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Modeling the Behaviour of Igbokoda Loamy Sand Soil, under Uni-Axial Compression

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Abstract: The compaction problems associated with the use of heavy machinery in Igbokoda in Ilaje Local Government of Ondo state, Southwestern Nigeria has led to the concern to study the compaction behaviour of this major soil in the area. A description of the compaction behaviour was obtained by the use of a simple unit-axial compression technique that enabled the compaction behaviour of the soil to be described and analyzed and modeled. Plots of bulk density, against applied pressure describe the compaction behaviour at varying moisture levels. Models that describe the relationships vary from linear to intrinsically linear models: linear; exponential; power and logarithmic functions with very high coefficients of determination (R^2>0.9). Multiple regression analysis was also used to analyze the effects of moisture content and applied pressure on bulk density with (R^2 =0.6114). The analysis also showed that the principal factor influencing compaction of the loamy sand was water content rather than applied pressure at the time of compaction. The plot of bulk density versus moisture content was best fitted by parabolic (or quadratic) model. At applied pressure of 17.5 kPa, the bulk densities were 1.599 and 1.475 Mg m^{-3} when the soil was dry and when it approached saturation, respectively. At applied pressure of 618 kPa, the corresponding values were 1.6393 and 1.5990 Mg m^{-3}, respectively.

Key words: Compaction, loamy sand, applied pressure, bulk density, models

INTRODUCTION

Soil compaction is a potential problem in many agricultural soils because fields are often trafficked and tilled when soils are in a condition prone to compaction. When soil is compacted, its bulk density increases because soil particles are more closely packed (Erbach, 1986).

Increased bulk density reduces porosity and can hamper plant growth if porosity is reduced below that for which air-filled pores represent 10 % or less of total soil volume (Chanceller, 1977).

In commercial Agriculture and Forestry, concern has been expressed that the widespread use of heavy wheeled and tracked vehicles during timber harvesting operation; land preparations may result in a considerable decline of future sites productivity (Greaeen and Sands, 1980). Impacts due to these activities may include soil compaction, destruction of soil surface structure, nutrient decline through erosion or biomass removals and increased s ediment yield as a result of erosion (Moffat, 1991). However, it is only recently that attention is being drawn to the potential impacts of heavy wheeled and tracked vehicles on soils of Igbokoda, Southwestern Nigeria.

Studies regarding the effects of various harvesting machinery on soil properties have been made in timber plantations in South Africa (Grey and Jacobs, 1987), Australia (Jakobsen and Greacen, 1985) and the United States (Diskersan, 1976). However, it is often extremely difficult to extrapolate from these studies to other soil types as detailed soil descriptions and information on compression behaviour are lacking. Even in agriculture where a substantial research effort has been focused on soil compaction, researchers acknowledged that data in the literature on the compressibility of agricultural soils are limited. In Nigeria, information on compressibility of agricultural and forestry soils is even more scarce.

The development and implementation of practical guidelines in order to manage soil compaction for a wide range of machinery types and forestry soils depend upon an understanding of the relative importance of applied pressure and water content during the compaction process.

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Table 1: Physical properties of the experimental soil

Soil type	Texture Sand %	Silt %	Clay %	Bulk density Mg m^{-3}	Sat. hydraulic conductivity mm min	Clay ratio	Clay+silt %	LOI % %
Loamy Sand	85	3	12	1.56	5.3	13.6	15	1.12

The objective of this study therefore was to describe, and model the compaction behaviour of Igbokoda loamy sand soil in southwestern Nigeria, using a simple uni-axial compression technique.

MATERIALS AND METHODS

Experimental soil and description: The soil used in this study was the major soil predominant in Igbokoda (headquarters of Ilaje Local Government area), Ondo State, South Western Nigeria. The soils were collected from the main agricultural production areas. This region is predominantly rainforest zone. Rainfall is in the order of 150 to 300 cm per annum, and mean annual temperature ranges from 25 to 28°C. Soil samples were taken from freshly cut faces in open shallow pit to dept of 40 cm. Soil texture was determined by the pipette method (Day, 1965) after treatment with calgon (Sodium hexametaphosphate and sodium carbonate) and ultrasound. The organic matter content was determined by wet-oxidation using Walkley-Black method (1974). Loss-On-Ignition (LOI) was determined by the loss in mass after ignition at 450°C and expressed as a percentage of oven dry (105°C) soil mass. The water content ranged from 0 to 13 (% db). The physical properties of the soil are shown in Table 1.

