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THE INFLUENCE OF ORGANIC MATTER ON SOIL COMPACTIBILITY AND AIR PERMEABILITY OF SOME SOILS IN BORNO STATE

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Abstract

A laboratory experiment was conducted to determine the influence of an organic material (groundnut haulms) on the compactibility and air permeability of three most common agricultural soils (clay, sandy clay and sandy loam) in Borno state. The organic material was incorporated into the soils at three levels (2, 4 and 6% by mass of dry soil) and the soil-organic matter mixtures were compacted at three levels (5, 15 and 25 hammer blows). Incorporation of the organic material into the soils reduced their bulk densities and increased their air permeabilities. The bulk density for Ngala town clay, Nguma sandy clay and University sandy loam soils when incorporated with 2% organic matter and compacted using 25 hammer blows at 10% moisture content were 1.50, 1.59 and 1.74 Mgm-3 respectively. When the organic matter level was increased to 6% and compacted at 10% moisture content using 25 hammer blows, the bulk densities of the soils reduced to 1.41, 1.49 and 1.63 Mgm-3 for Ngala town clay, Nguma sandy clay and University sandy loam respectively. The air permeability for Ngala town clay, Nguma sandy clay and University sandy loam soils when incorporated with 2% organic matter and compacted using 25 hammer blows at 25% moisture content were 17, 23 and 37 μm² respectively. When the organic matter level was increased to 6% and compacted at 25% moisture content using 25 hammer blows, the air permeability of the soils increased to 28, 32 and 48 μm² for Ngala town clay, Nguma sandy clay and University sandy loam, respectively. For each level of organic material, air permeability of each soil decreased with increase in the number of hammer blows. Incorporation of the organic material into the clay soil increased its susceptibility to compaction and this resulted in much lower values of air permeability than in the sandy loam soil. Statistical models were generated to predict the air permeability of the soils in terms of silt and clay contents, moisture content, compaction and organic material levels. The implications of the results obtained in determining severity of compaction on these agricultural soils were discussed.

1. Introduction

Soil compaction caused by increasing weights of agricultural machinery can affect the structure of arable soils either positively or negatively. The degree to which soil compaction affects soil physical properties and consequently crop yields is dependent upon soil type, the number of tractor passes, tyre contact pressure, soil moisture content at the time of compaction and crop type (Voorhees, 1977; Oni and Adeoti, 1986; Ohu and Folorunso, 1989). Soil compaction reduces soil porosity and thereby deteriorates soil aeration by curtailing the exchange of air from the root zone with air from the surface (Negi *et al*., 1980). Compaction can reduce the transmission of water and air through the soil profile, change the heat capacity, increase surface runoff and increase potential of erosion (Al-Adawi and Reeder, 1996). Soil compaction increased soil bulk density, soil shear strength, penetration resistance and reduced hydraulic conductivity and pore numbers in a vertisol (Boone *et al*., 1994; Radford *et al*., 2000). Lowery and Schuler (1988) reported that a soil compacted with a 12.5 to 18 Mg axle load reduced maize yield considerably in a rainy year and in a dry year (Voorhees, 1992) but not in years with normal precipitation.

Besides grain and dry matter yield of crops, product quality can also be affected by soil compaction (Alakukku and Elonen, 1995). Soil compaction by a 5 to 20 Mg axle loads

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delayed the ripening of maize, raising the grain moisture content at harvest and thus the drying costs for several years (Gaultney *et al.,* 1982; Voorhees *et al*., 1989). Similarly, soil compaction decreased the yields and nitrogen uptake of oats, wheat and barley and lowered seed moisture contents of these crops at harvest (Alakukku and Elonen, 1995). Kayombo (1989) stated that not all instances of soil compaction are necessarily harmful. It was noted that in some dry climates a rather heavy compaction of highly permeable sandy soils might improve the efficiency of scarce rainfall and irrigation. In a field experiment with a sandy loam soil, the highest grain yield of sorghum (Ohu *et a*l., 1991) and millet (Mamman and Ohu, 1997; Mamman and Ohu, 1998) were at 15 tractor passes, while zero pass gave the least. Bicki and Siemens (1990) found positive response of corn and soybean yields to wheel traffic when rainfall was limiting and negative when rainfall was adequate.

Compacted soils may recover naturally if compaction forces are no longer applied. Natural recovery is, however, a slow process and depends on geographical location (Al-Adawi and Reeder, 1996). Some of the factors considered to alleviate soil compaction are wetting/drying, freezing/thawing, biological activity and tillage (Hakansson and Reeder, 1994). A legume, *stylosanthes guianensis* was found to be suitable for restoring compacted and eroded Alfisols in West Africa (Lal *et al*., 1979). Ohu *et al*. (1991) also reported that groundnut haulms alleviated soil compaction and improved the hydraulic properties of some agricultural soils in Borno state.

