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COMPACTION CHARACTERISTICS OF SOME AGRICULTURAL SOILS IN NIGER STATE OF NIGERIA

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Abstract: The movement of farm tractors and other heavy duty machineries leads to soil compaction. The dry density, penetration resistance and hydraulic conductivity are seriously influenced as a result of this, thus affecting plant physiology. In this study, soil samples were collected from three locations in Niger state, Nigeria namely Gidan kwano, Maikunkele and Maizube farms. Particle size analysis showed the textural class of the soils as sandy clay loam, loamy sand and clay loam, respectively. Atterberg limits of the soils samples were determined using the consistency test. The soils were characterized for their compaction behavior using 5, 10, 15, 20 and 25 blows compactive efforts of a proctor hammer in the moisture range of 8 to 26% (wet basis). The results of the compaction test showed that dry density increased with increase in compactive efforts, and that loamy sand had the highest dry density with accompanying low moisture content at all compaction levels. The result of the consistency test revealed that the optimum moisture content required for machinery traffic occurred between the plastic and liquid limits for all the three soil samples. Consequently, the use of tractors in carrying out farming operations is better suited when the soils are not too wet, so that the soil can support the machinery and hence avoiding wheel skidding. Predictive equations were established to relate the dry density of the different compactive efforts with moisture content of the three soils.

Key words: *Compaction characteristics, agricultural soils, dry density, compactive effort, Nigeria*

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INTRODUCTION

Soil compaction is the process whereby soil particles are constrained to pack more closely together through a reduction in the air voids due to external pressure [1]. In agricultural field, the external force could be human, animal or machinery traffic. Compaction increases the strength properties of soils, namely bulk density and shear strength. Several authors have shown that soil moisture content is the most important factor in the compaction process and soil compatibility [2, 3]. A small increase in moisture content tends to increase the repulsion of particles and to facilitate their orderly arrangement. During the compaction process, additional application of water expels more air from the soil and increases the dry density of the soil until the optimum moisture content is attained. The maximum dry density of the soil coincides with optimum moisture content. When the water content exceeds the optimum value, the water pushes the soil grains apart, and because water is much more incompressible than the grain assembly and has no time to drain, the dry density starts to decrease.

According to [4], soil compaction varies with soil type: sandy soil have naturally higher bulk densities than clay soil due to the many small pores associated with clay. Several researchers have suggested ways of minimizing the effects of soil compaction. Increasing the soil resistance to compaction could be accomplished by increasing soil strength, thus enabling the soil to better withstand the compacting effects of applied loads. One method of increasing soil strength is to reduce soil moisture. A relatively dry soil may improve the soils ability to withstand compactive forces caused by vehicle traffic [4]. [5] observed that subsoil bulk density was unaffected by large axle loads when dry, but increased significantly when wet. [6] recommended that moderate compaction of the top soil may be beneficial to crop yield in a dry year, but to limit traffic and compaction to an absolute minimum level in wet years.

However, the control of soil moisture content during field machinery operations is a difficult task. According to [7, 8], knowing the change in soil compatibility with moisture content changes would assist farmers schedule farm trafficking and cultivation operations at the proper moisture content. [9] opined that the no-tillage system conserves energy, but results in lower yields, while conventional tillage with higher yields imparts compaction on the soil. Therefore, compaction studies must aim at striking a balance between yield and energy efficiency in order to optimize agricultural production and productivity. [10] stated that a soil moisture content lower than the plastic limit (pl) is desirable for cultivation. This desirable condition, however, is a function of the soil type [11].

Research has shown that compaction has the potential to depress crop yields, since extremely dense soil impedes root growth thereby limiting water consumption by plants [12]. Thus, farm managers must design strategies to manage soil compaction in order to minimize its detrimental effects. In this regard, researchers have adopted modeling approach to simulate soil compaction in order to address the problem [13, 14].

