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# Physical Shrinkage Relationship in Soils of Dissimilar Lithologies in Central Southeastern Nigeria

[1]E.U. Onweremadu, [2]F.O.R. Akamigbo and [2]C.A. Igwe
[1]Department of Soil Science and Technology,
Federal University of Technology, P.M.B. 1526, Owerri, Nigeria
[2]Department of Soil Science, University of Nigeria, Nsukka, Nigeria

**Abstract:** This study investigated the relationship between volume shrinkage properties of soils derived from different parent materials in Central Southeastern Nigeria as they related to selected soil physical properties. Using a free survey technique and guided by a geological map of the area, field sampling was conducted in the early months of 2005. Routine analyses were done using collected soil samples. Results showed significant ($p<0.05$) variation in sand, clay, waterholding capacity, Atterberg limits and Co-efficient of Linear Extensibility (COLE) among the 6 studied soil groups. Volume shrinkage results indicated severe shrinkage (20-30%) rating for soils derived from Shale, moderate shrinkage (10-20%) for soils formed over Lower Coal Measures and Falsebedded Sandstones and slight shrinkage (0-10%) ratings for the rest. The COLE, used as an index of VS correlated significantly ($p<0.05$; $n = 150$) with waterholding capacity (WHC), Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI) and clay content. A model was generated which expressed good predictive relationship between COLE and selected physical properties ($R = 0.87$; $R^2 = 0.75$; $1\text{-}R^2 = 0.25$, RMSE = 0.01 and Bias = +0.00001), indicating high accuracy and little over-estimation by the model. More soil and soil related variables may further improve generated model (s), thus should be included in future studies.

**Key words:** Atterberg limits, changes, texture, water, parent materials, tropical soils

## INTRODUCTION

Clay content and clay type influence many physico-chemical cum biological properties of soils. Among these properties is soil volume shrinkage which is widely used for characterizing soil structure. Measurement and modelling of volume shrinkage is of growing interest in the development of new pore-space approaches to soil structure studies (Tuller and Or, 2003). The shrinking and swelling of a soil matrix accompanied by vertical movements and cracking, essentially influences soil structure, hydraulic properties and water flow and their evolution with time (Chertkov *et al*., 2004).

Volume change is related to soil water content (Hillel, 1998) and this has been widely recognized as a determinant of soil compressibility (Soane, 1990; McNabb and Boersma, 1996; Sanchez-Giron *et al*., 1998). Adequate estimation of average water content of soils is important in the evaluation and management of drip irrigation systems (Souza *et al*., 2004), which can be done by deployment of a dense bank of sensors to monitor spatial distribution of soil water content (Coelho and Or, 1997).

Properties which influence volume change in soil include organic matter content (McBride and Watson, 1990; Soane, 1990), bulk density (Hakansson and Voorhees, 1998; Imhoff *et al*., 2004) soil mineralogy (Smith *et al*., 1997) and soil texture (Boivin *et al*., 2004). In all these, soil texture is considered one of the most relevant intrinsic soil attributes related to volume change (Horn, 1998; McBride, 1989), with coarse texture being less susceptible to volume change when compared with fine textured soils (Horn and Lebert, 1994; McBride and Joose, 1996).

Parent, materials influence soil properties (Brady and Weil, 1999; Akamigbo, 2001; Esu, 2005) and such characteristics among others include clay content. Knowledge of soil texture is important in geotechnical engineering (Atkinson, 1993) as this helps in the analysis and design of foundations and agriculture since Esu (1999) related it to ease of tillage, fertility, plasticity, permeability and water holding capacity.

In Southeastern Nigeria, land use is not according to suitability but availability. With heightened demographic pressure, the soil resource is subjected to conflictive uses without consideration of its load bearing capacity and response to moisture content changes. All these are happening amidst scanty scientific studies (Igwe, 2003; Akamigbo, 2005; Onweremadu, 2006). Consequently, soil degradation and collapse of engineering structures in

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**Corresponding Author:** Dr. E.U. Onweremadu, Department of Soil Science and Technology, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria

agriculture and non-agricultural enterprises tend to be on the increase in the region whose soils are derived from different lithological materials. This study aimed to investigate the relationship between clay content and volume shrinkage of soil groups prevalent in the area. We hypothesized that these soils vary in clay content hence the shrinkage characteristics.

