

ESTIMATION OF PENETRATION RESISTANCE AND HYDRAULIC CONDUCTIVITY OF LOAMY SOILS IN AKURE SOUTHWESTERN NIGERIA FOR SOIL MANAGEMENT PRACTICE

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ABSTRACT

Investigations were conducted to determine some physical, mechanical and hydraulic properties of agricultural soils at the Agricultural Engineering Research and Experimental Farm of the Federal University of Technology, Akure (FUTA). The response variables such as penetration resistance (PR), bulk density (BD), consistency limit (CL) and moisture content (MC) were monitored at ten locations. The PR was measured by Bush recording penetrometer, while hydraulic conductivity was determined by using Decagon mini disk infiltrometer. Soil analysis according to the USDA textural classification showed the texture of the soil was a sandy clay loam in nine out of the ten locations sampled and sandy clay at the remaining location. Results also showed that CI and BD increased with depth but were not significantly correlated. Mean values of PR varied from 1384 to 2248 kPa except at two locations where they were 455 and 753 kPa. Mean bulk density was in the range of 1.36 to 1.71 g/cm³. Similarly, mean hydraulic conductivity values ranged from 1.14 x 10⁻³ to 2.29 x 10⁻³ cm/s. The maximum CI occurred at a moisture content equal to about 33% of the liquid limit. The liquid limit of the soil increased with increase in the amount of (Silt + Clay) content. The moisture content during the study ranged from 5.6 to 23.1 (% db). The observed values would serve as necessary indicators of the soil quality for further research and experimentation.

Keywords: Penetration resistance, bulk density, hydraulic conductivity

1.0 INTRODUCTION

Field soil physical properties are quite variable both in vertical and horizontal directions. Since soil physical properties play a central role in transport and reaction of water, solutes and gases in soils, knowledge of them is very important to understand soil behavior to applied stresses, transport phenomena in soils, hence for soil conservation and planning of appropriate agricultural practices (Wijaya et al., 2004).

Soil factors influencing cone index are matrix potential (or water content), bulk density, soil compressibility or soil strength parameters such as soil structure and others (Bradford, 1986).

Many studies have been conducted to verify the influence of bulk density and water content on penetration resistance (Abedin and Hettiaratchi, 2002; Vanags et al., 2004; Kumar et al., 2006; Simmons and Cassel, 1989; Busscher et al., 1997; Vaz et al., 2001) from which both empirical and theoretical relationships were obtained. From the many different models that have been introduced to test the relationships (polynomial, exponential, power). Busscher et al.(1997) suggested that either the power or exponential equations are the most adequate.

1.1 Bulk Density and Soil Moisture Content

Bulk density is a measure of the weight of the soil per unit volume (g/cm^3) usually given on an oven dry (110°C) basis. Variation in bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil (Birkeland, 1984).

The specific objective of this study was to determine the penetration resistance (Cone Index), bulk density and hydraulic conductivity (and the correlations between them) of the experimental field with a view to using them for future soil management practices.

2.0 MATERIALS AND METHODS

2.1 Experiment Site

The site was the research farm of Agricultural Engineering Department, Federal University of Technology, Akure, Nigeria ($7^\circ 5' \text{N } 50^\circ 15' \text{E}$) and elevation 210m. Five locations were chosen and two points, 3m apart at each location were randomly sampled for the experimental collection of soil samples and field measurement of cone index and soil hydraulic conductivity.

2.2 Bulk Density

Soil samples were collected from the depth of 0-6, 6-12, 12-18, 18-24 and 24-30cm by the use of core samplers of 5.8 cm diameter and 6 cm height. The core sampler was driven into each depth of the soil and the collected soil was kept in an air tight polythene bag to avoid moisture loss. The sample was weighed and oven dried in the laboratory of 105°C for 24 hours. The oven dried soil sample was reweighed after it must have been allowed to cool for one hour. The bulk density was determined from observed data.

