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Some Physical and Dynamic Properties of Akure Clayloam Soils in Southwestern Nigeria

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Abstract: Experimental investigations were carried out in the laboratory and in the field to determine and evaluate some physical and dynamic properties of clay loam soil in Akure, southwestern Nigeria. The properties include cohesion and cone index. The soil studied has sand, silt and clay fractions of 40, 23 and 37% respectively. Bulk density ranged from 1360 mg m^{-3} to 1529 Mg m^{-3} in the field within the range of 9.9 to 30.6% moisture content (db) and down to depth of 300 mm. The cone index of the soil ranged from 475 kPa to 2626 kPa within the same moisture range. The cohesion of the soil ranged from 20.2 kPa to 114 kPa.There was good positive correlation between the cone index cohesion relationship within the range of moisture content studied. Linear regression models were used to fit the data points and to predict.

Key words: Soil, properties, cohesion, cone index, regression models, akure, Nigeria

INTRODUCTION

Soil tillage has been conducted for many thousands of years and over the years many advances have been made to quantify soil condition. The purpose of tillage operations has been to manipulate the soil so that a suitable soil condition (good tilth) can be provided for the germination of the seed and development of the root system. The physical, mechanical properties of soil include texture, soil structure, particle density, bulk density, porosity and permeability, soil consistency, soil colour, cohesion, adhesion, friction and cone index.

If these properties are well studied then the soil condition required for a particular seed or plant environment can be predetermined and achieved with appropriate tillage implements.

Availability of data relating to properties of agricultural soils is an important factor in selecting tillage requirement for a particular farm situation. Soil mechanical strength is an important soil parameter that affects root growth and water movement and controls nutrient and contaminant transport below the rooting zone. The most common way to assess soil strength is by using a soil penetrometer, which characterizes the force needed to drive a cone of specific size into the soil (Bradford, 1986). The measured penetration resistance or Cone Index (CI) depends on soil such properties as bulk density, water content and potential, texture, aggregation, cementation and mineralogy.

A lot of research has been done to study the physical and mechanical properties of agricultural soils of countries of Europe, United States of America, Asia and Latin America but not much has been done for agricultural soils of Africa and Nigeria in particular (Chessness *et al.*, 1972; Wells and Teesawen, 1977; Tollner and Verma, 1984; Perumpral, 1987; Ayers and Bowen, 1987; Ohu and Folorunoso, 1989; Ohu *et al.*, 1991; Ayers and Perumpral, 1992; Guruswamy and Verma, 1995; Fielke, 1996). The large population of Nigeria requires that tillage operations be mechanized and optimized to be able to feed the teeming population adequately. To be able to achieve this, dynamic properties of agricultural soils need to be studied.

Clay loam soil is one of the textural classes of agricultural soils that is found in many farmlands across Ondo State especially in Akure South Local Government Area. The soil is good for agricultural production and also exist, in many other parts of Nigeria.

The objectives of this study were:

- To study dynamic properties (cone index, cohesion) of clay loam soil both in the laboratory and in the field.
- To determine the relationship between these dynamic properties and with other physical properties of the soil.
- To develop models that can be used for prediction of these properties and test the adequacy of the models.

MATERIALS AND METHODS

Laboratory experiment: Soil texture from a farmland in Akure was collected for this laboratory experiment. The soil represents one of the textural classes commonly found in agricultural land in Ondo State. It was collected from the top 0 to 30 cm depth of the soil profile. For the mechanical analysis of the soil, about 2.0 kg were air-dried and passed through the 2.0 mm sieve for the analysis. Particle size analysis of the soil was performed using the hydrometer method (Lambe, 1951). The organic matter content of the soil was also determined using the method (Walkley and Black, 1934).

For further laboratory studies more air-dried soil was passed through a 4.75 mm sieve and the moisture content of the air-dried soil determined as the starting point moisture content for property studies.

The dynamic properties that were the main focus for this study are cohesion and cone index or penetration resistance as they vary with moisture content and density. Since moisture content has great influence on those properties, the samples were studied at six moisture levels from 5 to 30% (dry basis). At each moisture level, the samples were subjected to 5, 10, 15, 20 and 25 blows of standard proctor compaction hammer in cylindrical mould of 150 mm diameter and 200 mm height similar to the proctor compaction procedure (Lambe, 1951).

Cone index and cohesion: Cone index of experiment soil was determined using a 30 degrees cone tip penetrometer with a base area of 1.3 cm^2 following the fabrication, description and method reported (Manuwa, 1998). Cohesion of the soil was determined using a hand-held shear vane tester complete with 19mm vane range 0 to 120 kPa and 33 mm vane range 0 to 28 kPa. Measurements of those properties in the laboratory were taken at depths of 50, 100 and 150 mm and were replicated at least three times, before the average was taken.