## MATERIALS AND METHODS

**Study area:** Central Southeastern Nigeria lies between latitudes 4°40$^1$ and 7° 00$^1$ N and longitudes 6° 40$^1$ and 8° 15$^1$E (Onweremadu, 2006). Six major geological materials from which soils are derived in the area include Alluvium, Coastal Plain Sands, Shale, Lower Coal Measures, Upper Coal Measures and Falsebedded Sandstones. Rainfall is bimodal and ranges from 1800 to 2500 mm in a year. Temperatures are high and uniform throughout the year with slight variation. Rainforest vegetation dominates the area although it has been drastically altered due to demographic pressure on the resource. Major socioeconomic activities include agriculture, smallscale Industries, mining, hunting, gathering and deforestation for fuelwood.

**Field work:** Field surveys were conducted prior to a reconnaissance visit of the site in 2005. Guided by the geological map of the area, a free survey was used in locating soil profile pits. Five profiles pits were dug and described according to the procedure of FAO (1998) on 6 identified soil groups, namely soils formed on Alluvium, Coastal Plain Sands, Shale, Lower Coal Measures, Upper Coal Measures and Falsebedded Sandstones. Towns underlain by Alluvium are Amuzu Mbaise, Owerrinta, Akwette, Oguta and Egbema while the rest include Oforola Owerri, Umuahia, Okeikpe, Umuneise and Owerri-Aba (Coastal Plain Sands), Bende, Ibeku, Nkporo, Itumbuzu and Arondizuogu (Shale), Arochukwu, Ogafia, Uturu, Ututu and Abam (Lower Coal Measures), Lekwesi, Abiriba, Isuochi, Item and Nneato (Upper Coal Measures) and Ihube, Okigwe, Ezere, Ovim and Umulolo (False-bedded Sandstones). A total of 30 profiles pits from which 150 soil samples were collected formed the basis of this study. Soil samples were air-dried, crushed and sieved with 2 mm sieve preparatory to laboratory analyses. Three core samples were collected from each pedogenic horizon for the determination of bulk density.

**Laboratory analyses:** Particle size distribution was obtained by the hydrometer method (Gee and Or, 2002). Bulk density was measured by the core method of Grossman and Reinsch (2002). Soil water holding capacity was determined on undisturbed samples as the difference of water contents at -0.03 MPa, determined by pressure plate and at -1.5 MPa, determined by pressure membrane (Dane and Hopmans, 2002). Coefficient of linear extensibility was obtained using the procedure of Schafer and Singer (1976). Mathematically, it was obtained as follows:

$$COLE = (Lm - Ld/Ld) \qquad (1)$$

Where:
COLE = Coefficient of linear extensibility
Lm = Length of moist soil paste
Ld = Length of dry soil paste

Thereafter, shrink-swell hazard rating was estimated using volume shrinkage thus:

$$VS = (COLE + I)^3 - I\ 100 \qquad (2)$$

Atterberg limits were determined by Cassagrande method while Plasticity Index (P1) was computed as the difference between Liquid Limit (LL) and Plastic Limit (PL) (Grieve, 1980).

**Statistical analysis:** Soil data were subjected to analysis of variance (ANOVA) statistic using the PROC Mix-MODEL of SAS (Little *et al*., 1996). Means were separated using Standard Error of the Difference (SED) at 5% level of probability.

Multiple regression was used to calculate the variance associated with the best fitting linear combination of the variables according to the model below.

$$Y = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + \ldots + b_n x_n \qquad (3)$$

Where:
Y = Predicted Y (COLE)
A = Intercept
bs = Slopes corresponding to the Xs
$X_s$ = Independent soil variables
n = No. of variables used in the model.

