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Influence Of Poultry Manure Incorporation On Changes In Selected Physical Properties Of An Alfisol During Drying

O.B. Aluko
Department of Agricultural Engineering
Obafemi Awolowo University
Ile-Ife, Nigeria

D.J. Oyedele
Department of Soil Science
Obafemi Awolowo University
Ile-Ife, Nigeria

ABSTRACT

Changes in the physical properties during the drying of soil as affected by incorporation of different levels of poultry waste were investigated on an alfisol under fallow at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife, South-Western Nigeria. Bulk surface soil (0 – 15 cm depth) was air-dried and crushed to pass through a 4 mm mesh sieve, then moistened to 0.18 g g-1 moisture before mixing with poultry waste at different rates of 0, 40 and 80 g kg-1. Pre-determined quantities of soil were packed in cylindrical cores 76 mm in height and 36 mm in diameter to achieve a pre-determined dry density of 1.93 g cm-3. Batches of the soil samples were prepared in replicates for each rate of poultry waste mixture and subjected to drying regimes in the laboratory. At different drying regimes, replicates of the soil samples were subjected to axial compression at the strain rate of 2 mm min-1 until failure occurred. The shrinkage index (ΔV) of the soil samples was also determined as the difference between the initial sample volume at preparation and the final sample volume after drying. The soil dry density (ρd) increased gradually with degree of drying, attaining a maximum value within the decreasing moisture content range 0.14 – 0.10 g g-1 and then subsequently decreasing gradually. The porosity (n) of the soil expectedly followed an inverse trend as ρd. The rate of poultry waste incorporation, however, had no significant effect on n and ρd. Poultry waste addition increased the soil's unconfined compressive strength (UCS) implying that poultry waste enhances the integrity of soil aggregates when subjected to stress. The soil's UCS also increased as the soil progressively dried out. A strong negative relationship ($0.83 \leq r2 \leq 0.98$) was obtained between soil moisture content and the shrinkage index (ΔV). The strength of the relationship however decreases with increased rate of poultry waste addition implying that poultry waste reduces the dependence of ΔV on moisture content. In general, the results indicate that poultry waste incorporation enhances the maintenance of the integrity of soil aggregates under compressive loads thereby improving the workability of the soil. Drying also increased the compressive strength of the soil.

1. INTRODUCTION

The physical properties and mechanical strength of soil are very important in any arable crop production system as they control moisture and nutrient uptake and root growth in the root environment. From the tillage standpoint, the mechanical strength also determines the energy required for pulverisation and tilth formation. Tropical soils have weak structures, which are susceptible to degradation as a result of wetting, drying, compaction due to on-farm traffic and ill-timed tillage operations (Dutartre et al., 1993; Ley et al., 1995; Soyelu et al., 2001). The consequences of the structural degradation include restricted permeability for water and air, mechanical impedance to root growth, constraints to soil workability and depletion of soil organic matter (Carter, 1994; Blair, 2000; Ley et al., 1995; Soyelu et al., 2001). Some cultural farming practices, for example bush/vegetation burning, which are common features of many farming systems in Nigeria, further deplete the organic matter content of the soils (Blair, 2000).

The importance of soil organic matter in binding individual soil particles into aggregates, increasing the stability of soil structure and enhancing soil fertility and quality is well attested to in the literature (Tisdall and Oades, 1982; Oades, 1984; Oades, 1993; Syers and Craswell, 1995; Chaney and Swift, 1984; Dutartre et al., 1993). The incorporation of organic soil amendments, along with some form of conservation tillage, is increasingly being recommended as a strategy for improving soil quality whilst minimising the undesirable effects of tillage and compaction (Carter, 1994; Cannell and Hawes, 1994). Rahimi et al. (2000) reported increases in soil strength as a result of increases in soil organic matter. The improvement and maintenance of soil carbon and soil structure is necessary for sustainable agricultural systems and protection of the soil resource (Blair, 2000).

Whereas considerable work has been done on conservation tillage and soil management strategies for soils of temperate regions (Cannell and Hawes, 1994; Carter, 1994; Cassel and Wagger, 1996), further research is still needed on structural changes in tropical soils during wetting and drying processes in order to develop strategies for interfering with these processes so as to reduce strength development and/or promote structural development (Mullins et al., 1990). Indeed, such research constitutes an essential prerequisite to the development of suitable and sustainable management strategies for soils of Nigeria. Very little information is available, for instance, on the effects of organic waste incorporation on changes in soil strength, structure and other physical properties during wetting and drying processes, which are characteristic of the natural environment of these soils.

