with poultry litter were investigated. Poultry litter was added to the soil samples at four moisture levels of 6, 9, 12, 15 % weight basis to raise the organic matter content to 2, 4 and 6 % dry mass basis and then later subjected to three levels of compaction blows (5, 15 and 25 blows) using a standard proctor hammer in a cylindrical mould. Dry densities and the corresponding moisture content were measured at the different compaction loads. Penetration resistance was measured using the cone penetrometer. Results show that dry bulk density increased with increase in compaction load (5 to 25 blows) from 1.78 to 1.91, 1.68 to 1.88, 1.36 to 1.52, 1.48 to 1.70, and 1.47 to 1.78 g cm⁻³ but reduced with increasing poultry litter levels (0-6% weight basis) from 1.91 to 1.90, 2.08 to 1.99, 1.74 to 1.71, 1.88 to 1.78 and 1.96 to 1.82 g cm⁻³ for Apomu, Egbeda, Iwo, Oba and Ondo soil series respectively. The penetration resistance reduced with increased load from 50.1 to 44.5, 46.8 to 44.0, 49.6 to 44.0 and 39.5 to 36.1 N for Egbeda, Iwo, Oba and Ondo soil series respectively. The soil behaviour was not affected by the differences in soil series. These results show that soil compaction, litter application and penetration resistance are interrelated in their influences on soil dry bulk density and moisture content.

1. Introduction
Soil compaction is the rapid reduction in voids in the soil brought about by tamping or rolling and it usually leads to the reduction of porosity and permeability of soil with a consequent increase in soil strength, density and changes in various soil characteristics [1,2]. It occurs when a force compresses the larger soil pores and reduces the air volume of the soil [3]. Compaction of agricultural soils result mainly from rainfall and farm traffic, but the major one is farm traffic and has greatly affected crop production. Compaction problem is global especially where farm mechanization is adopted in various aspects and stages of crop production. Specifically, in the tropics where the soil is fertile and support large scale farming and crop production. Conventional tillage system has both negative and positive impact on the soil properties. Few among the negative impacts are high rate of erosion and soil compaction which have affected the soil nutrient availability and soil water intake and retention respectively [4]. Different parameters have been used in accessing the effect of soil compaction on soils properties. These include bulk density and total porosity [5, 6], penetration resistance [7], saturated hydraulic conductivity [8], moisture content [9] and infiltration capacity [10].
Soil infiltration and compaction reduction can be enhanced by various methods including soil tillage methods, soil amendment materials addition or replacement with a more permeable soil [11]. Of all these methods, using amendments which is mainly plant residues and farmyard waste have been adjudged to be the most feasible and cheaper than soil replacement [10, 12, 13]. Compost addition is according to [14], works by bringing together soil particles (sand, silt, and clay) to form a bigger particle, thereby increasing porosity, reducing the bulk density and improving water-holding and infiltration capacity of the amended soil.

Poultry industry is face with the challenges of waste management and disposal. The large-scale accumulation of wastes including manure and litter is a big problem today. Most of the litter produced daily by the poultry industry is currently being applied to land as a source of nutrients and soil amendment. It increases the moisture holding capacity of the soil and improves lateral water movement, thus improving irrigation efficiency and decreasing the general droughtiness of sandy soils [15]. Poultry manure application improves soil retention and uptake of plant nutrients. It increases the number and diversity of soil microorganisms, particularly in sandy conditions when applied on the soil. Organic matter has been used instead of inorganic fertilizer, as it improves the nutrient contents and reduce soil compaction [16]. However, no known studies have quantified the effects of poultry litter materials on the strength properties of agricultural soil subjected to various levels of compaction especially from farm machinery in the tropics. Organic matter that can be used on soil depends on the locality and their effects on a given soil type differs. Consequently, the effect of organic matter on the soil compaction and hydraulic properties of soil in Nigeria depends on the type of soil, its initial organic matter content, previous tillage operations on the soil and the season or time at which the soils were tested [17]. Soil Compaction affects soil moisture, aeration, temperature nutrition and soil strength. All these factors affect other relations and combinations of relations that affect the growth of plant.

