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Effects of Organic Matter (Rice Husk), Moisture Content and Compactive Efforts on Bulk Density and Penetration Resistance of Clay Soils (Vertisols)

T. Crowther, Y.M. Dzivama and J. Ijantiku
[1] Department of Agricultural and Bio-Environmental Engineering, Adamawa State College of Agriculture, P. M. B 2088, Ganye. Adamawa State, Nigeria
Contact: newtoncrowther@gmail.com

Abstract

A laboratory experiment was carried out to determine the effects of rice husk on the hydraulic characteristics of compacted vertisols. Three quantities of rice husk were incorporated into the clay soil as organic matter and then compacted at three moisture levels using four different compactive efforts. The three organic matter and moisture content levels were 4, 6, and 8 %, and 20, 35, and 50 % respectively. The four compactive efforts were 0, 5, 10, and 15 proctor hammer blows. Soil properties determined were soil bulk density, penetration resistance, and hydraulic conductivity. The maximum density obtained at any level of compaction was decreasing with higher organic matter incorporation in the clay soil. Soil bulk density and penetration resistance has the highest value at 35 % moisture content. This could be regarded as the critical moisture content of the soil. The hydraulic conductivity of the soil was found to increase with increase in organic matter content from 0 to 4 % decreased at 6 %, but rapidly increase at 8 % organic matter level.

Keywords: Compaction, Bulk Density, Penetration Resistance, Hydraulic Conductivity, Organic Matter

Introduction

The ever increasing food demand for millions of humans on earth have encouraged increase in s mechanized farm operations. The use of heavy equipment and repeated passes on agricultural fields lead to soil compaction. Soil compaction is defined as an increase in the oven-dry mass per unit volume of soil particle by application of mechanical force (Soil Science Society of America, 2005). It is described by soil dry bulk density (Db), or the mass of dry soil per unit bulk volume (Soil Science Society of America, 2005). Bulk density is calculated using only the fine earth fraction of soil (particle diameter less than 2mm). It is calculated by the equation;

$$\text{Dry bulk density} = (\text{dry mass soil}) \times (\text{volume of soil})^{-1}$$

Bulk density is expressed in unit of g cm^{-3}. Soil compaction can be affected by soil texture (Orr, 1960, Haveren, 1983), water content and organic matter (Howard *et al*, 1981).

Soil compaction may affect several physical and biological processes. Physical impedance of roots may limit plant access to water and nutrient by reducing the volume of soil exploited. Compaction may destroy soil structural units and change pore distribution, thereby slowing water infiltration and gaseous diffusion (Taylor and Brar, 1991, Orr 1960). Slow infiltration can also translate into increase runoff and erosion. Slower gas diffusion may increase carbon dioxide concentration in soil air, potentially affecting root respiration (Simojoki *et al*, 1991). Compaction can also slow decomposition, thereby slowing down the return of nutrients to the soil (Breland and Hansen, 1996).

Soil compaction also increases soil strength, which is defined as a transient localized soil property that is a combined measure of adhesive and cohesive qualities of the solid phase of a soil submit (Soil Society of America, 2005). Murphy *et al* (2000) describe soil strength as ‘the capacity of soil to resist a force without rupture, fragmentation or flow’. Compacted soil will not respond as easily to forces acting against it, such as root movement due to higher frictional forces between particles and less space into which particles can shift. Soil strength is affected by factors including soil structure, soil water content, soil texture, and cementing agents (Mirreh and Ketcheson 1972, Vepraskas 1988). It is also affected management variables including trampling intensity (Bryant *et al*, 1972), season of use (Chanasyk and Naeth 1995), and gracing regime (Donkoret *et al*, 2002).

Soil compaction is measured by bulk density and soil strength. Bulk density directly measures compaction, and generally does not vary with other soil properties because it is most often expressed on dry soil basis. Soil strength measures soil compaction indirectly, because soil strength is a function of several variables, including soil water content. It is possible for similar soil strength to exist at different levels of compaction.