This paper reports an investigation into changes in selected soil physical properties during drying of a South-Western Nigerian alfisol as affected by different levels of poultry manure incorporation.

2. MATERIALS AND METHODS

2.1 Soil Description and Sample Preparation

The soil for this study was collected from surface 0 – 15 cm on a 5 – year bush fallow plot at the Obafemi Awolowo University Teaching and Research Farm (OAUT&RF), Ile-Ife, South-Western Nigeria. The average daily minimum temperature at OAUT&RF ranged between 20 °C and 22 °C, and the average daily maximum temperature between 27 °C and 35 °C. The soil is classified locally as Iwo series (Ojanuga, 1975) and as Oxic Tropudalf (Okusami and Oyediran, 1985) derived from granite and gneiss. The texture of the surface 0 - 15 cm is loamy sand having 800 g kg^{-1} sand, 50 g kg^{-1} silt and 150 g kg^{-1} clay, with organic matter content of 21 g kg^{-1}.

Bulk surface soil from a depth of 0 – 15 cm was carefully collected with the aid of a hand shovel. The soil was air-dried and large clods were gently reduced to smaller fragments by hand. The air-dried soil was sieved using a 4 mm sieve to obtain a uniform grade and to remove roots, stones and foreign constituents. Poultry waste was collected from the poultry section of the farm, air-dried and sieved using the same procedure as for the soil. The soil was then moistened to a moisture content of 0.18 g g^{-1}, using water spray jets. The moistened soil was then allowed to equilibrate for 48 h in sealed plastic containers. All soil moisture contents in this investigation were determined gravimetrically by oven drying soil samples at 105 °C for 48 h. Prior to sample preparation, different portions of the soil were mixed with 0, 40 and 80 g kg^{-1} air-dried poultry waste, respectively. These were subsequently used in the preparation of different batches of soil test samples.

Cylindrical soil samples, each having a height of 76 mm and a diameter of 38 mm, were prepared in batches corresponding to the different levels of poultry waste treatment. The preparation of each sample entailed the compaction of a pre-determined quantity (196 g) of moist soil and poultry waste mixture to the diameter and height specified above using a cylindrical core sampler and a split mould. Each sample was thus prepared to the same initial dry density of 1.93 g cm^{-3}. Further treatments, measurements and testing were subsequently carried out on the prepared samples as described below.

2.2 Tests and Measurements

For each batch, unconfined compression testing of soil samples was preceded by the drying of different samples to different moisture contents. Using a similar procedure to that reported by Aluko and Koolen (2000), each sample was dried to a progressively lower soil moisture content than the preceding sample. After drying, each sample was weighed using an electronic balance and its dimensions (diameter and height) were carefully measured using a pair of vernier calipers. The sample was then subjected to a standard unconfined compression test using the triaxial test method and apparatus (Bishop and Henkel, 1962). The method, which is well known, consists of subjecting a cylindrical soil sample to an equal all round (spherical) pressure $\sigma 3$ and then loading the sample to failure by increasing the axial compressive load Fa on the sample. For unconfined compression tests, $\sigma 3$ is equal to 0. During each test, the sample was loaded at a constant strain rate of 2 mm min-1 and the load applied and the axial strain were monitored up till the point of failure. Unconfined compression tests at each of the moisture contents were replicated thrice as were other measurements taken.

Gravimetrically determined moisture content data were used in conjunction with measured sample dimensions (diameter and height) and weight to calculate the dry bulk density in g cm^{-3} for each sample. Using the same data (i.e., moisture content and sample dimensions and weight) in conjunction with the specific gravity of solid soil particles G_s (G_s = 2.65), porosity n in cm^3 cm^{-3} was calculated from standard soil mechanics phase relationships (Craig, 1983). The difference ΔV in cm^3 between the initial sample volume at preparation and the final sample volume after drying was taken as the index of shrinkage. Unconfined compressive strength in N cm^{-2} was calculated as the load at failure divided by the sample's cross-sectional area at failure A_f, which was estimated as (Koolen and Kuipers, 1983):

$$A_f = A_o\,(1 - \varepsilon_f) \qquad (1)$$

where A_o and ε_f represent initial cross-sectional area and axial strain at failure, respectively.

