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Quantification of moist and wet consistency of horizons of soils formed on different parent materials

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ABSTRACT

The research described and quantified soil consistency as cumulative consistency value (CCV) at two moisture levels for different horizons of soil profiles located on sedimentary and basement complex parent materials. It was found that the CCVs of soils formed on sedimentary deposits were between 18 and 28 while the CCVs for the soils formed on the basement complex were between 0 and 27. No significant difference was observed between the CCVs of sedimentary deposits' and basement complex soils. Correlating CCVs with clay and organic matter contents, no significant positive and negative relationships were observed with r = 0.20 and -0.28 respectively. It is pertinent to always determine soil consistency and expressed as CCV because it can be utilized in inferring the level of soil compaction and deciding on the best management practice which could include organic matter addition as well as in making choice of instruments for soil manipulation.

1.0. Introduction

Soil consistency is the strength with which soil materials are held together or the resistance of soils to deformation and rupture (Norlia *et al*., 2012). It is also the resistance of soil to insertion of instruments and farm implements, particularly, at a moisture level. Soil consistency may be estimated in the field using simple tests or may be measured more accurately in the laboratory. Consistency of soil is an important physical and dynamic property which varies with the variation of soil moisture and applied stress. It is considered a combination of soil properties dependent upon the forces of attraction between soil particles as influenced by soil moisture (Mitchell, 1993).

Soil consistency is also defined as the manifestations of the physical forces of cohesion and adhesion acting within the soil at various moisture contents (Sridharan *et al.,* 1999). These manifestations include the behaviour towards gravity, pressure, thrust and pull; the tendency of the soil mass to adhere to foreign bodies or substances; the sensations which are evidenced as feel by the fingers of the observer. Consistency of soil depends on the texture, nature and amount of inorganic and organic colloids, structure, moisture content amongst others. With decreasing moisture content, the soils lose their stickiness and plasticity and become friable and soft and finally when dry become hard and coherent. It has strong engineering implication, particularly with respect to construction (Nurly and Khairul, 2008) and the Atterberg Limits are defined based on soil consistency (Craig, 1993). Consistency has also been used as a basis for the classification of soils (British Standard Institution, 1990; Sridharan *et al.,* 1999). It is described on the basis of three moisture levels wet, moist and dry. In addition, soil consistency is also expressed based on the degree of cementation. For wet soils, it is expressed as both stickiness and plasticity.

The sustainable usage of soil is a function of the holistic knowledge of inherent attributes of the soil. In the sustainability evaluation of the soil, more considerations are given to fertility, pedological (genetic) and mineralogical features. For the physical properties, bulk density, structure and texture are the commonly incorporated in sustainability studies, with lesser attentions on other properties such as consistency, electrical conductivity, permeability amongst others. This may be associated with difficulties in the determination of these properties of soil. Although the determination of the Atterberg limits which are often used to quantify consistency is complex, however, soil consistency determination during description of soil is not as difficult and complex as are the determinations of most chemical properties and the other physical properties of the soil. Lack of holistic understanding of properties of the soil has often resulted to poor usage and management of soils agriculturally, and in engineering usage, construction errors that are costly with respect to efforts and material investment showcased.

Unveiling information on consistency (that is, a simpler parameter-CCV of expressing consistency) of soils is knowledge packed as a fall-out to a new ground of research in soil science. For the agriculturists (particularly, crop producers), information on consistency can guide them on the right implements to use in tillage, appropriate management practices to carry out on the farm with respect to soil degradation (erosion) mitigation efforts and of course, reveal possibility of crusting within the soil. Also, being able to determine the relationships between consistency and other soil properties such as organic matter content and texture (clay) would have lend the research a predictive value for other properties of the soil. Hence, this research described and quantified the consistency of soils formed on different parent materials, and determined the functional relation between consistency, organic matter content and texture (clay) of the soils.

1.1. Description of Soil Consistency

Soil consistency is commonly measured by feeling and manipulating the soil by hand or by pulling a tillage instrument through it. The consistency of soils is generally described at three soil moisture levels: wet, moist and dry. The consistency of fine grained soils is expressed qualitatively by such terms as very soft, soft, stiff, very stiff and hard. Water content significantly affects properties of silty and clayey soils (unlike sand and gravel). It has been found that at the same water content, two samples of clay of different origins may possess different consistency (FAO, 2012; Banglapedia, 2015). Soil strength decreases as water content increases; soils swell-up when water content increases; fine-grained soils at very high water content possess properties similar to liquids; as the water content is reduced, the volume of the soil decreases and the soils become plastic; if the water content is further reduced, the soil becomes semi-solid when the volume does not change.

