

Changes in Rheological Properties of Four Contrasting Soils as Induced by Cultivation

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Abstract – Atterberg limits are rheological properties that command strong influence on the physical properties of soils and therefore, could be used as an indication of soil quality for long-term land use management systems of soils. Thus the study was under taken to evaluate changes in rheological properties of four contrasting soils as induced by cultivation. The four soils studied were Entisol, Ultisol and two Inceptisol; all collected from four different locations, in Nsukka area of Southeastern, Nigeria. The land use types considered were fallow and cultivated. Soil samples collected from 0-25cm depth were air-dried at room temperature and then were separated into five aggregate fractions, 5-2mm, 2-1mm, 1-0.5mm, 0.5-0.25mm and < 0.25mm. Soils for the determination of consistency limit were further sieved using sieve N0. 36 (0.0045mm) to remove the coarse particles before being used to determine changes in their rheological properties due to cultivation. Two hundred grams (200g) of each sample were used for determination of Atterberg and Shrinkage limits. The result of the study showed that rheological properties of the soils were affected by cultivation. Cultivation decreased the value of plastic limit (PL) of IEh and ENsk, but increased the value of liquid limit (LL) and Plasticity Index (PI) of ENsk (45.6%, 23.4%), IEh (34.5%, 14.9%), and Iik (35.6%, 20.2%) in cultivated soils respectively relative to the fallow soils. The result of shrinkage limit and volumetric shrinkage (VS) limit values indicated that cultivation caused 10.71% and 40.49% increase in ENsk, IEh and 7.14% and 24.9% increase in Iik respectively in cultivated soils relative to the fallow soils. From the result of this study, it is evident that cultivation affected the rheological properties of these soils through their variability in the Atterberg limits.

Keywords – Atterberg Limits, Rheological, Soils, Fallow, Cultivated.

I. INTRODUCTION

One of the silent and very limited addressed challenges facing crop production in a tropical soil like Nigeria is the decline in the rheological (carrying capacity) properties or strength of the soil. These properties command a strong influence on the physical properties of the soil that invariably affect in a strong term the crop and animal production and efficiency of the machineries and implements used on the particular soil. An identified factor responsible for the decline in the rheological properties of a soil is the continuous or intensive cultivation. This reduces to a greater extent the soil capacity to provide for the requirement of human life (Brabant *et al*; 1996). Cultivation decreases the level of soil carrying capacity which resulted from continuous agricultural activities which weakens the soil structure, thereby making the soil very weak to carry loads (Khademi and Mermut 1999).

While Buhmann *et al.*, (1996) emphasized that an intensive agricultural practices on the soil reduces the soil elasticity, which can lead to low soil carrying capacity, the resultant effect of such soil is that tractor and its attendant implements working on such soil can easily sink into the soil or crack the soil on its passage on the soil.

Casenave and Valentin (1989) summed it up when they said that if soil surface is no longer in equilibrium with vegetation and soil fauna, surface crusting is a succession process corresponding to specified degradation stages. The reason being that every activity in agriculture ranging from cultivation down to harvest with its attendant machineries component has its own effect on the soil carrying capacity. Hence according to Braunack *et al*; (1979) agricultural soil must be kept in aggregated and well-aerated conditions so that crop growth will not be adversely affected. They also re-emphasized that the soil must have the ability and strength to support the considerable loads that will be exerted by modern agricultural machinery which tends to crush the individual soil aggregates and to compact the soil into a dense mass which may be anaerobic and impenetrable to roots. Where soil is cultivated frequently, aggregates are exposed frequently to physical disruption by rapid wetting and rain drop impact as well as to shearing by implements (Emmond, 1971, Martel and Paul, 1974; Juo and Lal, 1977). In view of this finding, therefore, stability as applied to soil structure should aim at resistance of the particle arrangement to change upon wetting and coming in contact with farming implements (Reeve, 1953). Furthermore, the development of a stable structure is highly desirable in attempt to ameliorate hard-setting behavior of soils which imposes severe restrictions on cultivation and plant growth (Mullins *et al.*, 1990). Water and level of clay mineral contents of the soil are some of the factors that influence the rheological behavior of soils. Berli *et al*; (2003) reported that vertical loads especially at high water content may bring a sudden change in the rheological behavior of soils. Thus under tension, the wet soil losses its strength and gradual structural changes take place through aggregate coalescence without the complete disintegration often observed in flooded surfaces (Keller 1970). He equally observed that aggregated soil subjected to external stresses show reduction in pore spaces and was largely attributed to plastic deformation of soil aggregates at their contact.