Recent changes in agricultural practices such as increased number of operations and use of larger equipment have made soil compaction more common. Most yield- limiting compaction is caused by wheel traffic from heavy equipment, often when operations are conducted on wet soils (Wolkowski and Lowery, 2008). Owing to machinery traffic, soil compaction causes substantial losses at the farm level, but the extend of it depends on the tractor size used, machinery use intensity, weather conditions, and the type of crop grown (Lavoie *et al*, 1991).

The type and condition of a soil affect the potential for compaction. Soils with low organic matter content tend to be more susceptible to compaction because they do not form strong aggregates. Clay soils, when wet are highly compactible because the clay minerals have bound water around them, which act as a lubricant, thus making it easier for soil particles to move against each other (Wolkowski and Lowery, 2008).

Organic matter (Crop residue) has low density and when incorporated into the soil or left on the soil surface could cushion the effect of external load and subsequently reduce the severity of compaction (Ohu *et al*, 2001). Gupta *et al*, (1989) state that organic material incorporated into the soil decompose over time to produce organic matter which can affect various soil physical structure, hydraulic conductivity and aggregate stability. At the same water content and machinery weight, a soil with more organic matter suffers less compaction. Organic matter (and the associated biological activity) protects soil from compaction by ‘cushioning’ aggregates and increasing the stability of aggregates. Organic amendments help prevent and loosen surface compaction by promoting biological activity and by raising the soil organic matter levels. Soils with higher levels of organic matter resist compaction more effectively (Lewandowski, 2016).

The resistance of a probing instrument is an index of soil compaction, moisture content, organic matter and the type of clay mineral (Baver *et al* 1972). Penetration resistance is an empirical, easy and cheap measurement technique of soil strength, widely used to access soil compaction and the effect of soil management (O’Sullivian *et al* 1987, Castrignano *et al* 2002). Penetration resistance attempts to mimic a root growing through soil. However, Whiteley *et al* (1981) and Atwell (1993) noted that soil strength as measured with this instrument may exceed that encountered by root by 2 to 5 times. Reason for this include preferential growth of roots into spaces or cracks of larger diameter, and higher friction between the penetrometer shaft and soil than between root and soil (Atwell 1993, Clark *et al* 2003).

Soil hydraulic properties like the retention capacity and hydraulic as well as gas conductivity have agronomical and ecological implications. Drainage, evaporation and water-uptake by roots are just few examples where the knowledge about the rate of water flow through the soil plays an important role (Plagge *et al*, 1990, Kutilet and Nielsen, 1994). The relative proportion of the three phases (water, gas and solid) of the soil is influenced by properties like texture, structure, biological activity, weather and soil management (Hillel, 1998). In these terms the porous media can be characterized in their volume and function which is of great relevance to understand processes related to water, air and heat transport in soils (Oschner *et al* 2001, Dörner and Horn, 2006).

Materials and Methods

The soil used for study was clay. It was collected from the top 20cm of the soil profile. The sample was grounded to pass through a 2mm sieve after which it was dried. Particle size analysis was performed using the hydrometer method following the procedure of Lambe (1951). The organic matter content of the soil was estimated from the carbon content of the sample using the method of Walkley and Black (1934). Rice husk was sieved through 2mm sieve and was added to the soil to raise its organic matter content.

The initial moisture content of both the sieved soil and rice husk samples was determined using the oven-dry method. The liquid and plastic limits of the soil were also determined. The initial moisture content of the soil and that of rice husk were added to form the initial moisture content used in computing the rise in each level. The moisture content levels used for this study were 20, 35, and 50% based on the optimum moisture content for compacting the soil and on the consistency limit of the soil. The soil-organic matter mixtures were packed into polythene bags and kept air-tight to prevent moisture loss and maintain equilibrium before, during and after experiment. Compaction (number of blows) was performed using the Proctor hammer of which 0, 5, 10, and 15 blows were applied to the soil at every moisture content and organic matter level following the Standard Proctor Compaction Procedure (Lambe, 1951). The soil-organic matter-moisture content was compacted in a mold of 101.56mm diameter by 105.29mm height as measured with a digital vanier caliper. After compaction, the bulk density of the mixture was determined using the method of Lambe 1951). The penetration resistance of the soil in the mold was determined using the pocket penetrometer following the American Society of Agricultural Engineers (ASAE, 1982) standard procedure. The hydraulic conductivity of the soil mixtures was determined without compaction using the constant head permeameter.