Field measurement: The field experiment covers an area of three plots referred to here as sites each of size 30 m x 20 m. The last time the sites were cultivated was in April 1997 when they were hand-hoed, ridged and vegetable planted. They were left fallow after harvest that year until July 1998, when the penetration resistance of the soil at site 1 was determined and other properties at that site. At site 1 the cohesion of the soil was also determined. Site 2 therefore was a plot that had lain fallow for two years before measurements of its properties were taken in August 1999 after the initial hand hoeing and ridging in 1997. Site 3 was a plot that was hand-hoed and ridged after it lay fallow for two years. Measurements of its prosperities were taken three months after the last tillage operations. On the ridges of site 3 were grown vegetables, namely tomatoes and pepper.

Data analysis: Statistical evaluation methods were used to test the models that fitted the data points. The methods include: coefficient of correlation (r), which gives the degree of association, coefficient of determination (r^2);which evaluates the degree of association between data points and predicted values and Absolute Mean Difference (AMD) between measured and predicted values which evaluates the degree of coincidence, and Relative Error (RE) between the measured and the predicted values:

$$AMD = \frac{1}{N}\sum_{i=1}^{N}|Mi - Pi|$$

$$RE = \frac{100}{N}\sum_{i=1}^{N}\frac{|Mi - Pi|}{Mi}1$$

Where, N = number of data points
Mi = ith measurement
Pi = ith prediction

RESULTS AND DISCUSSION

Mechanical analysis of soil: The result of the mechanical analysis of the clay loam soil under study is presented in Table 1. The Clay Ratio of this soil would be 66.6% according to the formula presented (Elbanna and Whitney, 1986) for calculating clay ratio. This high ratio is an indication of high strength for the soil (Guruswamy and Verma, 1995).

Cone index: For the experiments on the field, the variation of penetration resistance with depth at the sites are presented in Table 2. These values were determined in the soil moisture content range of 9.0% to 31.0% (dry basis). It is seen that cone index increases with depth from the surface till 300 mm depth. The result or trend was similar in all the sties except that the magnitude was higher at site 2 which had prolonged time of fallow.

Cohesion: The cohesion of the soil at the sites and their variation with depth are presented in Table 3. It is

Table 1: Soil mechanical analysis

Soil type		Particle size(μm)	Clay loam(%)
Soil particles	Sand	20-2000	40
	Silt	2-20	33
	Clay	<2.0	37
Organic matter			2.3

Table 2: Variation of cone index with depth at experimental sites

	Cone index (kPa)		
Depth(mm)	Site 1 (kPa)	Site 2(kPa)	Set 3(kPa)
50	325	777	475
100	702	1041	777
150	853	1380	1192
200	928	1985	1456
250	1680	2664	1946
300	2437	2966	2626
Range	290-2511	621-3145	403-2866
Mean	686	1802	1412
ρ(Mg m^{-3})	1430	1511	1380
MC(%db)	20.0	30.0	11.5
Date	23/7/98	10/8/99	12/8/99

observed that cohesion increased with depth from the surface to a depth of about 100mm when it assumed maximum value and thereafter, cohesion decreased with depth. This result also shows that cohesion is dependent on moisture content of the soil. Average cohesion was highest at the moisture content of 11.5% and least at the moisture content of 30%.

Laboratory experiment

Cone index-cohesion relationship: The relationship between penetration resistance and cohesion and how they are affected by moisture and density were studied in the laboratory. The results are presented in Table 4. The figure in parenthesis is the cone index corresponding to the cohesion beside if for the same soil treatment. The density of the soil was varied by the proctor compaction blows imposed upon it. In the relationship, the cone index was made the dependent variable (ordinate) while cohesion was made the independent variable (abscisa). Linear regression models were made to fit the data after the expression:

$$CI = a + b\tau \quad (1)$$

where,

CI = cone index, kPa

τ = cohesion, kPa a, b are regression constants. Regression analysis was carried out for each moisture content level as the density of the soil in the mould increases with the number of blows impinged on it. Thus six regression models were developed, the parameters of which are presented also in Table 4. These models are good for prediction of these dynamic properties in the laboratory and on the field since r > 0.5 as reported (Liu, *et al*., 1997).

Cone index-moisture content relationship: Cone index was regressed on moisture content. The regression was after the linear fit expressed in the form:

$$CI = a + bMC \quad (2)$$

Where a, b are regression constants. The regression analysis were carried out in two phases: the lower range of moisture phase (5 to 15%) and the upper range of moisture phase (20 to 30%) moisture content. It was observed that between these phases of moisture range, the soil changes from friable consistency to plastic consistency. The parameters of the regression models are presented in Table 5. At the lower moisture range the relationship is a good and positive one typical of high coefficient of correlation. At the higher moisture content range, the relationship is still a good one but negative in nature. This means that at higher moisture content of about 20%, cone index decreases as moisture content increases. The models were made at constant soil bulk density corresponding to the number of proctor's compaction blows. In the lower range of moisture content the correlation increases as the density decreases while in the higher moisture content range, the correlation coefficient increases as the density increases.