At very low moisture content, soil behaves more like a solid. When the moisture content is very high, the soil and water may flow like a liquid. Also, soil strength decreases as water content increases. Therefore, the soil behavior of the soil, based on moisture content is divided into four states: solid, semi-solid, plastic, liquid. Soil consistence provides a means of describing the degree and kind of cohesion and adhesion between the soil particles as related to the resistance of the soil to deform or rupture. Since the consistence varies with moisture content, the consistence can be described as dry consistence, moist consistence, and wet consistence.

2.0. Materials and Methods

2.1. Area of Study

The research was carried out in Niger state. Niger State shares international boundary with the Republic of Benin in the west and also shares state boundaries with Kebbi and Zamfara states in the north, Kaduna and Federal Capital Territory (FCT) in the east, and Kogi and Kwara in the south. Niger state is located between latitudes 8.02^0 N and 10.20^0 N and longitudes 3.38^0 E and 7.03^0 E (Niger State Bureau of Statistics, 2012; Ikusemoran, Kolawole and Adegoke, 2014). Ayinde *et al*. (2013) reported that the state experiences two distinct seasons, the dry and wet seasons. The annual rainfall varies from about 1,600 mm in the south to 1,200 mm in the north.

Sedimentary formations and basement complex define the geology of the state. The sedimentary rocks to the south are characterized of sandstones and alluvial deposits, particularly along the Niger valley and in most parts of Borgu, Bida, Agaie, Lapai, Mokwa, Lavun, Gbako and Wushishi Local Government Areas.

2.2. Research Procedure

Soil profiles of depths of 100 cm were dug at six locations from six local government areas of the state on different parent materials. At each site, the geographical positioning system (GPS) was used to determine the longitude, latitude and altitude. Then, the horizons of the profile of the soil at each location were identified and described as seen on the field. Also, the physiographic features of the land and land use in the area were described. Then, soils samples were collected from each horizon of the profiles constructed, prepared and analyze for pertinent soil properties.

2.2. Data Collection

Data on consistency (moist and wet), organic matter content and texture of horizons as well as GPS location of the sampling points were collected. Soil consistency was determined by rubbing soil sample between the thumb and the forefinger at the two moisture levels to allow for the description of soil appropriately. Five designations (descriptive concepts or magnitude of description) for each moisture level were utilized to allow for uniform rating at the different moisture levels. The rating was assigned numeric value from 1 to 15 for the magnitude of consistency of soils. Summation of ratings of consistency at the various moisture levels for a particular soil was done to generate a Cumulative Consistency Value (CCV). The gradations that were utilized to facilitate quantification of consistency are as shown in Table 1.

Soil organic matter were determined with the wet oxidation method (Walkley and Black, 1934) and texture of soils were determined using the hydrometer technique (Day, 1965) whereas longitudes, latitudes and altitudes

Table 1 Rating System of Consistency of Soils at Different Moisture Levels

Moisture Levels/Descriptions (Rating)					
Moist	Rating	Wet			
		Stickness	Rating	Plasticity	Rating
Loose	1	Non-sticky	6	Non-plastic	11
Friable	2	Slightly sticky	7	Slightly plastic	12
Very friable	3	Sticky	8	Plastic	13
Firm	4	Very sticky	9	Very plastic	14
Very firm	5	Extremely sticky	10	Extremely plastic	15

were determined using the GPS.

2.3. Data Analysis

T-test, correlation and regression analyses were employed to analyze data collected. Means in all cases were separated using the Standard Error of Means (SEM).

3.0. Results and Discussion

3.1. Physiographic Features of Sites of Profiles Location

The profiles were located mainly on flat to gently sloped landscape on latitudes of between 9.04^{0}N and 9.66^{0}N; and between longitudes 4.91^{0}E and 6.00^{0}E at altitudes of between 88 m and 187 m above sea level, on either the sedimentary deposits or basement complex rocks. The lands are mainly use for agriculture as evident in the presence of maize and guinea corn farms as well as short fallows and planted tree species. Mango, locust bean, cashew, gmelina, teak and shea butter are dominant tree species common to the landscape (Table 2).