2.3 Statistical Analyses

The data collected were subjected to *t*-test and analysis of variance with separation of means by both the Duncan multiple range test (DMRT) and LSD, using SAS software (SAS Institute, 1987). All tests of significance were done at the 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Treatment Effects

The summary of the F-distribution for the analysis of variance (ANOVA) is presented in Table 1. Table 1 indicates that although the level of poultry manure application had no significant effect on the soil's bulk density, porosity and strength, it significantly affected the soil's shrinkage index. The pre-test soil moisture content however affected soil unconfined compressive strength and shrinkage index.

3.2 Soil Porosity

The relationship between soil moisture content and porosity is shown in Fig. 1, where the porosity n of the soil is plotted as a function of soil moisture content for the different levels of poultry waste application. The figure shows that in general, as the soil dries progressively from an initially wet state, the porosity at first decreases. It appears that at all three waste application levels, the porosity attains a minimum value in the moisture range 0.14 – 0.11 g g^{-1}. Further moisture loss beyond this range can be seen to lead to a gradual increase in porosity. The changes in soil porosity with moisture content shown in Fig. 1 agree with previous reports from studies carried out on temperate soils (Koolen, 1978). The observed differences in the soil porosity at different drying stages were not

Table 1: Summary of the F-Distribution of Analysis Of Variance (ANOVA) On the Effects of Drying On Selected Soil Physical Properties

Soil properties	Degree of Freedom	Sum of squares	Mean square	F-ratio
Dry density (ρ_d)	6	0.08197	0.001366	1.52^{ns}
Porosity (n)	6	0.00118725	0.00019454	1.52^{ns}
Unconfined compressive strength (UCS)	6	1534	255	54.10^{**}
Shrinkage index (ΔV)	6	0.00151856	0.0000253	44.18^{**}

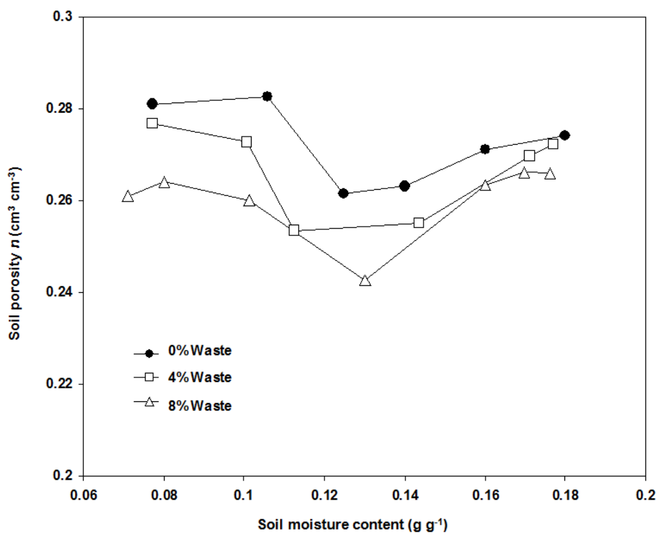

Fig. 1: Soil porosity versus soil moisture content for different levels of poultry waste

statistically significant. The levels of poultry waste incorporation also had no significant influence on the porosity of the soil.

3.3 Soil Dry Density

The soil dry density for the different levels of poultry waste application is shown plotted as a function of soil moisture content in Fig. 2. At any level of poultry waste application within the range studied, the soil dry density was initially observed to increase gradually as drying proceeded, attaining a maximum value within the moisture content range 0.14 – 0.10 g g^{-1}. Further drying of the soil resulted in a gradual decrease in the soil dry density. This trend agrees with that reported by Ayers and Perumpral (1982), Ohu (1985), Arvidsson (1998) and Ohu *et al.* (2001). The initial increase in the soil dry density is due to a gradual increase in compactability as the soil dries out. The subsequent decrease in the dry density after attaining the maximum value can be accounted for by reduction in soil cohesion in the drier moisture range. Figure 2 shows that progressive increases in the amount of poultry waste applied produced corresponding increases in the value of the maximum dry density of this soil. Although the maximum dry density at all three waste application levels was attained within the moisture content range 0.14 – 0.10 g g^{-1}, the optimum moisture content decreased as the waste level increased (0.1248 g g^{-1} at 0% waste level, 0.1124 g g^{-1} at 4% waste level and 0.1013 g g^{-1} at 8% waste level).

