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Using Selected Structural Indices to Pinpoint the Field Moisture Capacity of Some Coarse-Textured Agricultural Soils in Southeastern Nigeria

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ABSTRACT

Over- or underestimation of field capacity (FC) of agricultural soils could misguide soil and water management and this might have negative agronomic and environmental impacts. The study sought to identify the moisture tension for reliably estimating in the laboratory the FC of some sandy soils with low-activity clay minerals and at different levels of structure development in Nsukka agroecological zone in southeastern Nigeria. Fifty-four samples of top- and subsoils under contrasting vegetation cover at three locations in the zone were analyzed for texture, organic matter contents, bulk density and total porosity. Saturated hydraulic conductivities (K_{sat}) of the samples were equally determined. Water-conducting and water-filled porosities at each of 0.06-, 0.10- and 0.33-bar tensions were implied from water retention data at the respective tensions. The soils were categorized based on their levels of structure development using a structural stability index [(organic matter: silt+clay) %] as follows: very low (< 4%), low (4-7.5%) and moderate to high (> 7.5%) stability soils. Series of simple correlation tests were run among the water-conducting porosities at the various tensions and the K_{sat} of the soils. In each case, the soil was assumed to have attained FC at that moisture tension which the associated water-conducting porosity showed significant positive correlation with the K_{sat}. Our results revealed that the 0.06-bar tension overestimated the FC of the soils. The 0.10-bar tension, the commonly used moisture tension for the purpose in the study area, proved suitable only for soils within the moderate to high structural stability category. From all indications, the 0.33-bar tension best corresponded to the FC of the less structurally developed soils in the other two categories. The level of soil structure development should therefore be considered before deciding the suitable moisture tension for the determination of FC of these and similar soils in other tropical locations.

Keywords: Coarse mineral soils, field moisture capacity, saturated hydraulic conductivity, structural stability, water-conducting pores

INTRODUCTION

For many practical soil and water management purposes, the upper limit of available soil water under field conditions is of great importance to environmental soil scientists, agronomists, hydrologists and agricultural engineers. This which is often referred to as field (moisture) capacity represents the potentially allowable amount of water in the soil capillary or water-filled pores. The concept of field capacity (FC) was introduced by Veihmeyer and Hendrickson (1931) to overcome the inadequacies of the earlier used 'moisture equivalent' in estimating the water retention of agricultural soils and coarse-textured soils. Information on the upper limit of available water finds wide useful application in partitioning of rainfall into runoff and infiltration, in timing of tillage operations, and in water budgeting and planning for irrigation. It is generally believed that, following irrigation or rainfall, superfluous water undergoes downward movement through the drainable or water-conducting pores in soils. At the end of this process, all the water-filled pores are instantaneously filled with water and the soil is said to be at its FC. Available water capacity of soils is usually calculated from the upper and lower limits of the available water. The latter is regularly substituted with the moisture content at 15-bar

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tension, with adequate justifications and minimized errors. In contrast, no laboratory method can be a real substitute for FC (Salter and Williams 1965). However, it is usually matched with moisture contents at various soil water tensions, as there has not been an agreement among workers as to the matric potential corresponding to FC of different soils (Gaiser *et al.* 2000; Twarakavi *et al.* 2009; Nemes *et al.* 2010).