The extent of soil compaction worldwide from vehicular traffic is estimated to be 68 million hectares of land [15]. In recent years, the need to achieve food security for the teeming population in Nigeria has led to the massive importation of agricultural machinery for increased mechanization. According to [16] increased use of power machinery system particularly heavy machines with high wheel load is one of the major reasons for compaction of subsoil layers in agricultural fields. They further opined that

during the last two decades, mechanization level has increased manifold in developing countries. Citing India as a typical example, [17] reported that the production of tractors with matching power in the category of more than 45 kW increased because of the increased use of heavy machinery. The situation in Nigeria is akin to that of India and other developing countries. Over 83% of the tractors imported into Nigeria and tested at the National Centre for Agricultural Mechanization (NCAM), Ilorin from 2005 to date come from Asian countries, namely India and China. Seventy two (72) percent of these tractors exceed 45 kW (60 hp) capacity with weights of over 35 kN which exceeds the limit set for soils resistant to compaction [18, 19]. Severely compacted soil impedes root growth and development and restricts plants ability to utilize soil water and nutrients by reducing the soil volume utilized by roots. The resultant effect is reduced crop yield and low financial returns to the farmer.

[16] noted that compaction phenomenon in the field due to machine passage and its impact on crop growth is site-specific and also influenced by edaphic, climatic and environmental factors. Taking into cognizance that there is not yet a country-wide study on compaction of agricultural soils of Nigeria as previous studies were limited to Northeastern and Southwestern Nigeria [20, 21, 22], it becomes imperative to investigate the compaction characteristics of soils of Niger state of Nigeria.

The objectives of the study was:

1. to determine the optimum moisture content and maximum dry density at different compactive efforts of three major soils of Niger state, Nigeria; and
2. to establish the most suitable moisture content for each soil type for field machinery operations.

MATERIALS AND METHODS

Study Area

The study sites fall under Minna senatorial zone of Niger State, North-central Nigeria (Fig. 1). The sites are Maizube Farms (Lat. 9°37'N and Long. 6°30'E); Gidan Kwano (Lat. 9°32'N and Long. 6°28'E) and Maikunkele (Lat. 9°42' N and Long. 6°28' E). Maizube Farms is a large-scale mechanized farm. Gidan Kwano houses the Federal University of Technology, Minna Research Farm; while Maikunkele is the headquarters of Bosso local government area of Niger State where in addition to mechanized farming, the traditional farming system is prevalent. Niger state falls within the Southern Guinea Savannah vegetation of Nigeria. The zone has distinct dry and rainy season with a mean annual rainfall of about 1200 mm. The rainy season usually commences in April or May and ceases in October with a five (5) month dry period which extends from November to March. The average minimum and maximum temperatures of the area are 23 and 35°C, respectively. The soils of Niger State are sharply divided between the two geographical formations of the state: the soils of the Basement Complex rocks and those of the sedimentary Nupe Sandstone. The Nupe sandstones dominate the sites of study and consist mainly of the semi-consolidated coarse grits, conglomerates, fine grained sandstone.

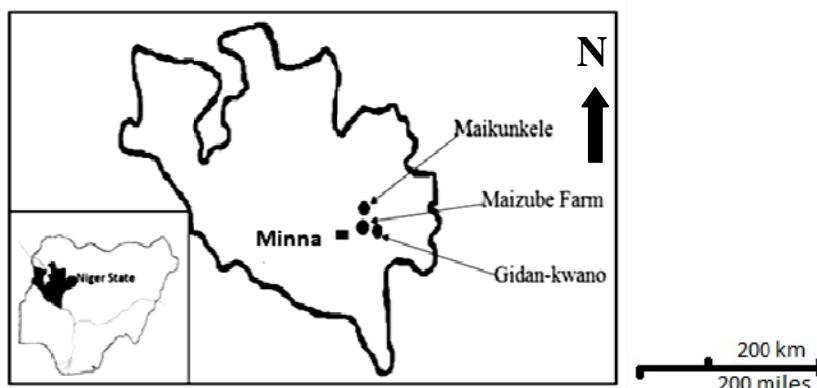


Figure 1. Map of Niger State indicating the study sites

Methodology

Soil samples were collected in three replicates within 0-30 cm depth. The soils were characterized for their physical properties- particle size distribution, moisture content (MC), liquid limit, plastic limit and plasticity index using standard procedures as specified in BS 1377 part 2 [23]. The compaction test was done for the three (3) soils using Proctor test procedures. The particle size distribution and consistency limits of the three soils are given in Tab. 1.