Results and Discussion

The result of the particle size analysis was 18% sand, 21% silt and 61% clay and was classified as heavy clay. The organic matter content of the soil was found to be 2.14%. The initial moisture content of the sieved soil sample was determined to be 4.12%. The liquid and plastic limits of the soil as determined were 53.70% and 18.18% respectively.

Fig.1 shows the effect of compaction on bulk density of the soil at different soil moisture content and organic matter levels. The ANOVA result indicates that number of blows, organic matter and moisture content as well as their interactions had significant effect ($p<0.05$) on the bulk of the soil.

It was observed that, with increase in organic matter content of the soil at any level of compaction, the bulk density was decreasing. Thus, the maximum density obtained at any level compactive level was found to decrease with higher organic matter incorporation in the clay soil. Since the bulk density of soil particle (2.65kg/m^3) is greater than that of organic matter (1.40kg/m^3), then the decrease in bulk density should be expected as reported by Ohu *et al* (1989). This is because organic matter added to the soil will make them resistance to compaction. This may also result from the dilution of soil matrix with less dense material as reported by MacRae and Mehyus, (1985) and Ohu, (1985). The resulting effect of high resistance to compaction and dilution will be a decrease in bulk density value. The value of bulk density was highest at 15 blows, 4% organic matter and 35% moisture content. The 35% moisture content that recorded the highest value of soil bulk density could be regarded as the critical moisture content for compacting the soil – organic matter mixture. The lowest value of bulk density (0.78kg/m^3) was recorded at zero blows, 6% organic matter level, and 50% moisture content. This suggests that incorporation of organic matter into clay soils could reduce the effect of compaction, which invariably improved its workability.