3.4 Unconfined Compressive Strength

There was a strong positive relationship ($0.96 \le r^2 \le 0.98$) between the unconfined compressive strength of the soil and its moisture content (Table 3). The relationships between unconfined compressive strength (UCS) and moisture content at different levels of poultry waste incorporation are shown in Fig. 3. The plotted points represent the mean of three replicates at each moisture content. It can be seen that UCS generally increases with decreasing moisture content (i.e., as the soil dries). The initial rate of increase is gradual but generally becomes more pronounced in the lower moisture content range (≤ 0.14 g g^{-1}). The trend of UCS in Fig. 3 is similar to that reported by Panayiotopoulos (1996). Causarano (1993) and Aluko and Koolen (2000) have also reported similar trends for the tensile strength of some soils in temperate regions.

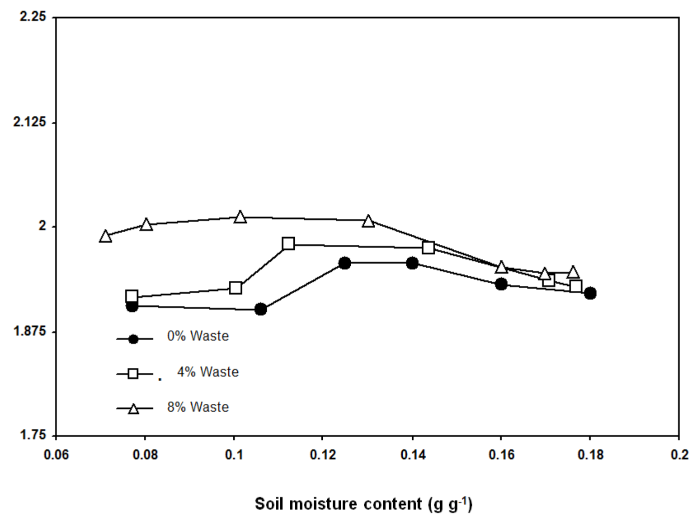

Fig.2: Soil dry density versus soil moisture Content for different levels of poultry waste

Figure 3 shows that the UCS of the soil increased as the level of poultry waste application was increased from 0 to 8%. This indicates that the application of poultry waste enhances the ability of the soil aggregates to maintain their integrity under increased compressive loads such as may result from human, animal and vehicular traffic. Simalenga and Have (1994) described a workable soil as one having sufficient compressive strength to withstand the weight of the machinery working on it. Applying this definition, increasing poultry waste application to the present soil enhances the workability of the soil.

3.5 Shrinkage Characteristics

A strong negative relationship (0.83 ≤ r2 ≤ 0.98) was found to exist between shrinkage index and soil gravimetric moisture content (Table 3). The strength of this relationship, however, decreased with increased rate of poultry waste incorporation with r2 ranging from 0.98 under 0% to 0.89 and 0.83 under the 4% and 8% rates of poultry waste incorporation, respectively. This implies a reduction in the dependence of the shrinkage index (ΔV) of the soil on moisture content with increased rate of poultry waste incorporation. The shrinkage characteristics of the soil are shown in Fig. 4, where the soil shrinkage index after drying is plotted as a function of soil moisture content for the different levels of poultry waste application. In general, the shrinkage index ΔV at the different levels of poultry waste application increased as the soil was

Table 2: Summary of the f-distribution of analysis of variance (ANOVA) on the effects of poultry manure addition on selected soil physical properties

Soil properties	Degree of Freedom	Sum of squares	Mean square	F-ratio
Dry density (ρ_d)	2	0.000564271	0.00280038	3.13^{ns}
Porosity (n)	2	0.00079925	0.00039962	3.13^{ns}
Unconfined compressive strength (UCS)	2	16.408	8.2041	1.74^{ns}
Shrinkage index (ΔV)	2	0.00004782	0.00002391	4.17^{*}

ns = not significant at P = 0.05
* = significant at P = 0.05

progressively dried from a wet condition. In the intermediate soil moisture content range 0.17 – 0.13 g g-1, it can be seen that ΔV