2.3 Soil Penetration Resistance (or cone index)

Soil penetration resistance PR, or cone index CI was determined using a Rimick CP20 recording penetrometer (model CP 20 ultrasonic, Agridry Rimik Pty Ltd, Toowoomba), with a standard 30° cone of 322-mm^2 base area. The penetration rate was less than 10 mm/s. Data were recorded at depth increments of 50 mm. Cone index was the average of 15 measurements for each experimental point. Penetration was carried to depth of 30 cm.

2.4 Soil Hydraulic Conductivity Using Hand Held Mini Disk Infiltrometer

The top and bottom chambers were both filled with water. The top chamber controlled the infiltrometer's suction. The lower chamber contained the water that will infiltrate into the soil. The full infiltrometer was placed on the soil and water level was recorded every 30 seconds. This was repeated for all the selected locations.

2.5 Theory

A number of methods are available for calculating soil hydraulic conductivity from these data. The method proposed by Zhang (1997) is quite simple and works well for measurements of infiltration into dry soil. The method requires measuring cumulative infiltration versus time and fitting the results with the function:

$I = C_1 t + C_2 \sqrt{t}$ (1)
 The hydraulic conductivity was then calculated from the equation 1 (Decagon, 2008).

$$K = \frac{C_1}{A} \quad (2)$$

Where C_1 is the slope of the curve of the cumulative infiltration versus the square root of the time and A is a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk. A is computed from:

$$A = \frac{11.65(n^{0.1} - 1) \exp[2.92(n - 1.9)\alpha h_0]}{(\alpha r_0)^{0.91}} \quad n < 1.9 \quad (3a)$$

$$A = \frac{11.65(n^{0.1} - 1) \exp[2.92(n - 1.9)\alpha h_0]}{(\alpha r_0)^{0.91}} \quad n \geq 1.9 \quad (3b)$$

where N and α are the Van Genuchten parameters for the soil, r_0 is the disk radius and h_0 is the suction at the disk surface. The van Genuchten parameters for the 12 texture classes of soil were obtained from Carsel and Parrish (1998) as quoted by Decagon(1998). The mini disk has a radius of 1.25cm and a suction 2.0. Values of A computed for mini disk are obtained from table (Decagon, 2008). The volume is converted to depth of water infiltrated by subtracting the starting volume reading and dividing by the area of the disk on the infiltrometer, 4.91 cm². C_1 is determined by using Excel spread sheet to form a quadratic equation and taking the gradient as C_1 (Decagon, 1998).

3 RESULTS AND DISCUSSION

3.1 Physical and chemical properties of experimental soils

The properties of the experimental soils are shown: consistency limits (Table 1); chemical properties (Table 2); cone index, bulk density and hydraulic conductivity of the soils (Table 3). Soil textural classification shows that all the experimental soils except C1 (sandy clay) were sandy clay loam. They did not have high clay content which certainly affected their behavior.

Table 1: Material Moisture contents, consistency limits and particle size distribution of the experimental soil

Soil samples	Moisture content	Liquid Limit %	Plastic Limit	Shrinkage Limit	Particle Size %			Textural class
					Sand	Silt	Clay	
A ₁	15.4	29.1	-	2.1	54.8	20.0	25.20	Sandy clay loam
A ₂	15.3	29.1	-	2.1	52.8	24.0	23.2	Sandy clay loam
B ₁	13.6	27.3	22.3	4.3	60.8	16.0	23.2	Sandy clay loam
B ₂	14.7	22.8	-	3.6	58.8	14.0	27.2	Sandy clay loam
C ₁	13.3	25.6	19.2	5.0	52.8	8.0	39.2	Sandy clay
C ₂	13.7	26.8	19.2	6.4	56.8	12.0	31.2	Sandy clay loam
D ₁	14.9	34.4	21.3	9.3	46.8	17.2	36.0	Sandy clay loam
D ₂	12.9	34.2	18.3	8.6	54.8	17.2	28.0	Sandy clay loam
E ₁	12.6	24.6	-	2.9	52.8	24.0	23.2	Sandy clay loam
E ₂	10.9	22.4	-	3.6	64.8	10	25.2	Sandy clay loam