Most studies involving the delineation of the available water capacity of the genetically similar soils in Nsukka Agroecological Zone in southeastern Nigeria assumed FC to be the water retained at 0.10-bar tension (*e.g.* Mbagwu 1995; Obi 1999; Anikwe *et al.* 2003; Igwe 2005; Nwite and Obi 2008). The FC is rarely assumed to be attained at a lower tension of 0.06 bar, in spite of the fact that the soils are texturally coarse. Instead, the only reported case in the Zone of deviating from the conventional 0.10-bar tension was at a higher tension of 0.33 bar (Epebinu and Nwadialo 1993). Between the 0.06- and the 0.33-bar tensions, the mean difference in volumetric moisture content of these soils could approach 10% due primarily to their coarse texture and the associated large and continuous water-conducting pores (Obi and Nnabude 1988). Under laboratory condition, drainage out of a hitherto saturated soil would seem to have virtually ceased under any of the above moisture tensions. It therefore becomes difficult for researchers to ascertain the exact moisture tension at which drainage becomes negligible (Hillel 1998). On the other hand, use of a benchmark moisture tension for estimating FC could sometimes mislead and so may no longer be fashionable (Twarakavi *et al.* 2009). As the moisture tension increases, the mean radius of pores that retain water decreases. Whether all, some or none of the pores larger than the water-filled pores at a specific moisture tension would conduct water or not depends on the soil's actual FC relative to the moisture at that tension. Apart from the influence on the value of available water capacity, erroneously estimated FC can have some agricultural and engineering management implications for the soils.

Perhaps, one of the major reasons for the difficulty in standardizing FC is the assumption that the finer in texture a soil is the higher the moisture tension needed to bring the soil to FC (Gaiser *et al.* 2000; Twarakavi *et al.* 2009). Even within a textural class, particle size distribution of soils exhibit a kind of gradation. It thus becomes hard to ascertain when to move on to the next level of moisture tension for a reliable determination of the FC. Moreover, the FC of especially tropical soils is, unlike moisture retention at high tensions, highly dependent on soil structure and hydraulic properties (Ottoni Filho and Ottoni 2010). This further poses a problem since soil structure is amenable to changes due to management and hence a highly variable soil property. Obi and Nnabude (1988) attributed increases in saturated hydraulic conductivity (K_{sat}) in Nsukka to improvement in soil structure and the associated increases in water-conducting pores. Similarly, Mbagwu (1995) reported a positive linear relationship between macroporosity and K_{sat} in soils from various locations in the area. In most soils, the size of the water-conducting pores governs K_{sat} (Carey *et al.* 2007); just as only the water-filled pores retain water at FC. For the Nsukka soils with clay mineralogy dominated by kaolinite (Igwe *et al.* 2009), the relationships between water-conducting porosity and K_{sat} could be reliably employed to predict their FC. Moreover, the soils are generally of low silt, clay and organic matter (OM) contents, thus rendering them poorly aggregated and structurally unstable. This suggests that such relationships may be strengthened by confining them within structural stability classes based on those constituents (silt, clay and OM) that define the structural stability of the soils.

Owing to the textural attribute of the soils in Nsukka Agroecological Zone in southeastern Nigeria, we hypothesized that their FC could be attained at a lower tension of 0.06 bar. However, it appears from all indications that structure more than texture of soils with low-activity clay has greater influence on their FC. Another hypothesis of this study, therefore, is that the K_{sat} of coarse-textured mineral soils with low-activity clays is dependent on the extent of their structural development. When such soils are subjected to satiation, the relationship between water-conducting porosity and K_{sat} would be positive and significant unless the former is determined at a tension too low to drain all the water-conducting pores or too high to have drained some of the water-filled pores. This study was aimed at establishing in the laboratory the FC that would approximate field conditions for the structurally fragile soils in Nsukka, using samples from three representative locations in the zone. Considering the contributions of silt, clay and OM to soil aggregation, a structural stability index based on these parameters is worthwhile.

Our objectives were therefore to use such an index to categorize the soils, and to establish the FC of the soils within the categories.

MATERIALS AND METHODS

Theoretical Background of the Study

A very strong linear relationship has been established between K_{sat} and macroporosity of the soils in the study area (Mbagwu 1995):

$$K_{sat} = 0.07e^{0.08(Pe)} \qquad (r^2 = 0.95)$$

In the above relationship, P_e is the macroporosity defined as the quotient of the volume of macropores (pores with equivalent radius > 15 µm) and the volume of the bulk soil. The relationship implies that the smaller (in size) or the fewer (in number) the macropores, the lower the K_{sat}. This highlights the influence of soil structure on K_{sat} of the soils. On the other hand, the FC has been shown to depend on the prevailing gravitational force tending to remove water from the soil and that this force is equivalent to the thickness of a hydraulically continuous water body (Smagin *et al.* 2008). Such hydraulic continuity can be assumed to apply in an open system like the soil when the soil is saturated and there is free internal drainage. In that case, the thickness of a water body is represented by the length of the saturated soil column. This study therefore assumes that the soils are of free internal drainage and thus allows free outflow of superfluous water.