Table 1. Particle size distribution and consistency limits of the three soil types

Soil Characteristics	Soil texture		
	Gidan kwano Sandy-clay loam	Maikunkele Loamy sand	Maizube farms Clay loam
<i>Particle size distribution (%)</i>			
Sand	66.12	78.00	39.32
Silt	7.00	12.50	26.50
Clay	26.88	9.50	34.18
<i>Consistency limits (%)</i>			
Liquid limit	20.20	20.00	32.40
Plastic limit	15.76	0.00	22.88
Plasticity index	4.24	0.00	9.52

Sample Preparation

A homogeneous sample was obtained from each soil after thorough mixing. The initial moisture content of the three soil samples were 7.10%, 7.03% and 7.92% (w. b.) for sandy clay loam, loamy sand and clay loam, respectively. These moisture contents were brought to eight moisture levels in the range of 8 to 26% (w.b.). Each soil type was subjected to 5, 10, 15, 20 and 25 blows of a proctor hammer in a cylindrical mould with internal diameter of 10.15 cm, internal effective depth of 11.7 cm and a capacity of 944 cm³. The mould consists of a detachable base plate, collar 5 cm in effective height, and

rammer 2.5 kg in mass falling through a height of 30.5 cm. The average dry density of three replicates for the compacted soils corresponding to each moisture level was computed.

Statistical analysis

The optimum moisture content and maximum dry density were correlated with soil components using simple and multiple correlation and regression analysis.

RESULTS AND DISCUSSION

The liquid limits, which were found to be highest in clay loam and least in loamy sand, were used to determine the moisture range for the compaction test of the soil samples (Tab. 1). The plastic limit was highest in clay loam and gave zero value in loamy sand. The low silt and clay content of the loamy sand could be reason for its non-plastic behaviour. It is possible to roll clay loam owing to its high plasticity index into a crumbling thread of 3 mm when the water level of the soil is increased beyond the plastic limit. However, if the water level is less than the plastic limit, the soil thread will crumble at a diameter more than 3 mm. The optimum moisture contents of the three soil samples occurred below the liquid limit and between plastic and liquid limits. Similar studies were conducted by [7] and [21] for soils of North and South western Nigeria, respectively. In their respective studies, they found the soils to be well below the liquid limits. Consequently, farm tractors are better suited when the soil is not too wet, so that the machinery can be supported and skidding can be avoided [24].

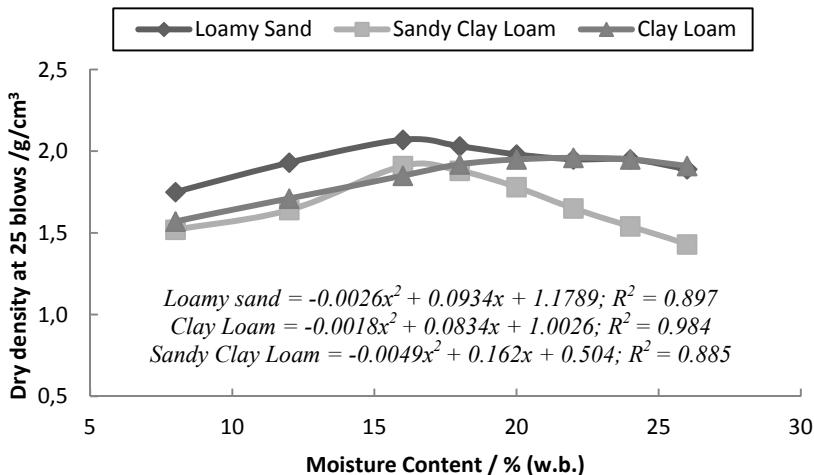


Figure 2. Moisture content Vs Dry density at 25 blow compactive effort

Figs. 2 to 6 show the results of the dry density of the three soils with respect to moisture content at 25, 20, 15, 10 and 5 blows, respectively. The bulk density was found

to increase with increase in compactive effort, from 5 to 25 blows, on the soils. The dry density at 25 blows compactive effort increased from 1.52 to 1.91 g·cm⁻³, 1.57 to 1.96 g·cm⁻³, 1.75 to 2.07 g·cm⁻³ and decreased to 1.88 g·cm⁻³, 1.95 g·cm⁻³, 2.03 g·cm⁻³ with further increase in moisture content from 8 to 26% (w.b.) for sandy loam, clay loam and loamy sand, respectively.