In order to evaluate average prediction uncertainty of the model, Root Mean Square Error (RMSE) was used and calculated as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{1=1}^{n} di^2} \quad \text{(Moldrup } et\ al.\text{, 2004)} \qquad (4)$$

Where:

RMSE = Root mean square error
di = Difference between the predicted and measured value at a given level
n = Number in the data set

Furthermore, the bias of the model was computed to evaluate overestimation or underestimation. It was calculated thus:

$$\text{Bias} = \frac{1}{n}\sum_{1=1}^{n} \text{di}^2 \tag{5}$$

Components are defined in Eq. 4

## RESULTS AND DISCUSSION

**Particle size and bulk density distributions:** Table 1 show that clay and sand-sized fractions varied significantly ($p<0.0001$) while silt particles did not vary much in consonance with the findings of Akamigbo (2001). Although, soils of the area are generally sandy, shale-derived soils are least sandy and most clayey due to the nature of parent material. Shale consists of fine to coarse sandstones with intercalations of thin shelly limestone materials. Highest sand content on soils derived from Alluvium is attributed to old deltaic, lacustrine and fluvial deposits. Generally, climate and land use history may be contributing to slight textural differences in the area (Akamigbo, 1999). Bulk density was not statistically different among parent materials but was numerically highest in soils derived from Upper Coal Measures and least in soils formed over Coastal Plain Sands. Although variability in bulk density values could be attributed to engineering-related anthropogenic activities, organic matter distribution in the epipedal horizons may have contributed greatly to the differences. In this study, the relationship between bulk density and organic matter was not investigated. However, differences in bulk density are possibly due to variations in depth, moisture content and particle size distribution. This is consistent with the findings of Heuseher *et al.* (2005) that soil texture, moisture content and depth correlate significantly with bulk density ($p<0.0001$).

Table 1: Particle size and bulk density distributions in the study site

| | Sand | Silt | Clay | Bulk density |
|---|---|---|---|---|
| Parent material | ----------------- | (g kg$^{-1}$) | ----------------- | (mg m$^{-3}$) |
| Alluvium | 719±33.6 | 42.0±11.2 | 149.6±15.0 | 1.45±0.01 |
| Coastal plain **Sands** | 708±305 | 73.2±21.3 | 233.6±161.1 | 1.41±0.02 |
| Falsebedded **Sandstone** | 638±349 | 72.8±153 | 183.2±32.4 | 1.46±0.00 |
| Lower coal Measures | 165±36.1 | 201.6±32.1 | 312.8±42.4 | 1.42±0.00 |
| Shale | 376±29.1 | 131.2±28.1 | 492.8±43.8 | 1.45±0.00 |
| Upper Coal **Measures** | 640±39.6 | 31.6±5.2 | 133.2±28.5 | 1.47±0.00 |
| SED$_{(p=0.05)}$ | 30.7 | 25.2 | 45.8 | 0.03 |
| Pr>F | <0.0001 | 0.0271 | <0.0001 | NS |

NS = Not significant

**Soil shrinkage:** There were significant variations ($p = 0.05$) in all these parameters. Highest COLE value was recorded in soils derived from Shale, which had the highest value of clay sized fraction, followed by soil from Lower Coal Measures, Falsebedded Sandstones, Coastal Plain Sands, Alluvium and Upper Coal Measures (Table 2). It was found that although soils from Coastal Plain Sands had higher value of clay than those of Faslebedded Sandstone they were associated with lower value of COLE, suggesting that other factors apart from clay contribute substantially to COLE and soil volume shrinkage. Boivin *et al.* (2004) reported that shrinkage capacity of the soil increases with clay content and that this is related to clay type, pore size and moisture content. Shrinkage ratings show that soils formed over Shales possess severe shrinkage characteristics, followed by Lower Coal Measures, Falsebedded Sandstones, Coastal Plain Sands, Alluvium and Upper Coal Measures.

Results (Table 3) show that positive correlation coefficients exist between COLE with waterholding capacity ($R = 0.73$), liquid limit ($R = 0.59$), Plastic limit ($R = 0.67$), Plasticity index ($R = 0.50$) and percent clay ($R = 0.61$), all at a probability of less than 0.05 while bulk