In the laboratory procedure for the determination of the K_{sat}, the ratio of the steady state volume of outflow and the magnitude of the hydraulic head gradient is a constant. So, the K_{sat} result is dependent not on the pressure due to the hydraulic head, but on the soil structural attributes. And that is because soil structure normally determines the sizes of the water-conducting pores (Mbagwu 1995) which in turn govern the K_{sat} (Carey *et al.* 2007). Since soil structure also determines the capillary force retaining water in the soil at FC (Smagin *et al.* 2008), the relationship between water-conducting porosity and K_{sat} could give an indication of when the FC is attained. The validity of this inference rests on the fact that the present soils are dominated by low-activity clay minerals. Gaiser *et al.* (2000) showed how differing clay mineralogy could influence the predictability of water retention at FC for some coarse-textured tropical soils. In the present study, the term water-conducting pores is used to refer to the soil pores through which superfluous water is drained, while water-filled pores refers to the pores which retain water against gravity in the soil. This is because the existing classifications of pore sizes into macropores, mesopores and micropores are characterized by inconsistency and many of them do not even relate to water flows in soils (Skidmore 1993).

Study Locations and Sampling Techniques

Three locations (Nsukka, Obimo and Ibagwa-aka) in Nsukka Agroecological Zones in southeastern Nigeria were selected for the study. Nsukka is centrally located and is approximately 11 km from Obimo and 7 km from Ibagwa-aka. These locations lie between 06°47´ and 06°57´ N and 07°17´ and 07°27´ E. The zone is characterized by a sub-humid tropical climate receiving a mean annual total rainfall of about 1550 mm, with evapotranspiration exceeding rainfall in most months of the year. Above 85% of the rainfall occurs during the ‘wet season’ which spans April to October; the rest occurs during the ‘dry season’ which spans November to March. The relative humidity could be as high as 80% around August but rarely drops below 55% during December-January. The mean minimum and mean maximum air temperatures are about 22 and 31°C, respectively.

The soils are deep, porous, well-drained and red to brownish red in colour and derived from sandy deposits of false-bedded sandstones (Obi 1999). They have been classified as Typic Paleustult using the keys of Soil Survey Staff (2006), which corresponds to Haplic Nitisol by the legend of FAO/UNESCO (1988). Within the solum, they have an ustic moisture regime and an isohyperthermic thermal regime (Soil Survey Staff 2006). There is usually a soil moisture recharge of about 104 mm with sometimes a moisture surplus of about 260 mm during the wet season, but this depletes to an average deficit of about 650 mm in the dry season (Mbagwu 1987). Steady state infiltration rate could range from 240 to 750 mm h^{-1} (Obi and Nnabude 1988). By the prevailing vegetation, the area is within the derived savanna in southeastern Nigeria.

At each of the three locations, soils under bare fallow, grass-legume fallow and secondary forest and between 40 and 60 m apart were identified. They were sampled from the top-(0-30 cm) soil and the sub-(30-60 cm) soil layers. Eighteen samples each of undisturbed and auger samples were collected from each location. In the case of the undisturbed samples, cores of dimension 5 cm × 5 cm were driven into the soil, removed with the soil intact, trimmed and covered at both ends before conveyance to the laboratory. On the whole, there were 54 each of undisturbed and auger soil samples.