Table 2: Chemical properties of the experimental soils

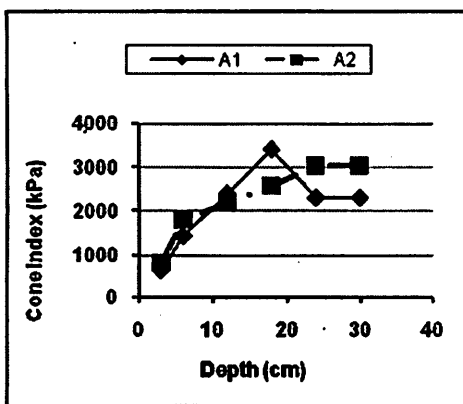
Soil samples	pH	Chemical composition				o/c %	O/M %	N	P
		Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺				
A ₁	5.65	3.10	2.00	0.38	0.19	2.16	3.73	0.18	2.44
A ₂	5.72	2.60	1.00	0.17	0.13	1.80	3.10	0.16	2.21
B ₁	5.51	2.80	1.40	0.29	0.15	1.44	2.48	0.13	2.87
B ₂	5.75	1.10	0.50	0.18	0.15	1.11	1.92	0.10	1.96
C ₁	5.45	1.10	0.60	0.17	0.12	0.94	1.62	0.09	2.69
C ₂	5.29	2.50	1.10	0.21	0.13	0.79	1.35	0.07	2.86
D ₁	5.08	2.60	1.00	0.23	0.13	1.17	2.01	0.12	2.58
D ₂	5.60	1.20	0.60	0.30	0.15	1.07	1.85	0.10	2.72
E ₁	6.24	1.60	0.60	0.24	0.14	1.23	2.11	0.11	2.93
E ₂	6.24	1.60	0.70	0.23	0.15	1.24	2.15	0.11	2.44

Table 3: Mean Values of Cone Index, Bulk Density and Hydraulic Conductivity of Experimental soils

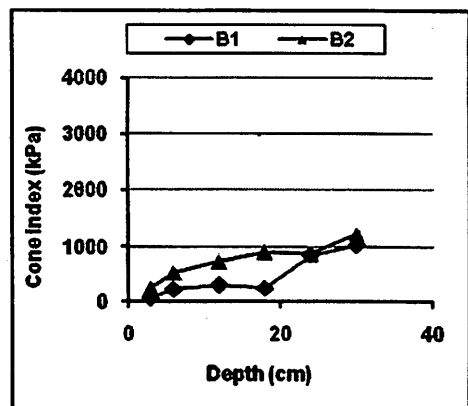
Location	Mean Cone Index (KPa)	Bulk Density (g/cm ³)	Non-Saturated Hydraulic Conductivity (10 ⁻³ cm/s)
A ₁	2079	1.41	2.29
A ₂	2248	1.39	2.29
B ₁	455	1.36	1.14
B ₂	753	1.40	1.14
C ₁	1384	1.56	1.94
C ₂	1531	1.71	2.29
D ₁	1682	1.42	1.14
D ₂	1897	1.52	1.14
E ₁	1663	1.59	1.14
E ₂	1887	1.63	1.14