Cone index-density relationship: The laboratory experiment also shows that there is good correlation between cone index and dry bulk density. A linear model fits the relationship after the expression:

$$CI = j + kDD \quad (3)$$

Table 3: Variation of cohesion with depth at experimental sites

	Cohesion (kPa)		
Depth (mm)	Site 1	Site 2	Site 3
30	35.2(0.92)	20.2(1.02)	57.4(0.96)
60	46.1(0.82)	31.8(0.93)	83.6(0.89)
90	60.5(0.65)	31.0(1.10)	96.1(1.01)
120	50.6(0.91)	30.1(0.99)	95.2(0.95)
150	38.8(0.79)	29.3(0.82)	93.0(1.02)
180	37.2(1.01)	25.2(1.12)	92.6(1.10)
210	29.4(0.82)	22.3(1.01)	91.3(0.80)
Range	20.3-62.4	16.2-35.4	45.3-102.2
Mean	42.54	27.13	87.0
ρ(Mg m^{-3})	1430	1511	1380
MC(%db)	20.0	30.0	11.5
Date	23/7/98	10/8/99	11/8/99

Standard deviation are shown in parenthesis ( )

Table 4: Effect of moisture content, density on cone index-cohesion relationship

	Moisture content					
	5%	10.0%	15.0%	20.0%	25.0%	30.0%
No of blows	Cohesion (Cone index), kPa					
5	10(272)	11.7(2888)	13.7(266)	11.3(230)	6.7(200)	9.7(180)
10	15.3(388)	19(510)	22(596)	20(512)	18(480)	15(380)
15	25(591)	26(678)	28(936)	29(691)	26.7(545)	21.3(468)
20	26.7(742)	28(789)	30.3(1003)	37.7(800)	31(600)	25.0(501)
25	30.7(909)	34(940)	37(1048)	43.7(982)	42.8(645)	29.3(523)
Regression coefficients						
r	0.9753	0.9971	0.9607	0.9883	0.9309	0.9380
a-	51.29	-53.09	-197.34	28.11	193.06	73.65
b	29.3	29.23	36.70	21.69	12.01	16.78

Table 5: Coefficients of regression models of cone index-moisture content relationship

	Moisture content (% db)					
	Lower moisture range (5-15%)			Higher moisture range (20-30%)		
No of Blows	r	a	b	r	a	b
5	0.9966	258.6	2.8	-0.9386	310.8	-1.1
10	0.9803	308.0	18.1	-0.9851	931.1	21.5
15	0.9614	390.0	34.5	-0.9817	1416.1	-37.3
20	0.9380	583.6	26.1	-0.9956	1752.6	-63.7
25	0.9524	826.6	13.9	9-0.9994	2249.8	-63.7

Table 6: Coefficients of regression models of cone index-dry density relationship

Moisture content (% db)	Correlation coeff. (r)	Intercept (j)	Slope (k)
5.0	0.9131	-4648.1	4.66
10.0	0.9703	-12489.0	10.89
15.0	0.9678	-11016.6	10.10
20.0	0.9802	-2917.7	3.11
25.0	0.9393	-1224.9	1.40
30.0	0.9959	-19.94	0.26

Table 7: Evaluation of predictive, model for cone index-cohesion relationship at 15% moisture content

	Cone index		Residual	
Cohesion measured (kPa)	Measured (kPa)	Predicted (kPa)	(kPa)	%
13.7	266	284	-18	6.7
16.0	364	363	1	0.2
19.0	467	467	0	0
22.0	569	571	-2	0.3
25.0	675	674	1	0.1
28.0	800	778	22	2.7
30.3	900	858	42	4.6
33.0	951	951	0	0
35.0	1020	1020	0	0
37.0	1048	1089	-41	3.9

Correlation Coeff (r)= 0.9969, Model:CI= 188.9 + 34.55τ, AMD= 12.7kPa, RE= 1.85%

Where, DD is dry bulk density, kg m^{-3}, j and k are model constants. The coefficients of the models are presented in Table 6. There is good relationship between these two variables as indicated by very high correlation coefficients.

Model evaluation: A linear model was developed to fit the relationship between cone index and cohesion at 15% (db) moisture content. The model is given by:

$$CI = -188.9 + 34.55\tau \quad (4)$$

The 15% moisture content was selected because it is in the range of friable consistency for this soil (clay loam). The measured and predicted values and the residuals are presented in Table 7. The high (nearly 1.0) correlation coefficient of 0.9969 and the small relative error (1.85%) of prediction show that the model is very adequate, for prediction. The absolute mean difference which is the degree of coincidence of the measured and the predicted values of cone index is 12.7 kPa.

CONCLUSION

From this study, the following conclusions are made:

- Some dynamic properties of clay loam soil have been studied both in the laboratory and in the field.
- There is good relationship between these properties viz cone index and cohesion and some other physical properties like bulk density and moisture content.
- The relationships between there properties are linear and the models thereof are very good for prediction purposes.
- There is close range between the properties determined in the laboratory and those determined in the field. The difference may be due to the heterogeneity of the soil the field.

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