Laboratory Methods

The auger samples were air dried, passed through a 2-mm sieve and analyzed for texture and OM content. Mechanical analysis of the samples was by the hydrometer method (Gee and Bauder 1986). Soil OM content was determined by the modified Walkley-Black wet digestion and combustion method (Nelson and Sommers 1982). The undisturbed core samples were saturated and used to measure the hydraulic conductivity by the constant head permeameter method (Klute and Dirksen 1986). Saturated hydraulic conductivity was, thereafter, calculated using the transposed Darcy's equation for vertical flows of liquids:

$$K_{sat} = (Q/At)\ (L/\Delta H);$$

where K_{sat} = saturated hydraulic conductivity (cm h^{-1}),
Q = steady state volume of outflow from the entire soil column (cm^3); A = the cross-sectional area (cm^2); t = the time interval (h); L = length of the sample (cm); and ΔH = change in the hydraulic head (cm).

For the simulation of water-conducting and water-filled porosities at varying tensions, the saturated samples were successively drained from 0.06- through 0.10- to 0.33-bar tensions. They were first subjected to the 0.06-bar tension by the method of hanging column of water. Similar determination at 0.10- and 0.33-bar tensions was done in a pressure chamber using plates with porous membranes (Cassel and Nielsen 1986). The size boundary of water-conducting and water-filled pores was taken to be the pore radius corresponding to the different moisture tensions. This was calculated using the Kelvin equation for surface tension-capillary rise relationship:

$$r_p = (2\lambda\ \mathrm{Cos}\ \alpha)/(\rho gh)$$

where r_p = pore radius (m); λ is the surface tension of water (N m^{-1}); α is the wetting angle of water and pore wall (assumed to be nearly zero, so that Cos α ~1); ρgh represents the pressure difference across the air-water interface; with ρ as the density of water (kg m^{-3}), g as the acceleration due to gravity (N kg^{-1}) and h as the moisture tension in equivalent height of water column (m).

The pore radii corresponding to 0.06-, 0.10- and 0.33-bar tensions are 25, 15 and 5 µm, respectively. At each tension stage, water-conducting porosity was defined as the ratio of the volume of moisture so far drained from the saturated soil and the volume of the soil (core), and this was expressed in percentage. On the other hand, the water-filled porosity was defined as the ratio of the volume of moisture retained at the same tension and the volume of the soil (core), also expressed in percentage. The moisture content of the soil corresponding to a given tension was assumed to be the FC associated with that tension. Total porosity was measured as the volumetric moisture content of the soil at saturation. Finally, soil bulk density was determined by the core method (Blake and Hartge 1986).

Data Analysis

The data on the soil OM and the silt and clay contents were used to establish a structural stability index for the soils as proposed for mineral tropical soils, especially those found in the West African savanna (Pieri 1991):

$$\text{Structural Stability Index (SSI)} = \left[\frac{\text{percent soil OM}}{\text{percent (silt + clay)}}\right]\%$$

Using the above index, the soils were placed under three structural categories namely very low, low and moderate to high; corresponding to SSI values of < 4, 4-7.5 and > 7.5%, respectively. Descriptive statistics of the SSPS for Windows (version 15) was used to summarize the data and calculate the means and the standard deviations for all the determined soil properties. Relationships among the assumed water-conducting and water-filled porosities at varying moisture tensions and the saturated hydraulic conductivities were established by simple correlation. The statistical summary and the simple correlations were done for the entire soil samples as well as for each of the three structural categories.

RESULTS AND DISCUSSION

Selected Physical Properties of the Soils

Table 1 shows the data on the mechanical composition, OM contents and structural properties of the soils. On the average, soil particles in the order of sand constitute over 80% of the soils' skeleton, with the dominance of the coarse sand over the fine sand fractions. Hence, the silt and the clay contents of the soils are generally low. This textural attribute of the soils is a reflection of the influence of the parent materials, which are mainly deposits of false-bedded sandstones and coastal plain sands (Obi and Nnabude 1988). Furthermore, the silt-clay ratio showed overall high values (range, 0.45-0.87) compared to the threshold value of 0.15 for tropical soils with low to moderate weathering intensity (Young 1976). This is an indication that the soils have weathered for years, which would

Table 1. Mechanical composition and other selected physical properties of the soils.