3.2 Penetration Resistance (Cone Index) and Bulk Density

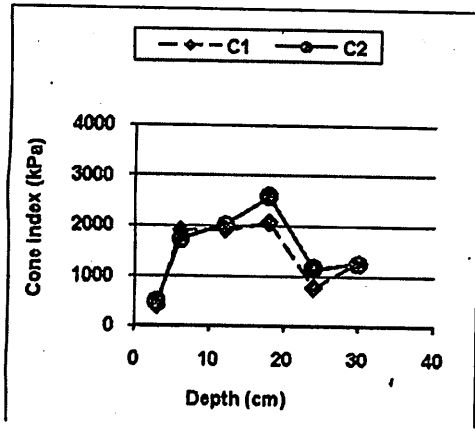
The variation of cone index with depth is presented in Fig. 1. Cone index increased with depth to a point and later decreased, however the increase was non-linear. The maximum mean cone index was 2248 kPa. At points B1 and B2, the values of mean cone indices were 455 and 753 kPa, respectively. These values were significantly different from the other points on the field. The relationships between cone index and bulk density is as shown in Fig. 2. In this study, cone index had no linear correlation with bulk density, in other places; there were no correlation at all. This was similar to the findings reported by Fulton, et al. (1996). However, it was established that, cone indexbulk density relationships can be described by polynomial and power functions (Fig. 2). Observation at point D, showed that linear, exponential, power, logarithmic and polynomial models fit cone index-bulk density relationships with coefficient of determination ranging from 0.674 to 0.801. This agreed well with findings of other researchers.



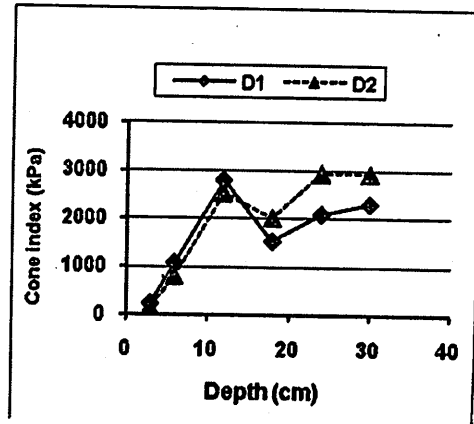
(a)



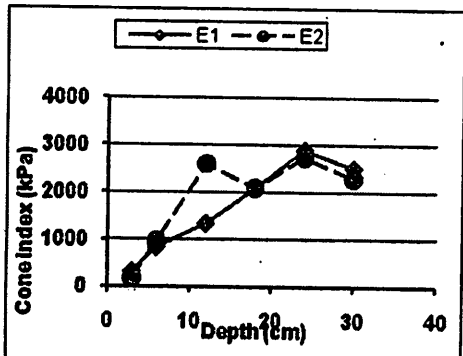
(b)



(c)



(d)



(e)

Figure 1 Variation of cone index with depth (a) sandy clay loams (b) sandy clay loams (c) sandy clay (C₁), sandy clay loam (C₂) (d) sandy clay loams (e) sandy clay loams