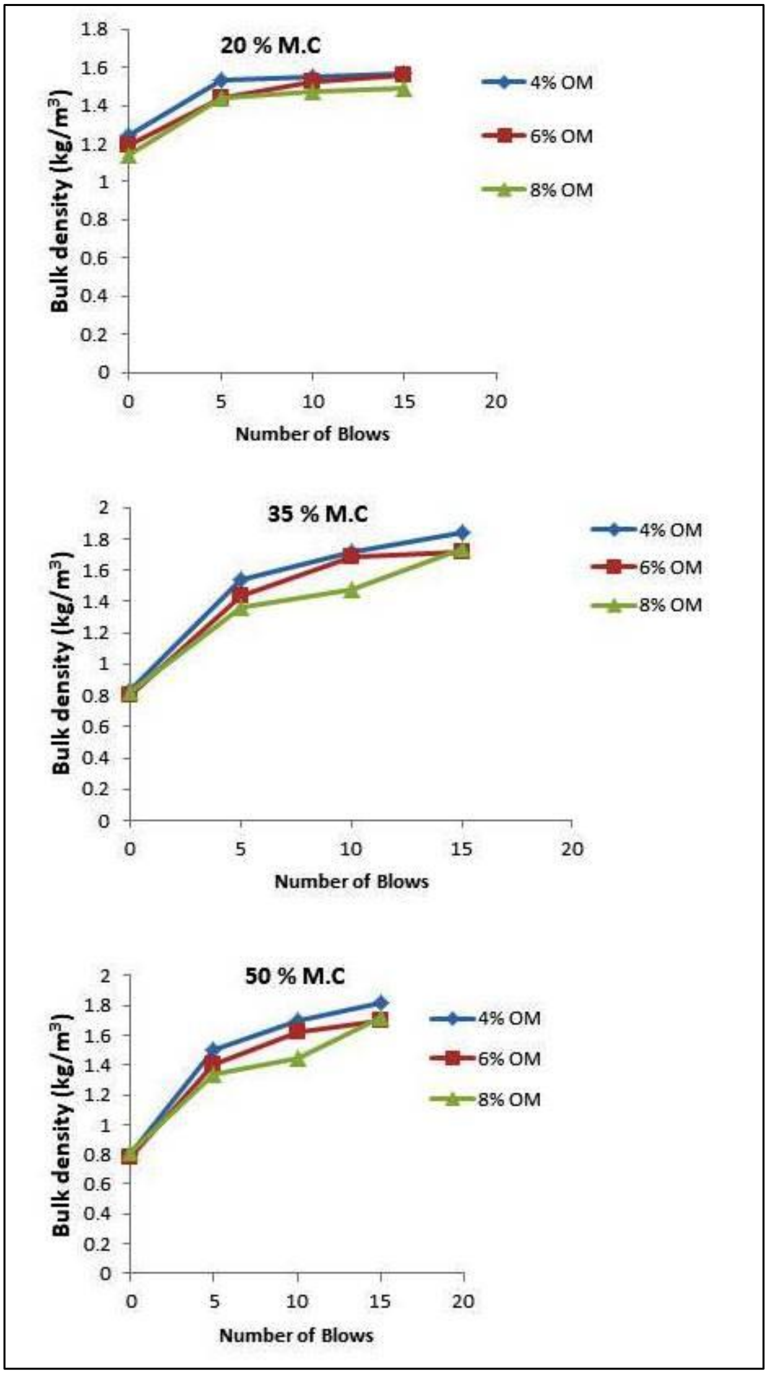

Figure 1: Effects of Number of Blows, Organic Matter and Moisture Content on Bulk Density for Rice Husk

Figure 2 shows the effects of compaction on penetration resistance of the soil. The ANOVA result indicates that number of blows, organic matter and moisture content had significant effect ($p<0.05$) on the mean penetration resistance of the soil. The interactions of these factors also had significant effect ($p<0.05$) on the mean penetration resistance of the soil except for the interaction of moisture content and organic matter. It was observed that penetration resistance increases with increase in moisture level to 35% and then decreases at 50% moisture level. The decrease in penetration resistance at higher moisture level can be attributed to the fact that higher moisture in soils dislodges the bonding between soil particles.

Considering 5 and 10 blows, penetration resistance decreased with increase in percentage organic content from 4 to 8%, but for 15 blows, penetration resistance increased with increase in percentage organic matter. It was observed that penetration resistance increased from 20 to 35% moisture content and drastically decreased with further increase in moisture content to 50%. Even though Ohu *et al*., (2001) reported that addition of organic matter could cushion the effect of compaction in the soil, it is now evident that the extent of alleviation will depend on the moisture content of compaction.