This study is aimed at determining the effect of poultry litter incorporation on compaction characteristics and penetration resistance of some major agricultural soil series prevalent in the study area, southwestern Nigeria.

2. Materials and methods

Five soil samples were obtained as representative of the major soil series (Apomu, Egbeda, Iwo, Oba and Ondo) in southwest Nigeria. They were collected from the top 15cm of the soil profile. The samples were air dried and passed through an ASTM No 10 sieve with 2mm aperture to remove plant residues, roots and foreign materials contained in them. Particle size determination using modified hydrometer method and the initial organic matter content were determined using the combustion method described in [18].

The organic material (poultry litter) was collected from the Teaching and Research Farms of Obafemi Awolowo University, Ile-Ife and was left for one week to allow for uniform decomposition. It was then spread and air dried for two weeks after which it was pulverized and allowed to pass through an ASTM No 35-sievesize with 0.500mm aperture to obtain its fine material. The organic material was thoroughly mixed with the soils in an air-dried condition to raise the organic matter by 2, 4 and 6 percent respectively on dry mass basis.

Particle size analysis was done by the modified hydrometer method. The initial organic matter contents of the five soils were determined using the [19] described in [20]. The organic matter was calculated according to the following formula:

\[
\text{% Organic matter} = \frac{(me \ K_2SO_4 - me \ FeSO_4) \times 0.003 \times 100 \times f \times 1.729}{\text{Weight of air-dried soil}}
\]

Where, correlation factor “\(f\)” = 1.33, me = normality of solution × millilitre of solution used and 1.729 = conversion.

The liquid limit and the plastic limit were determined for the five samples at the different organic matter content levels. This test was carried out by the method described by [21].
Among the sieved soil sample, 2.5 kg was thoroughly mixed with the organic material (poultry litter). The water level of the mixture was increased at different levels below the consistency limit and then compacted. The organic matter levels were varied in percentage by mass to obtain the 2, 4 and 6 % poultry litter levels respectively. At each of these levels, the soil-organic matter mixture was subjected to 5, 15 and 25 blows of the standard proctor hammer in the standard proctor cylinder of 100 mm diameter and 115 mm height and a collar following the compaction procedure described by [22]. The penetration resistance of each soil sample was determined using the cone penetrometer after the samples were compacted.

3. Results and Discussion

3.1 Particle size and organic matter content
The mechanical analysis of the soil samples shown in Table 1 indicated that the soil varied in texture from sandy loam to sandy clay loam with the clay content ranging from between 16.6 to 22%. The result showed the relationship between liquid limit (LL) and Organic matter content (OMC) to be inversely related for the three soil series from Apomu, Oba and Ondo series but not for Egbeda and Iwo. The silt content was high for Iwo and Apomu with high LL.

Table 1. Particle Size Distribution and Initial Organic Matter Content of the Soils

| Soil series | Liquid limit | Organic matter content (%) | Particle Size distribution (%) | Textural classification |
|-------------|--------------|-----------------------------|------------------------------|------------------------|
| Egbeda      | 16.6         | 0.67                        | 73.7                        | Sandy clay loam        |
| Iwo         | 27.0         | 2.01                        | 68.2                        | Sandy loam             |
| Apomu       | 20.5         | 0.20                        | 67.7                        | Sandy loam             |
| Oba         | 19.4         | 1.68                        | 76.4                        | Sandy loam             |
| Ondo        | 15.6         | 1.74                        | 74.5                        | Sandy loam             |

3.2 Consistency limit
The liquid limit moisture contents for the different poultry litter addition is shown in Table 2. The soil did not show plasticity at the addition of poultry litter. There was a noticeable increase in the consistency limits with increasing poultry litter level. This is so because the organic matter makes first demand of the antecedent moisture in the soils and this accounts for the high values of moisture content and porosity of soils with higher amount of poultry litter as in [23,24] and these are all expected of the soils from earlier works reported by [17].