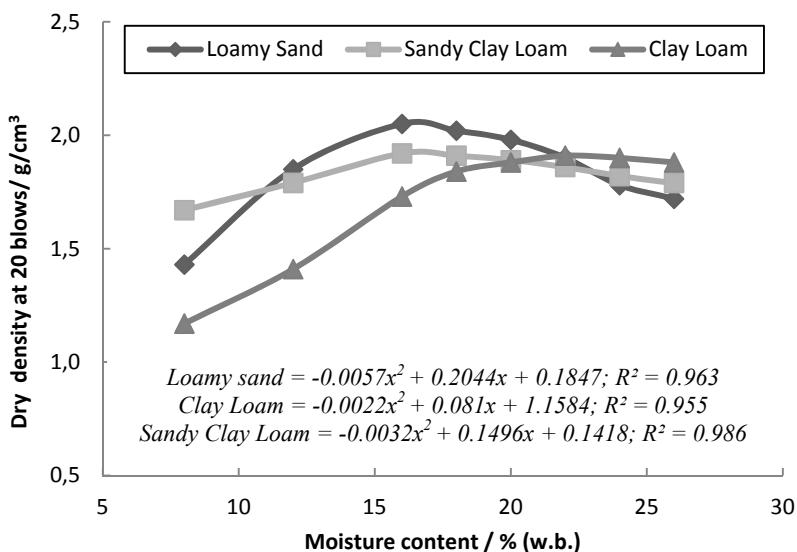


Figure 3. Moisture content Vs Dry density at 20 blows compactive effort

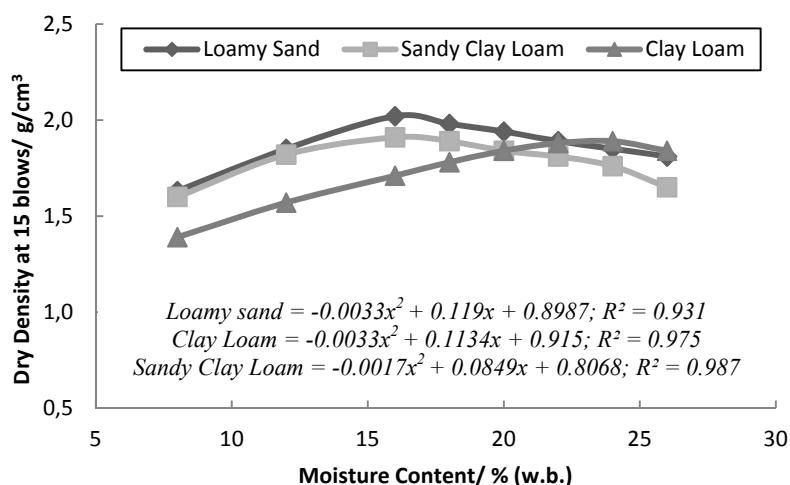


Figure 4. Moisture content Vs dry density at 15 blows compactive effort

Similar trend were observed in the variations of dry density with moisture content at all other compactive efforts. The increase in dry density for all three soils samples at all compaction levels were expected because the higher the number of blows, the more air is expelled and the higher the mass per unit volume. The structural disparity associated with the three soil samples in terms of their classification as sand, silt or clay explained why there were small differences in the values of their dry densities.