Table 2 Physiographic Features of Locations of Soil Profiles

Location	Coordinatotes	Altitude	Topography/Land Use
Parent Material: Sedimentary Deposits			
BidaPoly	9.04^{0}N, 6.0^{0}E	187.0m	Flat upland with guinea corn farmland.
Mokwa	9.30^{0}N, 5.06^{0}E	88..0m	Flat upland with Gmelina and Teak as predominant tree species and grass
Ibbi	9.66^{0}N, 4.91^{0}E	111.0m	Flat land with cashew, Gmelina and Shea butter. Not used ffor >5yrss.
Parent Material: Basement Complex			
Kuta	9.860N, 6.710E	2922.5m	Gentle slope with locust bean and mango as the predominant plant species
Kagara	10.18^{0}N, 6.27^{0}E	253.5m	Gentle slope with locust bean and mango as the predominant plant species.
Rijau	11.1^{0}N, 5.27^{0}E	349.0m	Flat upland with planted mango.

The geographical coordinates of the locations of the soil profiles fall within the descriptions of the land area of Niger state by Ikusemoran, Kolawole and Adegoke (2014) and Niger State Bureau of Statistics (2012).

3.2. Consistency Description and Quantification of Horizons

The consistencies of the horizons are described at the moist and wet moisture levels. At the moist level, the consistency varies between loose and very firm while at wet moisture level, the consistency varies between non-sticky and very plastic with cumulative consistency values of between 18 and 28 for the soils formed on the sedimentary deposits whereas the cumulative consistency for the soils formed on the basement complex was between 0 and 27. There was no significant difference ($P \leq 0.05$) between the consistency of the soils formed on the sedimentary deposits and the soils formed on the basement complex. Consistencies of the horizons of the soils formed on the sedimentary deposits and basement complex are shown in Tables 3.

3.3. Clay and Organic Matter Contents of the Soils and Relationships to Consistency

The clay content of the soils formed on the sedimentary deposits varies between 6.54 % and 15.56 % whereas it is between 6.54 % and 25.66 % for the soils formed on the basement complex. These contents did not differ significantly ($P \leq 0.05$). The organic matter contents of the soils formed on the sedimentary deposits and basement complex were not significantly different ($P \leq 0.05$) but the values vary between 0.22 g/kg and 0.86 g/kg for soils formed on the sedimentary deposits and for the soils formed on the basement complex, the organic matter content varies between 0.07 g/kg and 0.96 g/kg. Results of the clay and organic matter contents are shown in Tables 3 and 4 for the sedimentary deposits and the basement complex respectively.

Generally, clay and organic matter contents increased and decreased with increasing soil depth respectively. However, at Ibbi, organic matter content was in the reserve trend but at Rijau, both clay and organic matter contents were in the reverse trends to the one stated above. Correlation of CCV, clay and organic matter contents of the soils revealed correlation coefficients of between -0.62 and 0.20. Only the relation between clay and organic matter contents was significant ($P \leq 0.05$).

The negative value of r for CCV and organic matter content implies that with higher organic matter content, the soil is lesser resistant to insertion of instrument (that is, soil consistency decreases); and positive value of r for CCV and clay content indicates that higher content of clay makes the soil to be more resistant to insertion of instrument (that is, consistency increases). This is in the same light that clayey soils are described as heavy soils. The findings corroborate Shreeja (2017) report that plastic limit (a measure of soil consistency) becomes higher as the percentage of clay increases and plasticity limits decreased due to oxidation of organic matter.

4.0. Conclusion and Recommendations

Consistency value (as CVV) is a useful index that can be used to determine the best instrument (equipment) that should be employed in the tillage of a land. The research found that clayey soils (that is, soils where clay content is very high) exhibit greater resistance to penetration of instruments. It is also shown that organic matter moderates the consistency of soils such that high organic matter content is associated with reduced consistency.

It is important to determine the consistency of a soil that is to be put to any use, particularly, agriculture (crop production) because it can give clues to best management practice to adopt, such as manure application to improve soil structure. Hence, the following recommendations are put forward:

Regular incorporation of organic matter to soil as manure or by practicing agricultural system that supports organic matter build up should be encouraged in order to mitigate against soil compaction that could be due to increase in soil consistency.

Simple consistency assessment as has been done in this work should be related to crop production and soil productivity to generate standards for reference for soils at different places.

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