Table 2. Liquid Limit at different poultry litter levels

| Soil Type | Poultry Litter Level |
|-----------|----------------------|
|           | 2%       | 4%       | 6%       |
| Apomu     | 23.6     | 24.5     | 26.3     |
| Egbeda    | 16.9     | 20.1     | 22.2     |
| Iwo       | 21.7     | 20.9     | 26.1     |
| Oba       | 19.8     | 22.3     | 25.1     |


3.3 Compaction tests

The plots of dry bulk density (DBD) against moisture content for the soils at different levels of poultry litter addition for 25 blows are as shown in Figures 1 to 5 for Apomu, Egbeda, Iwo, Oba, Ondo soil series respectively. The plots for 5 and 15 blows showed the same trend but with different values. The values of the maximum dry bulk density with its corresponding critical moisture content (CMC) at which compaction is undesirable in agriculture are as summarized in Table 3. The values of DBD increased with increase in soil moisture until a peak value was reached after which the values decreased on further increase in soil moisture, all which was in consonance with previous findings [25]. These peak values of DBD also referred to as maximum DBD decreased with increase in poultry litter addition which confirms an earlier report by [26]. The decrease was particularly significant for Egbeda, Oba, and Ondo soil series.

| Soil Series | DBD (g/cm³) at 5% Moisture Content | DBD (g/cm³) at 15% Moisture Content | DBD (g/cm³) at 25% Moisture Content |
|-------------|-----------------------------------|------------------------------------|------------------------------------|
| Ondo        | 16.0                              | 17.5                               | 22.4                               |

**Figure 1.** Graph of dry bulk density against moisture content - Apomu soil series
Figure 2. Graph of dry bulk density against moisture content - Egbeda soil series

Figure 3. Graph of dry bulk density against moisture content - Iwo soil series
3.4 Penetration resistance

The penetration resistance values recorded showed a declining trend as the MC increased, there was a visible decrease in its peak values for Egbeda and Iwo soil series, while the decrease for all other soil series were not spread over the compaction levels. Peak values of penetration resistance are as shown in Table 3.
3.5 Relationships between soil treatments and compaction blows

The interaction of factors like soil types, poultry litter levels and compaction blow with dry bulk density are as shown in Figures 6 to 8e respectively. Figure 6 shows decrease in dry bulk density as the level of poultry litter increased for all the soil types. Figure 7 showed that the highest values of dry bulk density generally occurred at 25 proctor hammer blows. Figures 8a-e show the dry bulk density interactions with compaction blows and poultry litter level for all the soil types.

![Graph of dry bulk density against organic matter all soil types](image-url)

**Figure 6.** Graph of dry bulk density against organic matter all soil types
**Figure 7.** Graph of dry bulk density against compaction blows all soil types - control experiment

**Figure 8a.** Graph of dry bulk density against compaction blows Apomu soil
**Figure 8b.** Graph of dry bulk density against compaction blows Egbeda soil

**Figure 8c.** Graph of dry bulk density against compaction blows Iwo soil
4. Conclusion
The Liquid limit of the soils increased as poultry litter level increases. The dry bulk density of the soils decreased with increasing poultry litter addition with the greatest effect on the Iwo soil series but least in Egbeda which has the highest clay content. These decreases were significantly increased as compaction levels increased. It is safe to also conclude that poultry litter aside its popular use as organic amendment can thus be used effectively in reducing the undesirable effects of compaction on agricultural soils especially those farmlands with higher machinery traffic and commercial use. Therefore, farm-traffic induced compaction which adversely affects production of agricultural soils, wear and tear of tillage equipment, and increased energy requirements may be alleviated by poultry litter
amendments. Generally, it is important to note that soil texture has an overriding influence on the parameters of dry bulk density and critical moisture content. However, it was not possible to link the variation in maximum dry bulk density and critical moisture content to difference in their geographical landscape positions.

Acknowledgements
The authors appreciates the laboratory staff for their efforts in analysing the numerous samples obtained as well as gratefully acknowledge the critical comments and corrections of respected reviewers whose comments and corrections improved this work considerably.

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