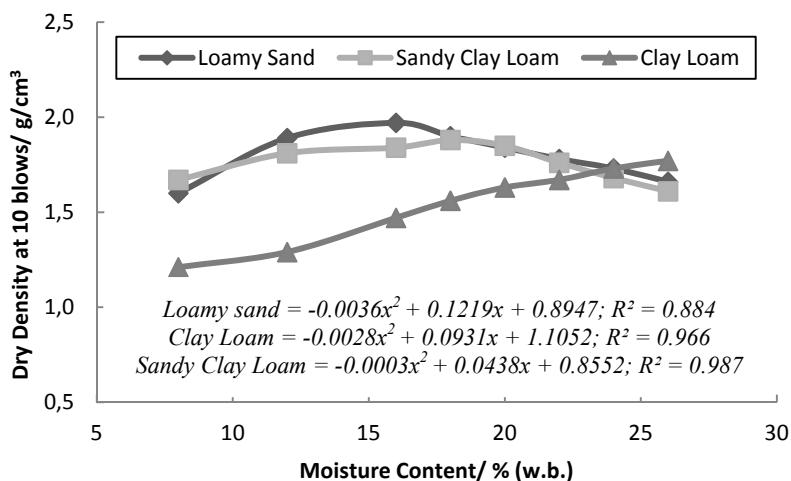


Figure 5. Moisture content Vs Dry density at 10 blows compactive effort

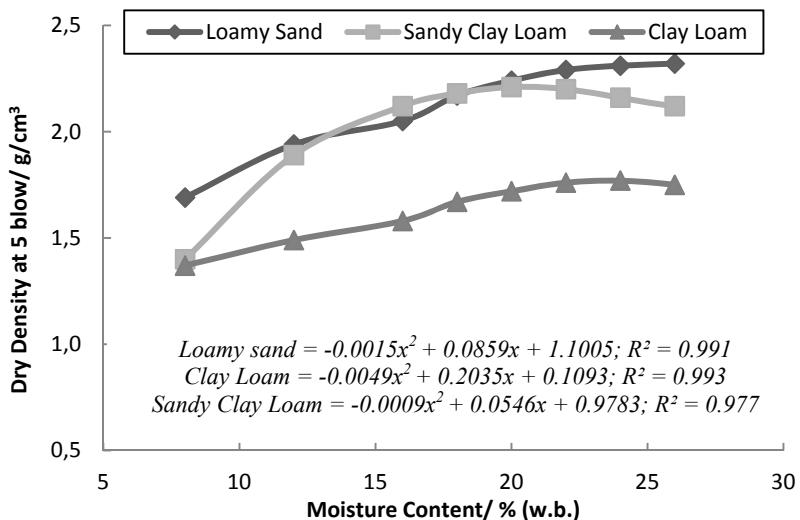


Figure 6. Moisture content Vs dry density at 5 blows compactive effort

CONCLUSIONS

The soils obtained at Gidan kwano, Maikunkele and Maizube farms in Minna, Niger state Nigeria are generally sandy in particle size composition and this seemed to have an overriding influence on their compaction characteristics. Classifying the soils revealed that the soils are sandy clay loam, loamy sand and clay loam with respect to the three locations. The maximum and minimum dry densities occurred at 25 and 5 blows compactive efforts, respectively. The dry density of the soil at traffic increased with increasing moisture content up to a predetermined level, which was below the liquid limit, and thereafter decreased as moisture content increased. The optimum moisture content required for machinery traffic occurred between the plastic and liquid limits. Consequently, the use of tractors in carrying out farming operations is better when the soils are not too wet, so that the soil can support the machinery and wheel skid is avoided. Predictive equations were established to relate the dry density of the different compactive efforts with moisture content of the three soils. The moisture content of the soils affected compaction behavior. Hence, the degree of compaction is a function of mass, moisture and soil type. Developing specifications for the limit of compactness required for mobility of farm machineries in the field is suggested.

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KARAKTERISTIKE SABIJENOSTI NEKIH POLJOPRIVREDNIH ZEMLJIŠTA U DRŽAVI NIGER U NIGERIJI

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Sažetak: Kretanje poljoprivrednih traktora i drugih teških mašina uzrokuje sabijanje zemljišta. Zapreminska težina, otpor penetracije i hidraulična provodljivost su pod značajnim uticajem sabijanja, što ugrožava i fiziologiju biljaka. U ovom istraživanju sakupljeni su uzorci zemljišta sa tri lokacije u državi Niger u Nigeriji, farme: Gidan kwano, Maikunkele i Maizube farms. Analiza dimenzija čestica pokazala je da teksture zemljišta pripadaju klasama peskovito-glinovita ilovača, pesak i glina ilovastog sastava, redom. Atterberg granice uzorka ovog zemljišta određene su testom konzistentcije. Uzorci zemljišta su bili karakterisani koristeći intervale za sabijanje od 5, 10, 15, 20 i 25 udaraca Proctor čekića u opsegu vlage od 8 do 26% (mokra osnova). Rezultati testa sabijanja pokazuju da se zapreminska težina suvog uzorka povećava sa povećanjem broja udaraca i da frakcija ilovasti pesak ima najveću gustinu koja prati nizak nivo vlage na svim nivoima sabijanja. Rezultat testa konzistentcije je pokazao da je optimalna vlažnost potrebna za saobraćaj mašina bila između plastične i tečne granice za sva tri uzorka zemljišta. Shodno tome, upotreba traktora u obavljanju poljoprivrednih radova je bolje prilagođena kada zemljišta nisu prevlažena, tako da zemljište može da izdrži opterećanje mašina, a da pri tome bude izbegnuto proklizavanje točka. Postavljene su jednačine za predviđanje odnosa zapreminske težine suvog uzorka za različit broj udaraca čekića sa sadržajem vlage kod tri uzorka zemljišta.

Ključne reči: karakteristike sabijanja, poljoprivredna zemljišta, suva zapreminska težina, udarac Proctor čekića, Nigerija

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