While McMurdie and Day (1958) in their studies of microscopic aggregate yielding processes observed that flow of soil is initiated only when the stress acting upon the inter aggregate contact exceed a critical yield point and that beyond the yield stress, soil aggregates flow in a

manner similar to viscous material at a rate proportional to the stress in excess of the yield stress (Keller 1970, Ghavami *et al.*, 1974, Vyalov 1986, Ghezzehei and Or 2000). When soil is too wet, tillage operations can have detrimental effect on soil structure (Mueller *et al.*; 2003).

The level of clay mineral in a soil influences greatly the structural behavior of the soil with regard to intensive agricultural activities on the soil. For instance Neaman and Singer (2000) reported that the higher the level of clay mineral contents, the lesser the effect of intensive cultivation on the rheological properties of the soil, and vice versa. Neaman (2000) observed that small addition of montmorillonite under intensive cultivation increased the rheological parameters, while increased addition under intensive cultivation decreased the rheological parameters, at even larger montmorillonite additions, the suspensions showed nearly Newtonian flow, with a plastic viscosity equal to the initial value of pure palygorskite suspension. When particle-particle interaction occur due to clay particles in the percolating solution, the viscosity of the flowing suspension may increase significantly and may decrease its fluidity, causing non-Newtonian flow, soil hydraulic conductivity decreased the more (Neaman and Singer 2000; Neaman 2000), because earlier Neaman (2000) explained that percolating solution in the soil is below the flocculation value of the clay and that under this situation, the flow of water in soil changes from flow of solution to flow of clay suspension. Mc Garry *et al.*; (2000) reported that Shrink/Swell clays might play an important role in both natural variability of soil structure and potential responses of soil hydraulic properties to management practices.

Intensive agricultural activities on a soil that has low clay mineral content reduced the binding forces between the soil aggregates, causing high leaching and erosion on the soil that washes away the soil binding agents and renders the soil very weak to carry loads thus leading to collapse of the soil (Khademi and Mermut 1999; Neaman 2000; Neaman and Singer, 2000). Atterberg limits are rheological properties of soil that are highly sensitive to management and therefore, could be used as an index of soil physical quality for land use management systems of soils. Atterberg limits are important parameters related to soil structural stability (Marinissen 1994). Plastic limit (PL) is one of the useful indexes of soil physical quality. Plastic limit of a soil is the moisture content at which the soil begins to crumb in attempting to form a thread, 3mm in diameter (Lal, 1981). Moisture contents of the soil above this limit create problems for cultivation and under moderate pressure create large clods devoid of coarse

pores (Russell, 1973). Davies *et al.*; (1972) reported that cultivation of such a soil at the extremes of moisture content is very difficult, if not impossible. Also moisture content above this limits might make the soil very unploughable and clay-pans might develop bellow the plough layer. This kind of soil however, can be improved through manure amendment (Mbagwu 1989b). The friable range is the intermediate moisture content between the above two limits, and this range is ideal moisture content for cultivation as good soil tilth is manifested in the range. This soil tilth tends to deteriorate under tillage and cropping operations (Baver *et al.*; 1972). Mueller *et al.*, (2003) identified the plastic limit as one of the most sensitive parameters to estimate the highest water content for optimum tillage across a broad range of soils and soil macro and micro structural properties can be significantly altered by untimely tillage ignoring the dynamics of soil consistency (Adam and Erbach, 1992; Barzegar *et al.*, 2004).

Several investigations indicated that much work have been conducted on the rheological properties of temperate soils, but relatively little or no work have been carried out on the rheological properties of tropical soils like Nigeria especially with regard to fallow as soil management system. Hence the need for this study-changes in rheological properties of four soils as induced by cultivation.