Table 2: Atterberg limits, COLE and WHC of soils of the study site

| | LL | PL | P1 | WHC | COLE | | |
|---|---|---|---|---|---|---|---|
| Parent material | ---------------- | (g kg$^{-1}$) | ---------------- | ---------------- | (cm cm$^{-1}$) | VS | Rating |
| Alluvium | 164.3±27.0 | 44.6±240 | 119.7±23.1 | 278±34.5 | 0.020 | 0-10 | Slight |
| Coastal Plain **Sands** | 192.8±27.1 | 37.4±24.1 | 155.4±19.6 | 334±24.6 | 0.026 | 0-10 | Slight |
| Falsebedded **Sandstones** | 335.5±28.2 | 162.9±24.0 | 272.6±30.6 | 388±34.6 | 0.042 | 10-20 | Moderate |
| Lower Coal **Measures** | 350.1±30.1 | 134.7±23.9 | 215.4±28.2 | 416±28.2 | 0.056 | 20-30 | Moderate |
| Shale | 604.4±28.1 | 325.1±24.6 | 279.3±22.8 | 487±32.1 | 0.012 | 0-10 | Severe |
| Upper Coal **Measures** | 30.8±11.2 | 18.2±1.09 | 12.6±2.3 | 174±17.8 | | | |
| SED$_{(p=0.05)}$ | 2.71 | 2.40 | 0.31 | 1.45 | 0.007 | | |

LL = Liquid Limit, PL = Plastic Limit, Pl = Plasticity Index, WHC = Waterhoding Capacity, COLE = Coefficient Of Linear Extensibility, VS = Volume Shrinkage

Table 3: Correlation between COLE and selected physical properties

| Factor correlated | Correlation coefficient (R) | Level of significance ($p<0.05$) |
|---|---|---|
| COLE Vs WHC | 0.73 | <0.0001 |
| COLE Vs LL | 0.59 | <0.0001 |
| COLE Vs PL | 0.64 | <0.001 |
| COLE Vs Pl | 0.50 | <0.001 |
| COLE Vs BD | 0.01 | NS |
| COLE Vs Clay | 0.61 | < 0.001 |

COLE = Coefficient Of Linear Extensibility, WHC = Waterholding Capacity, LL = Liquid Limit, PL = Plastic Limit, PI = Plasticity Index, BD = Bulk Density, NS = Not Significant

Table 4: Coefficient of linear extensibility model attributes ($p =\leq 0.0001$)

| Attribute | Value |
|---|---|
| R | 0.87000 |
| R2 | 0.75000 |
| $1\text{-}R^2$ | 0.25000 |
| Dependent mean | 0.05000 |
| CV (%) | 35.12000 |
| RMSE | 0.01000 |
| Bias | +0.00001 |

CV =Coefficient of Variation, RMSE =Root Mean Square Error

density had non-significant correlation with COLE. This shows that bulk density is not a major factor that influences the volumetric behaviour of soils when subjected to applied force and this is consistent with the findings of the study conducted by Igwe (2003). But the significant effects of water holding capacity, liquid limit, plastic limit, plasticity index and clay content on COLE, indicate that they exert great influences on the strength of soils for engineering purposes. Soil volume change is a function of soil water content (Assouline *et al*., 1997), clay content (Boivin *et al*., 2004) and Atterberg limit values (Onweremadu, 2006). Because clayey soils retain more water, it reduces their ability to resist volume change in the face of applied force. Brady and Weil (1999) remarked that particle size, moisture content and plasticity of colloidal fraction determine the stability of soils in response to loading forces from traffic, tillage and building foundations.

Modelling and Conclusion: Using five independent variables namely, bulk density, waterholding capacity, plasticity index, clay and sand contents, COLE model was established.

$$\text{COLE:} = 0.190+0.040\text{BD}+0.010\text{WHC}-0.001\text{PI}-0.002\text{Clay}-0.003\text{ Sand} \qquad (6)$$

Where:

COLE = Coefficient of linear extensibility
0.190 = Intercept
BD = Bulk density
WHC = Waterholding capacity
PI = Plasticity index
Clay = Clay-sized fraction
Sand = Sand-sized fraction.

Attributes of the model are given in Table 4, indicating a good relationship ($R^2 = 0.75$) between these independent variables and COLE. It implies that these variables are good predictors of volume shrinkage characteristics in soils of Southeastern Nigeria. The model also achieved high degree of accuracy with RMSE value of 0.01 and with minor overestimation of +0.00001. These results exist despite variability in the lithological origin of soils, differences in drainage classes, climatic regimes, land use history and present management practices. It is suggested that more independent variables involving soil chemical properties and other soil-related properties of the area be used in future modelling to increase reliability of resulting model(s).

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