†Structural stability category		C. sand	F. sand	Silt	Clay	Soil OM	SSI	BD (g cm^{-3})
		(%)						
All samples	Min.	27.3	11.3	1.1	5.1	0.14	0.77	1.22
	Max.	73.2	48.4	15.1	22.2	2.96	41.47	1.98
	Mean	49.8	33.4	6.2	10.5	1.04	7.42	1.58
	Std. dev.	10.6	10.9	4.7	4.2	0.61	7.07	0.17
Very low (SSI < 4%)	Min.	27.3	11.3	1.1	5.1	0.14	0.77	1.31
	Max.	73.2	47.3	13.4	22.2	0.89	3.87	1.88
	Mean	52.2	28.2	9.1	10.5	0.53	2.72	1.61
	Std. dev.	12.8	10.8	4.6	5.2	0.22	0.97	0.15
Low (SSI 4-7.5%)	Min.	33.7	16.7	1.4	5.1	0.62	4.06	1.29
	Max.	63.1	47.0	13.1	20.2	1.58	7.14	1.92
	Mean	47.6	34.9	5.5	12.1	0.97	5.60	1.61
	Std. dev.	10.3	11.0	4.3	3.9	0.21	1.06	0.16
Mod-high (SSI > 7.5%)	Min.	38.1	12.0	1.4	5.1	0.83	7.69	1.22
	Max.	65.8	48.4	15.1	12.2	2.96	41.47	1.98
	Mean	49.7	37.3	4.2	8.9	1.62	13.93	1.52
	Std. dev.	8.3	9.2	3.9	2.4	0.64	9.04	0.18

†Based on the structural stability index, SSI = [OM/(Silt + Clay)]%

Note: C. sand – coarse sand (2.0-0.2 mm); F. sand – fine sand (0.2-0.02 mm); Silt (0.02-0.002 mm); Clay (< 0.002 mm); Soil OM – soil organic matter; BD – bulk density.

possibly explain their low-activity clay status. The OM contents of the soils were also generally low (thereby qualifying them as mineral soils) and were highly variable. Since the soil samples were collected from the top- and subsoils under different land uses, the variability in their OM contents would be understandable. This manifested in the structural stability indices (SSI) of the soils.

Notably, the low OM status of the soils, coupled with their low silt and clay contents, would account for their generally low stability to degradative forces. The associated unfavourable aggregation status was partly responsible for the fairly high bulk densities of these predominantly coarse-textured soils. Indeed, the SSI showed a significant negative correlation (r = “0.43**) with the soil bulk density. Since bulk density is equally an index of soil structure, the above relationship would be understandable. Moreover, one-third of the soils were under bare-fallow and hence compacted further by the impact of direct rainfall and human traffic; and this might have contributed to the observed fairly high bulk densities of the soils (Obi and Nnabude 1988). Similar inference goes for the overbearing influence of topsoils on the bulk density of those soil samples from the subsoil.

Water-conducting and Water-filled Porosity Assumed at Various Tensions

The pore-size distribution of the soils computed based on the various moisture tensions is shown in Table 2. There was an overall increase in the size of what was assumed to be the water-conducting pores with a progressive increase in moisture tension from 0.06- through 0.10- to 0.33-bar tension. As would be expected, there was a corresponding decrease in the size of what was assumed to be the water-filled pores. Notably, the total porosity of each soil sample remained unchanged. These results show that we can influence our definition of the pore size through which superfluous water could be drained. In reality, however, the size range of such pores is more or less fixed for every soil.

The data in Table 2 show also that the increases in water-conducting porosity and corresponding decreases in water-filled pores with increasing moisture tension in the ‘very low’ and the ‘low’ structural categories were less pronounced between the 0.06- and 0.10-bar tensions than between the 0.10- and 0.33-bar tensions. This is a manifestation

Table 2. Pore-size distribution assumed at varying moisture tensions in relation to the saturated hydraulic conductivity of the soils.