II. MATERIALS AND METHODS

Soil samples from the 0-25cm depth were collected from cultivated and adjacent fallow lands in four different locations in Nsukka area of south eastern Nigeria. Care was taken to minimize disturbance during sampling and transportation. The area has a rainforest savannah type of vegetation with a mean annual temperature of 24^oc. The area lies within latitude 06^o 61¹N and longitude 07^o 25¹E of Nigeria. The soils sampled for the study are classified according to soil taxonomy as an Ultisol, belonging to the sub-group, Typic Kandistult (Nkpologu series), Entisol belonging to Lithic Ustorthent (Uvuru series), while the other two soils belong to Vertic Inceptisol (SSS, 1992). These soils has been under cultivation for relative 8years while fallow soils varied from 3 to 4years. The paramount crop culture in the study area is mixed cropping whereby the farmers' plant deep rooted and shallow rooted crops together on the same piece of land. Some examples of these mixed crops were cassava, yam, maize, pumpkin, okra, etc. Table 1

Table 1: Location, Classification and Land use type

Location	Classification	Treatment Symbol	Land use Type
Nsukka Hill Site	Lithic Ustorthent (Uvuru series)	ENsk (F)	Fallow
		ENsk (C)	Cultivated
Nsukka Poultry Site	Typic Kandistult (Nkpologu series)	ENsk (F)	Fallow
		ENsk (C)	Cultivated
Eha-Amufu Site	Inceptisol (With vertic properties)	IEh (F)	Fallow
		IEh (C)	Cultivated
Ikem site	Inceptisol (With vertic properties)	Iik (F)	Fallow
		Iik (C)	Cultivated

Laboratory method

The soil samples were air-dried at room temperature and then sieved through a 5.00mm sieve. Clods were carefully crushed by hand along lines of natural cleavages to pass the sieve. Two hundred and fifty grams (250g) of the sieved sample, at a time, were transferred to the upper most of a nest sieve of sizes 2, 1, 0.5 and 0.25mm. They were shaken mechanically for 10minutes. Further sieving by hand was done where necessary. This procedure, similar to that described by Kemper and Chepil (1965), resulted in the separation of the following aggregate fractions 5-2, 2-1, 1-0.5, 0.5-0.25 and < 0.25mm. The separation continued until enough quantity of each fraction was collected for further analysis.

Determination of Atterberg limit

In this study, soils for the determination of the Atterberg limits were further sieved using sieve N0 36 (450 microns = 0.0045mm) to remove the coarse particles before being used to determine the limits. Two hundred grams (200g) of each sample were weighed for determining the shrinkage and Atterberg limits.

The liquid limit (LL)

The classical Casagrande (1932) method and the procedure outlined by Sowers (1965) making use of the LL device, was used to determine the liquid limit. Two hundred grams (200g) of each stiff paste of the soil samples were mixed with enough distilled water to give the soil the consistency of soft paste. Some of the mixture was put into the cup of the LL device and smoothen level with the front of the cup with a sharp knife to form a pat that was 1cm thick above the point of contact. A dividing groove was used to cut a groove dividing the pat in the cup into two equal parts. The crank was turned at 2 revolutions per second while the blows (number of taps made by the cup on the hard rubber stage) required to cause the soil pat to flow together and obscure the bottom of the groove for a distance of (1/2 inch) 1.25cm was noted.

The soil paste of about 10g of the portion of the soil which flowed together was then taken and weighed and placed in the oven at 110^oc for 24 hours to dry. The above steps were repeated about five times and at least four determinations were obtained in the range of blows between 10 and 50 inclusive with some above and some below the required 25 blows of the LL were used. After 24 hours of oven-drying, the pastes were re-weighed and the percentage moisture contents determined for the different soil extracts (portions), by using the formula:

$$\text{Wt. of moisture} = \text{Wt. of wet soil} + \text{container} - \text{Wt. of dry soil} + \text{container} \quad (1)$$

$$\text{Wt. of dry soil} = \text{Wt. of dry soil} + \text{container} - \text{Wt. of container} \quad (2)$$

$$\% \text{ Moisture Content} = \frac{\text{Wt. of moisture}}{\text{Wt. of dry soil}} \times 100 \quad (3)$$

A flow curve was plotted of water content against the number of blows at the different points. The best-fitting straight line was drawn through the test points which showed a decrease in water content with increasing number of blows. The LL was determined as the water content of the flow curve that corresponds to 25 blows,

from the respective curves of the soils. The LL so determined is the water content at which 25 blows are required to close the bottom of the groove over a distance of 13mm (Craig, 1989.)