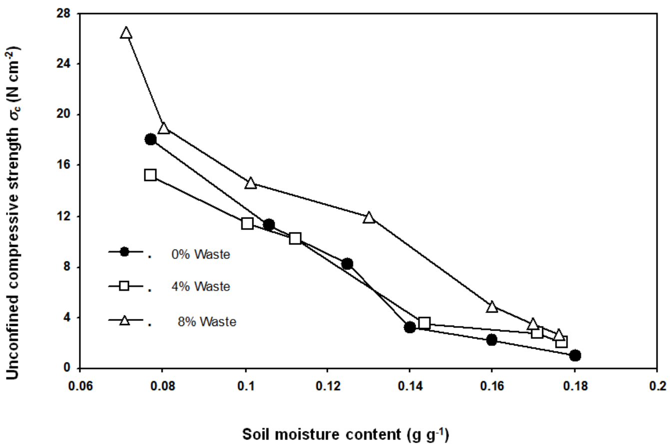

Fig. 3: Unconfined compressive strength versus soil moisture content for different levels of poultry waste.

increased with increasing amount of poultry waste application. In the drier (< 0.13 g g-1) and wetter (> 0.17 g g-1) moisture content ranges, respectively, however, the values of ΔV for the different levels of poultry waste application appear to converge.

Table 3: Relationships between soil moisture content and selected physical properties

Effects on UCS at different levels of poultry waste (PW)

$UCS = 48 - 474\theta_w + 1176\theta_w^2$ ($r^2 = 0.98$) - at PW = 0%
$UCS = 49 - 412\theta_w + 852\theta_w^2$ ($r^2 = 0.96$) - at PW = 4%
$UCS = 36 - 321\theta_w + 724\theta_w^2$ ($r^2 = 0.97$) - at PW = 8%

Effects on ΔV at different levels of poultry waste (PW)

$\Delta V = 0.1923 - 4.027\theta_w$ ($r^2 = 0.98$) - at PW = 0%
$\Delta V = 0.2167 - 4.6417\theta_w$ ($r^2 = 0.89$) - at PW = 4%
$\Delta V = 0.2216 - 4.76804\theta_w$ ($r^2 = 0.83$) - at PW = 8%

UCS = unconfined compressive strength
ΔV = shrinkage index
θ_w = gravimetric soil moisture content
PW = poultry waste

4. CONCLUSIONS

The effect of poultry waste incorporation on changes in soil dry density, porosity, unconfined compressive strength and shrinkage index during drying of an alfisol was investigated. The soil dry density initially increases as the degree of drying increases, attaining a maximum value within the moisture content range of 0.14 – 0.10 g g^{-1}. Further drying beyond this moisture content range produces a gradual decrease in the soil dry density. The porosity of the soil, on the other hand follows an inverse trend to that of the soil dry density. Soil unconfined compressive strength increases significantly with the level of poultry waste incorporation and as the soil dries out. The shrinkage index of the soil increases with both the rate of poultry waste incorporation and the degree of drying. However, the incorporation of poultry waste reduced the influence of moisture content on the shrinkage index with progressive drying.

In general, the results indicate that poultry waste incorporation enhances the maintenance of the integrity of soil aggregates under compressive loads thereby improving the workability of the soil.

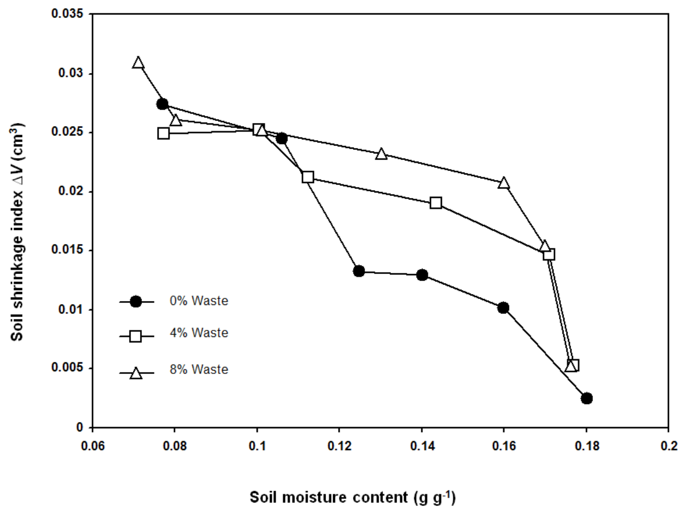

Fig. 4:Soil shrinkage index versus soil moisture content for different levels of poultry waste

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