The incorporation of organic material into the soil can reduce its compactibility and thus improve its physical and hydraulic properties (Ekwue, 1990; Ohu *et al*., 1991). Stone and Ekwue (1995, 1996) reported that incorporation of peat and sewage sludge into some soils in Trinidad increased their compressibility due to increase in void ratio of the soils and hence their porosities. They concluded that the extent of increased compressibility with organic matter addition depends on the properties of the organic matter, particularly its dry density.

Soil compaction is measured indirectly by studying the changes in one or more soil parameters such as cone index, bulk density, porosity, hydraulic conductivity and air permeability (Al-Adawi and Reeder. 1996). Many researchers use cone penetration measurements as indicator of soil compressibility because it provides a rapid, simple and economical means of indicating compaction (Perumpral, 1987). One of the most frequently used measures of soil compaction is bulk density. Within a given soil, the bulk density provides a measure of how close the soil particles are packed but does not yield any information about their geometric arrangement or the pore size distribution (Freitag, 1971). Measurements of fluid flow through a soil provide a meaningful description of compaction, because the fluid conductivity is related, generally, to the amount of pore space in the soil (Al- Adawi and Reeder, 1996). Air permeability, which is a measure of air flow through a soil has been observed to have a good physical basis to indicate changes in free interconnected pore spaces which in turn determines aeration limitation in soils (Bowen *et al*., 1983).

In Borno state, little information is available on the behaviour of agricultural soils to air permeability when they are incorporated with organic materials, especially when subjected to different pressures. Due to lack of this information, enormous quantities of crop residues and animal wastes are either not properly utilized or wasted completely. The objective of this study was, therefore, to quantify the effect of an organic material on soil compactibility and air permeability of some agricultural soils.

2. Materials and methods

Three soils representing some of the major agricultural soils in Borno state (Ngala clay soil, Nguma sandy clay soil and University sandy loam soil) were used for the purpose of this study. The soils were collected from the top 0.20 m depth of the soil profile, air-dried and ground to pass a 0.05 m screen. Particle size distribution was determined using the hydrometer method (Lambe, 1951) and organic matter content using the method described by Walkley and Black (1934).

The organic material (groundnut haulms) was grounded and passed through a 0.05 m sieve. The organic material was added to the soils at the rate of 2, 4 and 6% by mass of dry soil. For the purpose of determining the physical properties of the soils, water was added to the soil-organic material mixtures to bring up their gravimetric moisture contents to 5, 8, 10, 12 and 15% for the sandy soil and 10, 15, 18, 20 and 25% for the clay soils. These moisture content values were chosen according to the consistency limits of the soils (Ohu *et al*., 1989). Thereafter, each of the soils was subjected to three levels of compaction energy using 5, 15 and 25 blows of a standard proctor compaction hammer in cylindrical moulds of 102 mm in diameter by 116 mm height, following the proctor compaction procedure (Lambe, 1951). The choice of the three levels of compaction was borne from the equivalent static pressures for soil compaction as determined by Raghavan and Ohu (1985).

For each level of compaction, the air permeability of the soils were determined using the air permeameter designed, constructed and calibrated by Ohu *et al*. (1992). A randomized complete block design was used for the investigation. All the tests were performed three times on each soil. The data collected was subjected to statistical analysis to determine the effects of soil type, organic material, moisture content and compaction level on air permeability of the soils.

3. Results and discussion

The results of the grain size analyses of the soils used and their consistency limits are shown in Table 1. The sandy loam and sandy clay soils are classified as Typic Ustipsament (Rayar, 1984) while the clay soil is classified as Vertisol (FAO/UNESCO, 1974). Table 2 shows the dry bulk density of the soil-organic material mixtures. The dry bulk densities of these soils without organic material incorporation, compacted at 10% moisture content using 25 hammer blows were 1.53, 1.62, and 1.80 Mgm^{-3} for Ngala clay, Nguma sandy clay and University sandy loam respectively (Ohu *et al*., 1989). The incorporation of 2% organic material into these soils at 10% moisture content and compacted using 25 hammer blows reduced their bulk densities to 1.50, 1.59 and 1.74 Mgm^{-3} for Ngala clay, Nguma sandy clay and University sandy loam respectively.