The Plastic Limit:

The classical Casagrande (1932) method was also used to determine the plastic limit (PL). The method is described below. After making a homogenous mixture of the soil and distilled water to form a paste. Some of the paste was spread out evenly on a glass plate and allowed to dry to such a point that using the palm, it could roll into a thread, 3mm in diameter. The thread was collected and weighed and place in an oven at 110 and re-weighed after 24 hours. Two readings were taken and the PL calculated as the average of the percentage moisture contents of the two determinations using the formula below;

$$\text{Wt. of moisture} = \text{Wt. of wet thread} + \text{container} - \text{Wt. of dry thread} + \text{container} \quad (4)$$

$$\text{Wt. of dry thread} = \text{Wt. of dry thread} + \text{container} - \text{Wt. of container} \quad (5)$$

$$\% \text{ Moisture Content (x)} = \frac{\text{Wt. of moisture}}{\text{Wt. of dry soil}} \times 100 \quad (6)$$

The same procedure was used to get % moisture content of the second reading (Y). The PL was calculated from,

$$\text{Mean PL} = PL = \frac{X + Y}{2} \quad (7)$$

The plasticity index (PI) was calculated as the difference between the LL and PL.

$$PI = LL - PL \quad (8)$$

Shrinkage Limit (SL)

The soil pastes were collected when the groove closed at exactly 25 blows for the determination of the shrinkage limit (SL), while carrying out the LL test. The pastes were put in a shrinkage mould, 14 cm in length, and leveled to the brim of the mould and placed in the oven at 110^oc for 24hours. After the drying process, the new lengths of the soils in the mould were measured. The shrinkage was calculated as the ratio of the decrease in length to the original length in percentage. The calculated value where referred to as linear shrinkage, since the shrinkage was in a linear form. The linear shrinkage was calculated as follows:

$$SL = \frac{L_1 - L_2}{L_1} \times 100 \quad (9)$$

Where:

SL = Shrinkage limit in percentage of initial length of moist soil sample.

L₁ = Initial length (cm) of moist soil in mould (length of mould).

L₂ = Length of oven-dried soil.

The coefficient of linear Extensibility (COLE)

The coefficient of linear extensibility (COLE) was calculated from the reading,

$$COLE = \frac{L_m - L_d}{L_d} = \frac{L_m}{L_d} - 1 \quad (10)$$

Where:

L_m = Length of moist soil sample.

L_d = Length of dry soil sample.

The Volumetric shrinkage

The Volumetric shrinkage (VS) was computed from measured coefficient of linear extensibility (COLE) data using the relationship:

$$VS = (COLE + 1)^3 - 1 \times 100 \quad (11)$$

(Mbagwu, 1992)

Data analysis

Steel and Torrie (1980) biometric approach was used to analyze the data generated and LSD, 0.05 was used to compare the means.

III. RESULT AND DISCUSSION

The values of these rheological properties, Liquid limit (LL), Plastic limit (PL), Plasticity Index (PI), Coefficient of linear extensibility (COLE), Shrinkage limit (SL) and Volumetric Shrinkage (VS) of the soils are given in Table 2. Cultivation increased the LL and PI of ENsk, IEh and Iik, but decreased the value of PL of IEh and ENsk. The mere 0% value for PL recorded in fallow UNsk probable may indicate that the soil is not plastic.

Plastic limit (PL) is a useful index of soil physical quality (Dexter, 1988), relatively higher PL values recorded in fallow soils of ENsk and IEh, indicated that soils under this land use management have better physical structure than the other land use system. The differences