†Structural stability category		0.06 bar		0.10 bar		0.33 bar		Total Φ	K_{sat} (cm h^{-1})
		WC Φ	WF Φ	WC Φ	WF Φ	WC Φ	WF Φ		
		%							
All samples	Min.	1.4	23.1	2.0	18.1	7.7	10.2	31.1	0.4
	Max.	21.1	66.5	30.2	65.5	31.7	62.8	72.6	95.8
	Mean	7.0	42.6	9.7	39.8	16.1	33.5	49.5	22.8
	Std. dev.	3.8	6.6	5.0	7.1	4.9	6.9	6.7	22.5
Very low (SSI < 4%)	Min.	1.4	33.7	2.0	33.5	8.6	28.2	38.7	3.2
	Max.	9.8	66.5	12.5	65.5	22.8	62.8	72.6	95.8
	Mean	6.0	43.9	7.2	42.7	14.9	35.0	49.9	21.0
	Std. dev.	2.2	7.8	2.7	7.8	3.8	8.4	7.8	23.8
Low (SSI 4-7.5%)	Min.	2.2	33.2	4.2	32.1	7.7	29.2	37.3	0.4
	Max.	13.1	52.8	14.3	51.1	23.6	43.2	63.1	57.7
	Mean	6.4	43.7	8.9	41.1	15.4	34.6	50.1	21.3
	Std. dev.	2.9	4.8	3.1	4.9	4.5	4.5	5.8	18.7
Mod-high (SSI > 7.5%)	Min.	3.0	23.1	4.2	18.1	10.0	10.2	31.1	4.1
	Max.	21.1	51.7	30.2	46.6	31.7	42.3	60.6	81.2
	Mean	8.6	40.1	12.9	35.7	17.9	30.7	48.6	26.2
	Std. dev.	5.3	6.4	6.6	6.7	6.0	6.7	6.5	25.3

†Based on the structural stability index, SSI = [OM/(Silt + Clay)]%
WC – water-conducting; WF – water-filled; Φ – porosity; Mod-high – moderate to high.

of the fact that a much narrower gap exists between the 0.06- and 0.10-bar tensions than between the 0.10- and 0.33-bar tensions. In the 'moderate to high' structural category the reverse was the case, although not as pronounced as in the other two categories. Here the water-conducting porosity increased by about 50% while the water-filled porosity decreased by about 16% from 0.06- to 0.10-bar tension. The corresponding values from 0.10- to 0.33-bar tension were about 39 and 12%, respectively. These results demonstrate the influence of soil structure on hydraulic properties of the soils and also serve as the first evidence that, unlike the soils in 'very low' and the 'low' structural categories, the FC of soils in the 'moderate to high' structural category is exceeded beyond the 0.10-bar tension.

Saturated Hydraulic Conductivity of the Soils

The saturated hydraulic conductivity (K_{sat}) of the soils indicated high variability (Table 2). The range was from 0.4 to 95.8 cm h^{-1}, respectively from the subsoil in one location (Nsukka) and the topsoil under grass-legume fallow in another location (Obimo). In addition to depth of sampling, the high variability in K_{sat} may be attributed to the difference in land use in the different locations. The mean value was higher in the 'moderate to high' structural category than in the 'low' and 'very low' categories. This could probably be due to the relative degrees of soil structure development and hence water-conducting porosity among the soil categories (Obi and Nnabude 1988). Similarly, Eneje *et al.* (2005) showed how decreasing levels of OM content and the associated decreases in structural stability of similar soils in southeastern Nigeria could reduce their K_{sat}.

Field Capacity of the Soils

The soils' FC could be interpreted from the relationships between water-conducting pores at varying moisture tensions and the K_{sat} of the soils (Table 3). When considering the entire soil samples, the relationship was not significant at 0.06-bar tension. This implies that some of the water-conducting pores are smaller than 25 µm. Consequently, the soils, contrary to our hypothesis, could not attain FC at that tension. The relationship was positive and significant ($P \leq 0.05$) at both the 0.10- and 0.33-bar tensions. The correlation

Table 3. Correlation coefficients between pore size distribution (at various moisture tensions) and saturated hydraulic conductivity of the soils.