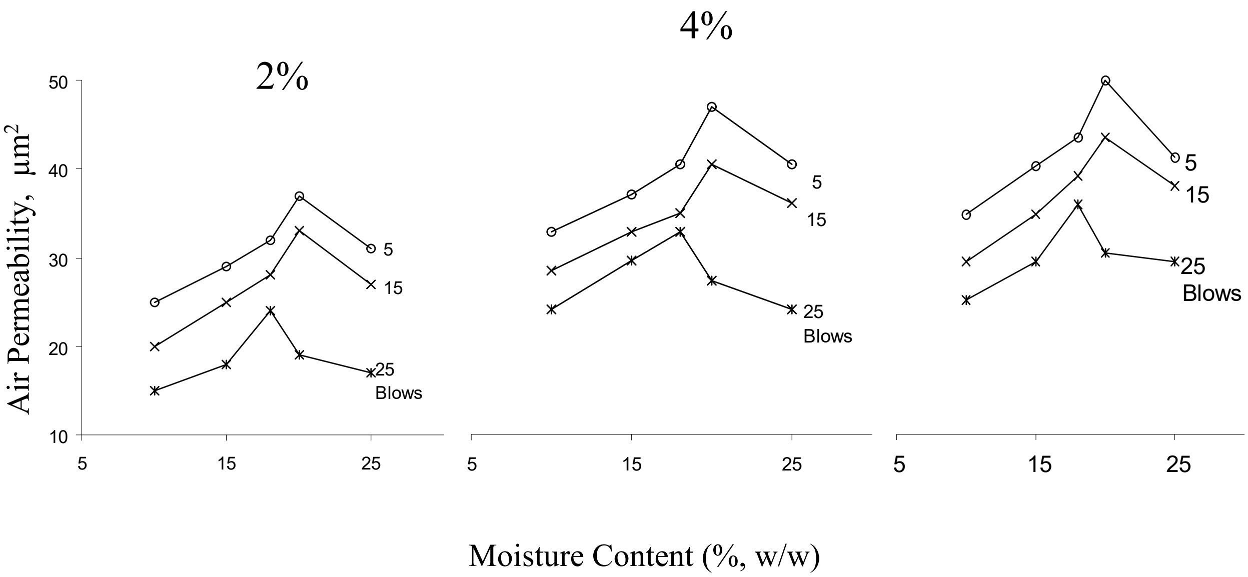

Figure 1: Air permeability vs moisture content for Ngala clay soil at different organic matter levels and proctor number of blows

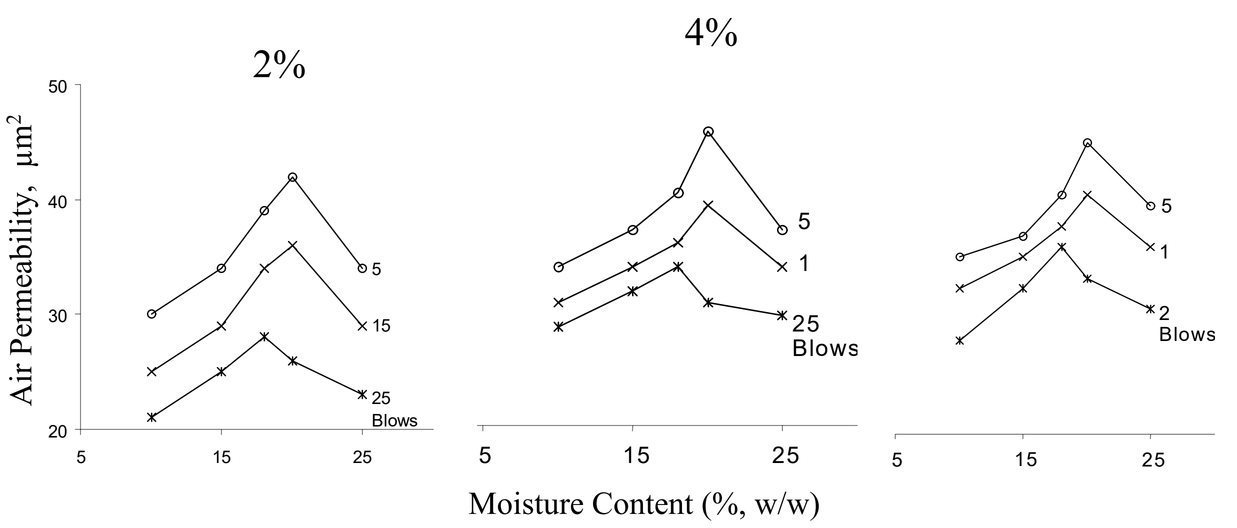

Figure 2: Air permeability vs moisture content for Nguma clay loam soil at different organic matter levels and proctor number of blows