observed in the values of LL, PL and PI probable suggest that the optimum water content for cultivation varies among the cultivated sites. When soil is too wet it can create problem for cultivation and tillage operations can have detrimental effects on soil structure (Davies *et al*; 1972, Russell 1973, Mueller *et al*; 2003). The results may as well be attributed to the kind of clay minerals (Neaman and Singer 200, Neaman 2000) and exchangeable ions present in the soils. Kemper *et al*; (1987) found out that highly dissociated cat ions such as Sodium (Na⁺) increase the liquid limit and plastic limit of soils. The plasticity index (PI) an indication of clay content is a measure of the plasticity of a soil and according to Das, (2006) outlined range, and the soils are of medium plasticity. The plasticity in the cultivated soils of ENsk, IEh and Iik were significantly greater than in the fallow soils. This could be attributed to the organic matter content in the fallow soils which might be most likely due to moisture holding capacity of the soil organic matter and its influence on soil structure and soil porosity (Raisah *et al*; 2004). The essence of this finding is that plasticity index which describes how much a soil expands and shrinks, determines the stability of soil structure and structure foundations on a particular soil. A Dam or foundation for building built on a soil with a high plasticity index is much more likely to crack and fall.

Table 2 Changes in rheological properties of four soils as induced by cultivation

Soil treatment	LL%	PL%	PI%	COLE	SL%	VS%
ENsk (F)	40.2	35.3	4.9	0.10	9.29	33.96
ENsk (C)	45.6	22.2	23.4	0.12	10.71	40.49
Mean	42.90	28.80	14.20	0.11	10.00	37.23
LSD 0.05	1.35	3.30	4.65	0.00	0.35	1.63
UNsk (F)	20.5	0.0	20.5	0.08	7.14	24.90
UNsk (C)	22.2	3.1	9.1	0.05	5.00	16.64
Mean	21.40	6.55	14.80	0.07	6.07	20.77
LSD 0.05	0.45	3.30	2.85	0.01	0.53	2.06
IEh (F)	31.1	22.0	9.1	0.08	7.14	24.90
IEh (C)	34.5	19.6	14.9	0.12	10.71	40.49
Mean	32.8	20.8	12.0	0.10	8.93	32.70
LSD 0.05	0.85	0.60	1.45	0.01	0.88	3.95
Iik (F)	31.0	21.1	9.9	0.04	3.57	11.53
Iik (C)	35.6	25.2	20.2	0.08	7.14	24.90
Mean	33.3	23.2	10.1	0.06	5.36	18.22
LSD 0.05	1.15	1.05	0.10	0.01	0.89	3.35

LL = Liquid Limit; PL = Plastic Limit; PI = Plasticity Index; SL = Shrinkage Limit; COLE = Coefficient of Linear Extensibility; VS = Volumetric Shrinkage, LSD = Least Significant Difference, F = Fallow; C = Cultivated; ENsk = Entisol at Nsukka, UNsk = Ultisol at Nsukka; IEh = Inceptisol at Eha-Amufu; Iik = Inceptisol at Ikem.

The SL and VS values of ENsk, IEh, and Iik were increased following cultivation, while the value recorded for COLE in UNsk, IEh and SL; VS in UNsk showed that cultivation decreased the values of these properties. Cultivation had effect on the rheological properties of these soils as evidence in the variations in these properties. Soil shrinkage creates inter-aggregates cracks and through consecutive swelling and drying, the aggregate strength increase and aggregate diameter becomes smaller (Horn *et al*; 1994). Therefore, stable aggregate formation

encouraged by the renew of the polysaccharides component that result from decomposition of fresh organic materials by soil organisms, might have influenced the shrinkage values recorded for the fallow soils relative to the cultivated soils. Tiller and Melia (1993) viewed that decomposition of biomass mainly plant, can increase the relative to the cultivated soils. Tiller and Melia (1993), viewed that decomposition of biomass mainly plant can increase cohesive force binding particles together to form improved soil structure and rheological capacity. The

result may also be dependent on the clay and water content of the soil aggregates this help in determining the actual strength of a soil (Guerif 1988).

The knowledge of differences in soil Atterberg limits results can allow for a better management of the soils, noting that if soil surface is no longer in equilibrium with vegetation and soil Fauna, surface crusting may result leading to soil degradation (Casenave and Valentin 1989). So soil quality should be ensured through natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain and enhance air and water quantity (Karien *et al*; 1997).

IV. CONCLUSION

The result of the study showed that cultivation affected the rheological properties of the soils. It is therefore advisable to know that any activity that will separate the soil particles from one another will gradually affect the rheological properties of the soil. Therefore unless the soil is allowed to regain its lost rheological properties and improve its quality and capacity to function, the soil capacity to perform at this point may be extremely low, if not impossible.

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