Soil samples preparation and compression tests: Soil samples were air-dried and pulverized to pass through a 2 mm sieve. Each soil was wetted to a range of water contents between saturation and wilting point. For each sample, approximately 2 kg or air-dry soil were poured into a plastic tray. The soil was wetted with an atomizer and thoroughly mixed to bring the soil to the desired water content. The tray was then placed in a plastic bag and the sample was allowed to equilibrate for 48 h. After equilibration, a soil sample at particular water content was placed in steel sleeve, 90 mm in diameter and 100 mm long. The cylinders were then placed on a 5 mm perforated metal base with cheesecloth before the soil was added. The cylinders were gently tapped to allow settling of the soil particles. Soil samples in the cylinders were then subjected to applied pressures of 0, 17.5, 100, 175, 289.5, 404, 511 and 618 kPa respectively, applied by a Universal Testing machine (SM100, model No CPI-60) of 0.1 kN sensitivity, manufactured by TEC QUIPMENT Ltd, Nottingham, England), consisting of an hydraulic ram connected to a piston. The compression force was read through a digital load meter. A hand pump was used to generate the required pressure on the soil. The pressure was maintained for a few second and then released. The samples were allowed to 'rebound' before final heights were measured. Water and air could escape around the piston and through fine perforations in the base plate. The depression in the soil surface from the rim of the cylinder was measured at three points around the core by using a vernier scale. This procedure was similar to that reported by research (Smith *et al*., 1997). These measurements were used later to calculate bulk density.

Data analysis: Simple and multiple regression analyses were used to analyze the data. Plots of bulk density versus applied pressure were observed at various water contents while the coefficient of determination (R^2) was used as a criterion for selecting the best fit. Multiple regression analysis was also carried out on bulk density (dependent variable) and water content, applied pressure (independent variables) to study the effect of each variable on bulk density.

RESULTS AND DISCUSSION

Compression curves models: Values of bulk density (ordinate) were plotted against applied pressure (abscissa). The best-fit models at each moisture level were established using regression analysis with the regression models and their coefficients shown (Table 2). The models vary from linear to intrinsically linear models: Linear Fit (LINFIT); Exponential Fit (EXPFIT); Logarithmic Fit (LOGFIT) and Power Fit (PWRFIT).

It was observed that experimental soil showed similar behaviour under compression when it is very dry and when it is almost saturation. This report is similar to that reported elsewhere (Smith *et al*., 1997). The linear model describing the compression at those moisture levels could explain this. At intermediate moisture contents, the models are only intrinsically linear. The high coefficients of correlation of the models showed that the models are adequate for the prediction of the soil behaviour.

The percentage increase in compaction (increase in bulk density over initial bulk density) as a result of varying applied pressure and water contents for the loamy sandy soil is presented in Fig. 1.Wet, moist and dry refer to water contents at matrix potentials of-33 kPa, -80 kPa and -500 kPa respectively, similar to the methodology reported elsewhere (Smith *et al*., 1997).

Table 2: Best-fit models describing bulk density-applied pressure relationships of loamy sand soil at different moisture content levels. LINFIT = Linear Fit EXPFIT = Exponential Fit LOGFIT = Logarithmic FitPWRFIT = Power Fit