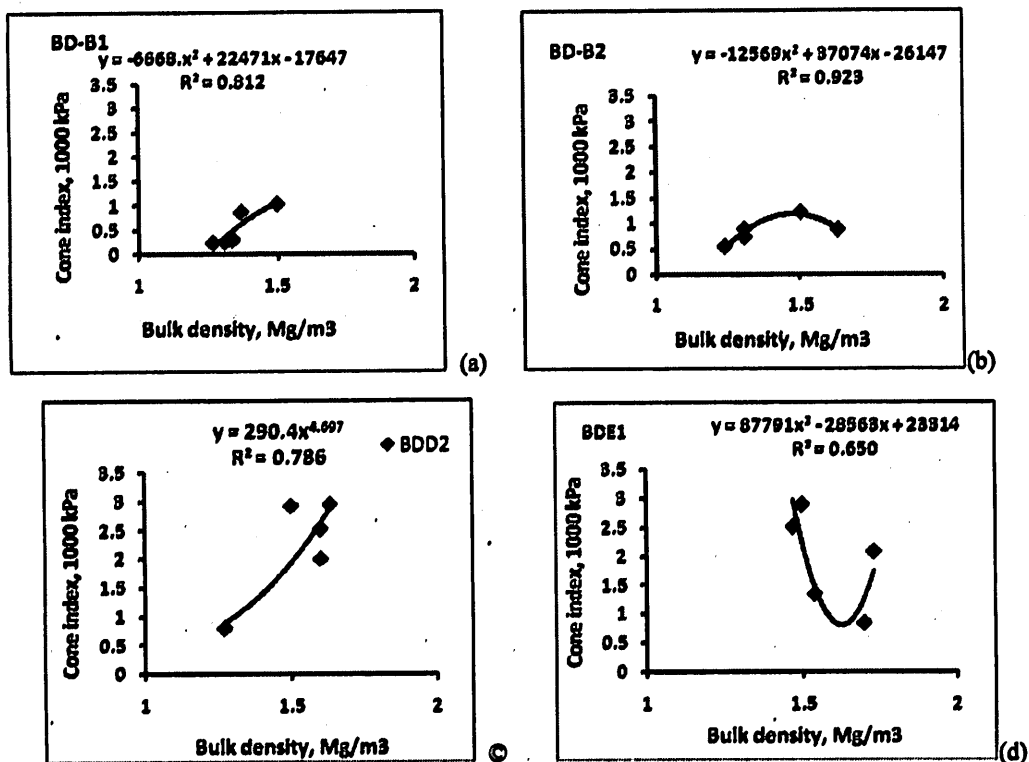
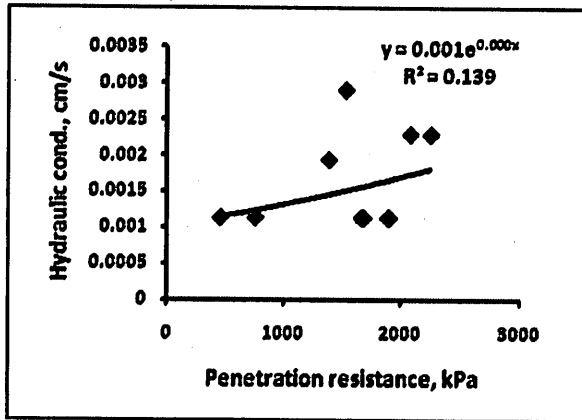


Figure 2 Model relationships between cone index and bulk density of experimental sandy clay Loam soils

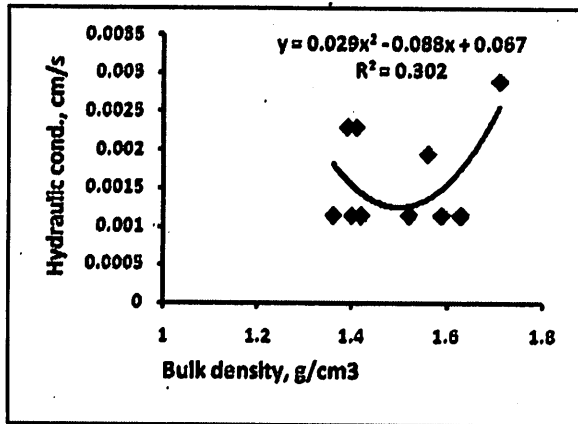
3.3 Penetration Resistance and Hydraulic Conductivity of the Soil

The hydraulic conductivity of the experimental soil is presented in Table 3. There appeared to be very little correlation between hydraulic conductivity and cone index. The value of the hydraulic conductivity varied from 1.14×10^{-3} to 2.29×10^{-3} cm/s in sandy-clay-loamy while that of the sandy clay is 2.94×10^{-3} cm/s. However, Azooz and Aschad (1996) reported 1×10^{-3} to 1.2×10^{-3} cm/s for sandy loam. These values also fall within the values reported by various scholars for sandy loam and silt loam as quoted by Ward and Trimble (2004). This constant variation may be due to individual sand, silt and clay contents of the soil:

Model relationships were established between hydraulic conductivity and penetration resistance (Fig. 3 a) and with bulk density (Fig 3 b). The relationships were non- linear and probably may not be suitable for predictive purposes. Model relationships of hydraulic conductivity were also established with liquid limit (Fig.4 a), clay content (Fig.4b), and clay plus silt (Fig. 4c). There was a form of relationship but they were not strong for the purpose of prediction as shown in the figures by their coefficient of determination which was very low. This result agreed with that reported by Benson and Trast (1995). Benson and Trast (1995) reported that lower hydraulic conductivities were obtained for soils having a larger percentage of fines, higher liquid limit, and higher plasticity index. Also, hydraulic conductivity was not uniquely related to any of the compositional variables, suggesting that a single index property was not sufficient to estimate hydraulic conductivity.

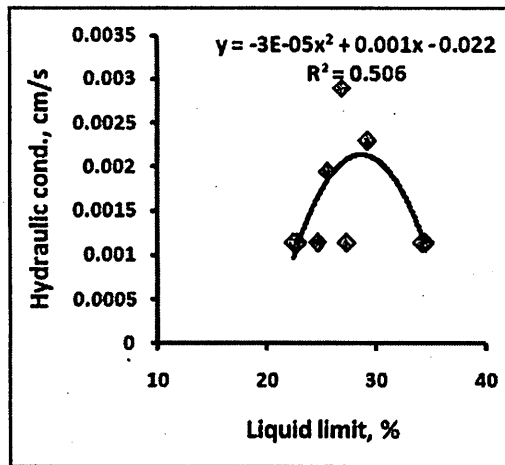


(a)

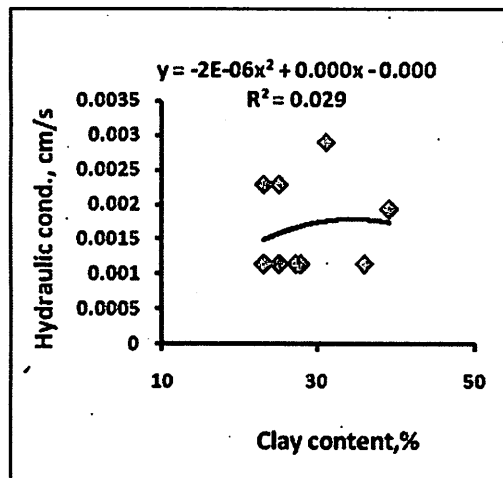


(b)

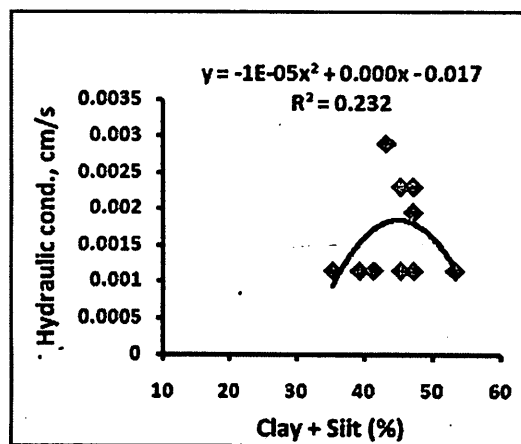
Figure 3 Model relationships between hydraulic conductivity and penetration resistance (a) hydraulic conductivity vs bulk density (b) for the experimental soils.



(a)



(b)



(c)

Figure 4 Model relationships between hydraulic conductivity and liquid limit (a) hydraulic conductivity vs clay content (b) hydraulic conductivity vs clay + silt content (c)

4.0 CONCLUSIONS

The following conclusions can be drawn from this study:

- (i) The relationship between cone index and bulk density can be modeled after polynomial, power, exponential, logarithmic and linear functions although the relationships were not very strong in some cases.
- (ii) Cone index increased with increase in depth to certain depth, thereafter, it decreased for all the sampled locations
- (iii) No correlation was found between soil hydraulic conductivity and penetration resistance. The low clay content was probably responsible for the poor correlation of penetration resistance and other soil properties.

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