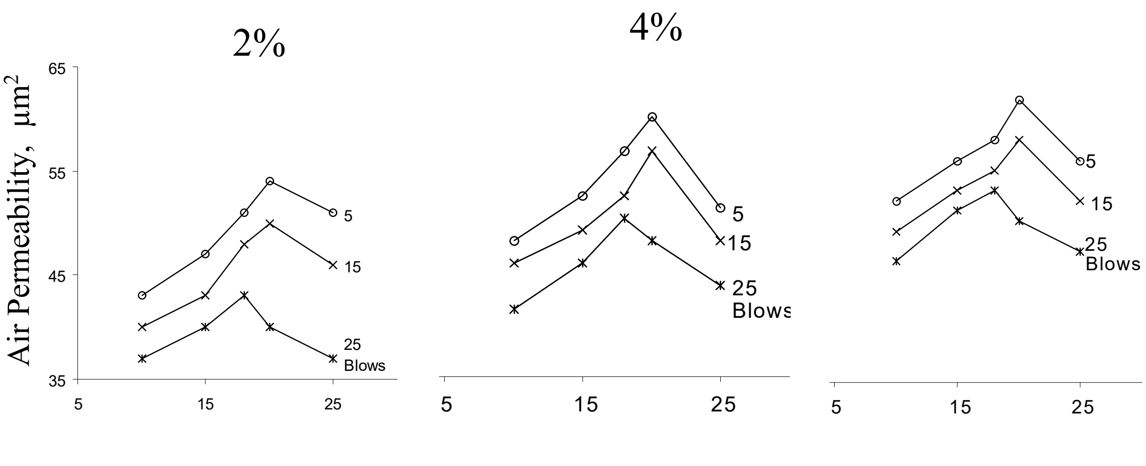

Figure 3: Air permeability vs moisture content for University sandy loam soil at different organic matter levels and proctor number of blows

Table 1: Particle size analysis and initial organic matter content of the soils

Sample location	Soil type	Sand (%,w/w)	Clay (%,w/w)	Silt (%,w/w)	Organic content	Moisture content (%,w/w) LL	PL	PI
Ngala town	Clay	5	60	35	0.97	46.0	25.0	21.0
Nguma Village	Sandy clay	47	46	7	0.14	28.5	17.0	11.5
University Farm	Sandy loam	77	17	6	0.12	21.0	-	-

LL= liquid limit; PL= plastic limit; PI= plasticity index

Table 2: Dry bulk density of the soil-organic matter mixtures at 10% moisture content and 25 hammer blows

Soil type	Dry bulk density at three organic matter levels (Mgm^{-3})		
	2%	4%	6%
Ngala town clay	1.50	1.46	1.41
Nguma sandy clay	1.59	1.53	1.49
University sandy loam	1.74	1.69	1.63

Figures 1 to 3 show the variations of air permeability with moisture content for the soils used. For all the soils, air permeability increased with organic matter but decreased with increase in the number of hammer blows. In Figure 1 for example, the air permeabilities of the soil compacted at 25% moisture content using 5 hammer blows were 31, 38 and 39 for 2 , 4 and 6% organic matter levels respectively. When the soil was compacted using 15 hammer blows at 25 % moisture content, the air permeability decreased to 27, 34 and 36 for 2, 4 and 6% respectively. This trend was the same for the other soil types (Figures 2 and 3). The increases in air permeability with organic matter were statistically significant at 5% level. This could be attributed to increase in porosity of the soils as indicated by the decrease in their soil bulk densities. The figures also show that irrespective of the soil type, organic matter content and moisture content at which the load was applied, the air permeability values peaked at specific moisture contents for the 5 and 15 hammer blows. The low bulk densities of the mixtures and the high values of air permeability at high organic matter levels indicate that the organic material has affected the soils positively.

The significant differences recorded in air permeability were a function of not only the organic material but also of silt and clay contents, moisture content and number of hammer blows. To establish relationships among these variables, multiple regression equations were used. The relationships that best described the air permeability of these soils were as follows:

$$A = 0.64 - 1.38M + 2.18X + 1.66S \ (R^2 = 72\ \%) \qquad 1$$
$$A = 0.36 + 3.57M + 4.12X - 2.19C \ (R^2 = 79\ \%) \qquad 2$$
$$A = 0.89 + 5.24M + 3.85X + 2.46G \ (R^2 = 92\ \%) \qquad 3$$

Where A is air permeability (μm^2), M is moisture content (%, w/w), X is compaction level (MPa), S is silt content (%, w/w), C is clay content (%, w/w), G is organic matter level (%).

The inclusion of organic matter level gave the best correlation as revealed by Equation 3. It is therefore evident that the organic material incorporated into the soils cushioned the effect of compaction, and improved the structure of the soils.

4. Conclusion

This study revealed that incorporation of groundnut haulms into the soils considered would reduce the problem of compaction and improve soil structure by reducing the dry bulk density and creating more voids for more air circulation. This is particularly beneficial in the area of study where tillage operations are carried out with heavy tractors and where large quantities of the organic material are available.

Although this organic material is used to feed domestic animals, our survey indicated that the economic returns would be more when incorporated into soils. It is, however, recommended that further studies be carried out to determine the optimum quantities of this organic material that can alleviate compaction and improve the structure of these soils.

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