MC (%) db	Model type	Correlation coeff. (r)	Model equation
0.01	(LINFIT)	0.9956	ρb = 1.5913+7.898E-5σ
0.1	(EXPFIT)	0.9908	ρb = 1.4405EXP (1.043E-4σ)
1.6	(LINFIT)	0.983	ρb = 1.3697 +1.411E - 4σ
1.9	(LOGFIT)	0.9943	ρb = 1.09158+ 5.413E-21nσ
4.5	(PWRFIT)	0.9977	ρb = 1.127σ 0.0397
4.7	(PWRFIT)	0.99	ρb = 1.216σ 0.0327
8	(LOGFIT)	0.9938	ρb = 1.0416 + 0.071n σ
10.4	(PWRFIT)	0.9828	ρb = 1.3086σ 0.0252
13	(LINFIT)	0.9919	ρb = 1.4728 +0.000213σ

Table 3: Regression coefficients of quadratic models ($y = A + Bx + Cx^2$) describing effect of moisture contents on bulk density of loamy sand soil at different compaction pressures

Pressure (kPa)	Model coefficients A	B	C	R^2
17.5	1.4827	-0.0717	0.00567	0.6312
100	1.499	-0.0415	0.00337	0.6421
175	1.4991	-0.034	0.00291	0.7344
289.5	1.5121	-0.0315	0.00291	0.214
404	1.5377	-0.0296	0.00265	0.6643
511	1.5377	-0.0281	0.00254	0.7516
618	1.5525	-0.0312	0.00281	0.6452

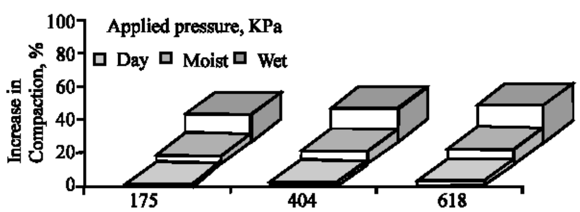

Fig. 1: Effect of applied pressure, moisture content in soil compaction for loamy sand soil (85,03,12)

It was reported (Smith *et al*., 1997) that the values for applied pressure should be regarded in a relative sense it has been noted that the pressure required in a uni-axial tests to produce the same bulk density in the field was considerably higher (O' Ssullivan, 1992).

Effect of moisture content on bulk density: The variation of bulk density with water content at the different levels of applied pressure is governed by a quadratic relationship of the type shown in Eq. 1. It is observed that bulk density decreased with increase in water content at any particular applied pressure, to a minimum density and then increased again. The range of applied pressure considered (17.5 to 618 kPa) covered the range common in agricultural productions. For the purpose of predictions, best models were established to fit the data of bulk density variation with moisture content. By simply eyeballing the data in the scatter diagram, it was apparent that a parabolic (or quadratic model) was the best model. This was confirmed by comparing the coefficients of determination of possible models:

$$y = A + Bx + Cx^2, \quad (1)$$

where

- y = Bulk density (Mg m^{-3})
- x = Moisture content, % (db)
- A,B,C = Regression coefficients
- R^2 = Coefficient of determination

The coefficients of the model are presented in Table 3. The values of the R^2 were high enough to make the models suitable for predictions.

Multiple regression of moisture content and applied pressure on bulk density: Multiple regression analysis was carried out to assess the effects of water content, applied pressure on bulk density. The range of pressure was 17.5 to 511 kPa and 0 to 13 (%db) water content. The multiple regression equation was:

$$y = 1.4359 + 0.00017\,X_1 - 0.0039\,X_2,\ R^2 = 0.6114 \quad (2)$$

were

- y = Bulk density (Mg m^{-3})
- X_1 = Applied pressure (kPa)
- X_2 = Water contents (%) db
- R^2 = Coefficient of determination

The multiple regression analysis Eq. 2 showed that the effect of moisture content was greater than that of applied pressure on the bulk density, judging from the higher coefficient of the independent variable, water content.

CONCLUSION

The behaviour of Igbokoda Loamy sand soil of, southwestern Nigeria has been studied .The soil showed similar behaviors in the dry and near saturation conditions. Bulk density varied from 1.2389 to 1.6393 Mg m^{-3} in the range of applied pressure 0 to 618 kPa. Linear, intrinsically linear and quadratic models can be used to describe the behaviour of the soil for the purpose of predictions. In a multiple regression analysis, it was observed that the principal factor influencing compaction of the loamy sand soil was water content rather than applied pressure at the time of compaction.

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