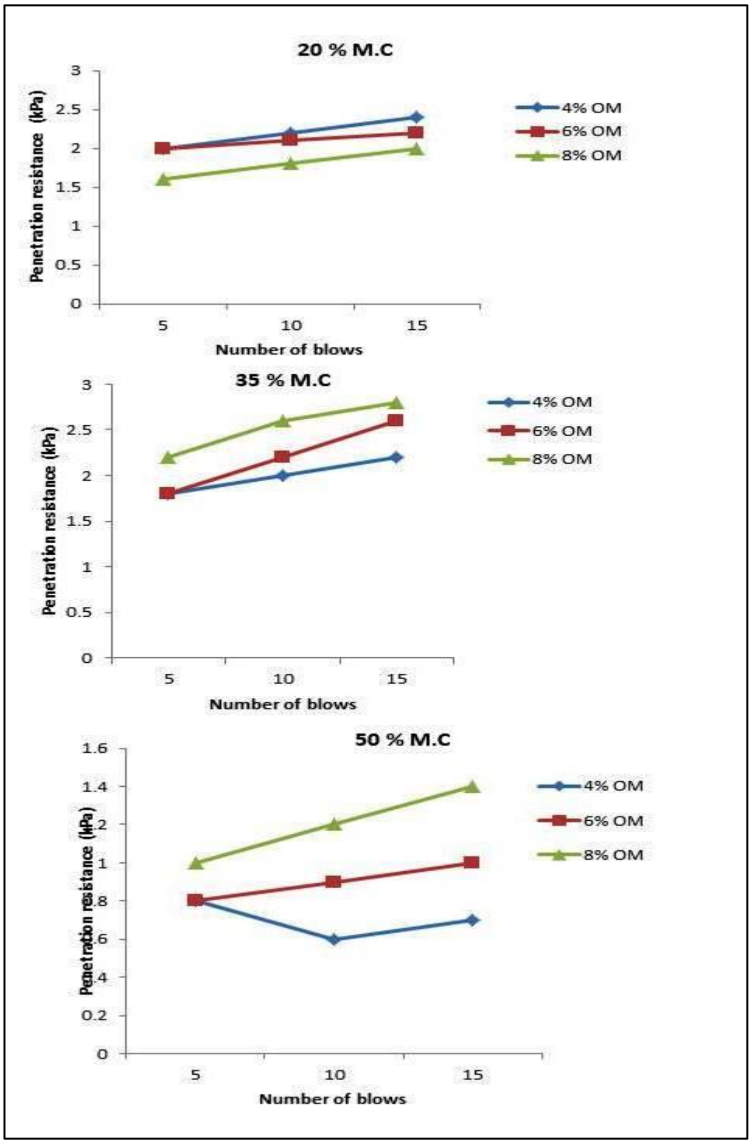

Figure 2: Effects of Number of Blows, Organic Matter and Moisture Content on Penetration Resistance Rice Husk

Figure 3 shows the characteristic curve of hydraulic conductivity at various organic matter levels. The hydraulic conductivity was found to increase with increase in organic matter content from 0 to 4% organic matter level, it decreased at 6%, but rapidly increase at 8% organic matter level.The increase in hydraulic conductivity at higher organic matter content in the soil presumably resulted from increased in total porosity.

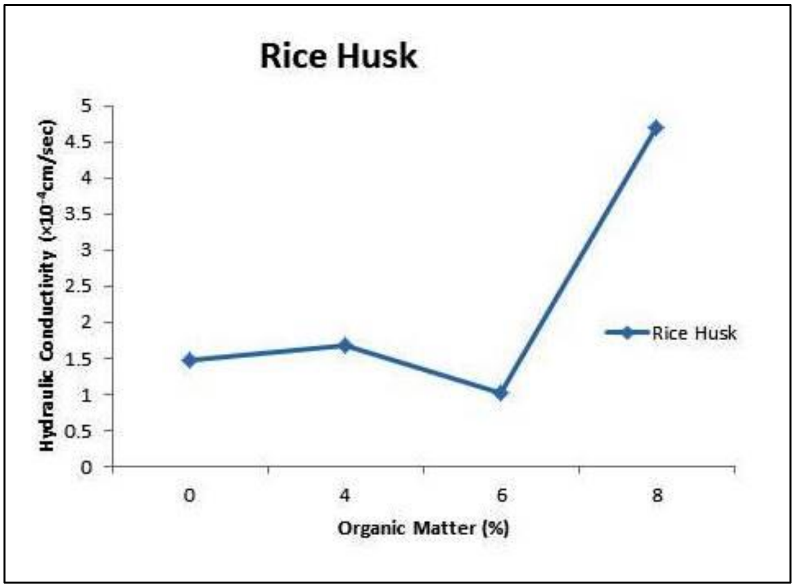

Figure 3: Hydraulic Conductivity of the Soil at various Organic Matter Levels

Conclusion

The result of ANOVA indicates that number of blows, organic matter and moisture content had significant effect (p<0.05) on the bulk density and mean penetration resistance of the soil. The maximum density obtained at any level of compaction was decreasing with higher organic matter incorporation in the clay soil. Soil bulk density and penetration resistance has the highest values at 35% moisture content. This could be regarded as the optimum moisture content of the soil. The hydraulic conductivity increases with increased organic matter content from 0 to 4% organic matter level, it decreased at 6%, but rapidly increase at 8% organic matter. Further research in the incorporation of other organic matter to clay soil before compaction and its effects on the hydraulic characteristics is suggested. This suggests that incorporation of rice husk into clay soils could help in the reduction of compaction, which will lead to improvement of soil physical properties for plant growth.

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