		0.06 bar		0.10 bar		0.33 bar	
		WC porosity	WF porosity	WC porosity	WF porosity	WC porosity	WF porosity
K_{sat}	†All samples	0.10	0.00	0.28*	-0.14	0.27*	-0.14
	¶SSI < 4%	-0.16	-0.08	-0.29	-0.02	-0.08	-0.08
	¶SSI 4-7.5%	0.27	0.50*	0.25	0.49*	0.31	0.40
	¶SSI > 7.5%	0.10	-0.10	0.51*	-0.52*	0.44	-0.40

WC – water-conducting; WF – water-filled; K_{sat} – saturated hydraulic conductivity
SSI – structural stability index, the ratio of soil organic matter to the sum of silt and clay in %
†number of samples = 54; ¶number of samples = 18.

coefficients were comparable in both cases. With the K_{sat} being the fixed variable in the correlation, it could be inferred that all the values of water-conducting porosity increased by virtually equal proportion from 0.10- to 0.33-bar tension (Palaniswamy and Palaniswamy 2006). This suggests that some of the water-conducting pores, probably those near the boundary of water-conducting and water-filled pores, were not yet drained at 0.10-bar tension but became drained at 0.33-bar tension. For the generality of the soils in the study area, the FC could therefore not be attained at 0.10-bar tension but at 0.33-bar tension. In terms of pore radius, the results imply that pores which retain water in these soils at FC are smaller than 5 µm. The mean gravimetric moisture contents of the soil at 0.06-, 0.10- and 0.33-bar tensions were 27, 25 and 21% respectively. The value at 0.33-bar tension most closely approximated to the mean value of in-situ FC data (20%) in the area reported by Mbagwu and Osuigwe (1985).

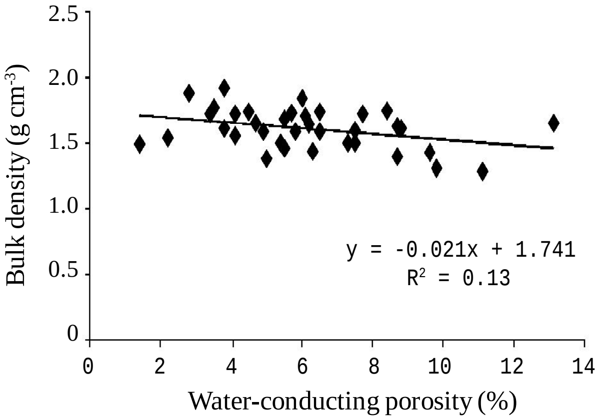

Figure 1. The regression of bulk density on water-conducting porosity determined at 0.06-bar moisture tension.

Within either of the ‘very low’ and the ‘low’ structural categories of the soils (corresponding to SSI < 4% and 4-7.5%, respectively), the correlations

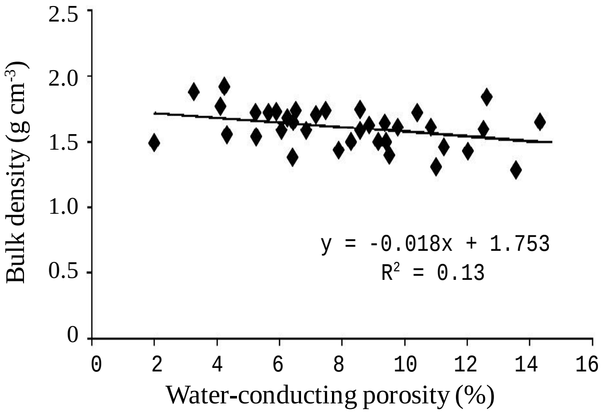

Figure 2. The regression of bulk density on water-conducting porosity determined at 0.10-bar moisture tension.

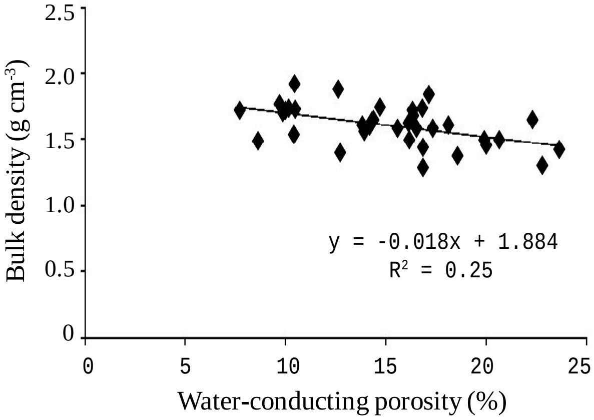

Figure 3. The regression of bulk density on water-conducting porosity determined at 0.33-bar moisture tension.

between the water-conducting porosity at the various moisture tensions and the K_{sat} were not significant. In the ‘very low’ category, the relationship was even negative across the three moisture tensions. Analogous to this in the ‘low’ category was that the water-filled porosity showed significant ($P \leq 0.05$) positive correlations with the K_{sat} at 0.06- and 0.10-bar tensions. Perhaps, the rather prolonged saturated condition of these structurally unstable soils subjected a good number of the water-conducting pores to destruction. The same condition might have also led to the detachment, dispersion and subsequent re-deposition of clay particles; thereby clogging any ‘resistant’ pores and decreasing further the K_{sat} (Dikinya *et al.* 2006). However, those phenomena which possibly decreased the K_{sat} only caused a reduction in size of the affected water-conducting pores and not in the relative abundance of the water-conducting and the water-filled pores. That is the most plausible explanation for the corresponding increase in water-conducting porosity and decrease in water-filled porosity. These results thus highlight the extent of structure deterioration and instability to water in the ‘very low’ and the ‘low’ structural categories. Although the relationships between water-conducting porosity and K_{sat} were not significant in either of the above two cases, it would be most rational to choose the 0.33-bar tension with the ‘most positive’ values of correlation coefficients as giving the best approximation of the FC. The regressions of the soil bulk density on the water-conducting porosity determined at 0.06-, 0.10- and 0.33-bar tensions (presented respectively in Figures 1, 2 and 3) show that the coefficient of determination was higher with the 0.33-bar tension than with the 0.06- and 0.10-bar tensions, thereby lending credence to the above inference.

In the ‘moderate to high’ structural category of the soils, the water-conducting porosity and the water-filled porosity determined at 0.10-bar tension respectively showed significant (*P* d” 0.05) positive and negative relationships with the K_{sat}. At the lower and the higher moisture tensions, the relationships were not significant. This implies that the FC of the soils in this structural category could be determined at 0.10-bar tension. Notably, the correlation coefficient in the present case is high relative to the one involving the entire soils, thus showing that the low values of the coefficients in the latter was due to the soils in the ‘very low to low’ categories. This confirms the inference that the FC was, as in the case of the entire soils, attained in those ‘very low to low’ structural categories at 0.33-bar tension. The mean gravimetric moisture contents of the soils in the ‘very low’, ‘low’ and ‘moderate-high’ categories at the moisture tensions corresponding to their FCs were 0.21, 0.22 and 0.25, respectively. The values just stated (FC of the soils on gravimetric basis) show a trend of increasing with an increase in structural stability of the soils, thus portraying the influence of soil structure on FC of the soils (Ottoni Filho and Ottoni 2010). Overall, these results imply that the soils in the ‘very low to low’ structural categories would have a narrower range of available water than those in the ‘moderate to high’ structural category.

CONCLUSIONS

Assumption of field capacity as the moisture retained at 0.06-bar tension would give false sense of water availability to plants and is so not recommended for the soils, irrespective of level of structure development. The 0.33-bar tension showed to be an all-purpose moisture tension corresponding to the field capacity of the soils in the study area. Information on structural stability of the soils using data on their silt, clay and organic matter contents could, however, serve as a useful guide to knowing when a lower tension would be more appropriate. Use of the lower tension of 0.10 bar is encouraged only in relatively well-structured soils, identifiable by an organic matter to silt + clay ratio of above 7.5%. The findings of this study are expected to have potentially large impact in other agroecological zones in West Africa with similar structurally impaired soils, especially where no uniform estimation of field capacity exists among researchers.

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