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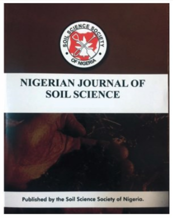

Use of point-based pedotransfer function to predict field capacity of the soil in Nsukka Area, Southeast Nigeria.

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ABSTRACT

Point-based pedotransfer functions are attractive for modelling soil water content; however, they have not been widely applied to predict field capacity (FC) of weathered tropical ultisols. Determination of field capacity at Nsukka area, was carried out using field and laboratory methods. Soils in the location were gravelly (Plots E and F) while others (Plots A, B, C and D) were deep and permeable. Core and auger samples were collected and subjected to laboratory analysis for particle size distribution, pore size distribution, bulk density, organic matter, water retention and saturated hydraulic conductivity. The results obtained revealed that the soils were dominantly loamy sand. Bulk density generally decreased with depth (Plots A, B, D and E). Pore size distribution values indicate a preponderance of micro-porosity. Organic matter was low and decreased down the profile. Hydraulic conductivity classes ranged from very slow to moderate. Laboratory estimates of field capacity at 60 cm tension were higher than the field results. The correlation coefficients indicated that the FC correlated negatively with coarse sand ($p<0.05$, $r = -0.493$) and bulk density ($p<0.01$, $r = -0.601$) and positively with fine sand ($p<0.05$, $r = 0.529$), total porosity ($r = 0.611$) and micro-porosity ($r=0.807$) at $p<0.01$. A predictive equation, $Y = 0.538 + 0.645X$ (Y = field capacity, X = microporosity) was obtained. The use of this kind of PTF in estimating field capacity is valuable in developing countries where soil data of adequate quality and reasonable quantity is critically important for sustainable land management.

1.0 Introduction

Most hydraulic soil properties like water retention are burdensome, time-consuming, and costly to measure, and they also change over short time. Soil scientists and hydrologists have explored alternative measurement methods for quick and precise prediction of difficult-to-measure soil properties. Over the past years, methods of estimations termed pedotransfer functions (PTFs) have been widely used by soil scientists in tropical and temperate regions due to the dearth of information on measured soil properties (Botula *et al.,* 2014). Pedotransfer functions (PTFs) are simple to complex knowledge rules that relate available soil information to soil properties and variables needed to parameterize soil processes (Van Looy *et al.,* 2017). PTFs play an essential role in quantifying and predicting soils' ecosystem services (Vereecken *et al.,* 2016). Ecosystem services of soils include regulatory services such as carbon sequestration and provisional services such as food supply and water storage. PTFs are used to quantify soil parameters and processes needed to estimate ecosystem services delivery and quantify degrading and supporting processes (Adhikari and Hartemink, 2016).

Pedotransfer functions for water-retention are categorized based on different criteria: class PTFs and continuous PTFs; point-based PTFs, parameter-based PTFs and pseudo-continuous PTFs; PTFs based on a specific approach; and equation-based PTFs and pattern-recognition PTFs. However, the terminologies as point-based PTFs and parameter-based PTFs are preferred (Botula *et al.*, 2014). PTFs that predict the water content at some chosen matric potentials are termed point-based PTFs. Those that estimate the parameters of analytical expressions of the soil water retention curves are termed parameter-based PTFs (Wösten *et al.,* 2001; Sharma *et al.,* 2006). The advantage of point-based PTFs is that fairly accurate prediction can be made for specific points along the water retention curve. Another advantage is that it offers insight into which soil properties are relevant for predicting the water content at a specific pressure head. (Wösten *et al.,* 2001).

It can be stated that water and soil are two essential resources of our agricultural environment (Rawls *et al.,* 1991). Soil productivity depends on the amount of water the soil will retain, which is available for plants. The plant available water is the difference between the field capacity and the permanent wilting point. Field capacity depends on soil profile characteristics, while the permanent wilting point is mainly dependent on the crops grown. Soil-water relations are among the most significant physical phenomena that affect soil for agricultural and engineering purposes (Kumar *et al.,* 1999).

Several soil properties influence soil water retention and transport of water and chemicals in soils. These include particle size properties (sand, silt and clay, median or geometric Mean, particle size, water-stable aggregates); hydraulic characteristics (water content at -33 and – 1500 kPa, reference moisture retention curve); morphological properties (soil horizon, structure, grade, size, shape, colour and consistency); chemical/mineralogical properties (organic carbon, CEC, clay type, etc.); mechanical properties (bulk density, porosity, penetration resistance) (Wösten *et al.*, 2001).

The quantity of soil moisture or water content held in the soil after excess water has been drained away is known as field capacity. The definition of field capacity (θ_{fc}) is the bulk water content retained in the soil at 30 cm) of the hydraulic head or suction pressure (Rai *et al.,* 2017). Once the rain or irrigation has ceased, water in the largest soil pores will drain downward rapidly in response to the hydraulic gradient. This becomes negligible as matric force plays a significant role in the remaining water movement after one to three days (1-3 days). Field capacity is a practical term because it refers to an approximate degree of soil wetness, at which several important soil properties are in functional (Brady and Weil, 1999). The permanent wilting point is the soil moisture content when plants' conducting tissue permanently collapses (Wild, 1996). It may be defined as the amount of water per unit weight or unit soil bulk volume in the soil, expressed in percent, held so firmly by the soil matrix that plant roots cannot absorb this water, and a plant will wilt. The soil moisture content at this matric potential has been successfully related to clay (Lund, 1959; Kivisaari, 1971) and organic matter content (Gupta *et al.,* 1979). Hydraulic conductivity is affected by any factor that changes the size and configuration of soil pores (Brady and Weil, 1999). Later, researchers discovered that the wilting point, like field capacity, is not a unique attribute. Like field capacity, it is dynamic. Depending on the soil profile (compaction, stratification and soil texture); the quantities of water in the soil at various depths, which influence root distribution; the transpiration rate of a plant; and the temperature, there is a range of values at which the degree of water supply to a plant is insufficient to prevent wilting (Kirkham, 2014).

The laboratory and field determination of field capacity gives an insight into an adequate prediction of field capacity. In the field, the soil is first saturated, and excessive evaporation prevented. After 24-72hrs, the soil moisture content can be determined (Salter and Williams, 1969). For laboratory determination, the saturated undisturbed core samples are subjected to appropriate suction. This principle uses the fact that soil moisture retention has been correlated to soil matric potentials (Larson. 1979). Field capacity has no unique retention value. In medium-textured soils, –0.33 bar matric potential is considered the approximate retentive value, and for coarse-textured soil, the approximate value is –0.1 bar. Values of –0.05 to 0.08 bar have been suggested for certain tropical soils (Obi, 2000). Lal (1979) reported that the field capacity of some Nigerian soils was better estimated by moisture retained at -0.06 bar or -0.1 bar suction than -0.3 bar suction.

Direct sampling in the field following rain or irrigation best reckons with field conditions; hence, its general accepted as the most satisfactory method for measuring the field capacity. It can also be stated that no laboratory method can be a real substitute for a field capacity measurement, which is necessarily influenced by many other factors, including especially the physical properties and initial organic matter content of the profile as a whole (Marshall, 1959). This is because of irregular pore geometry, discontinuity and variations in texture, and mineralogy and primary soil property, which affect available water capacity. Variability in these factors limits the certainty of predicting the field capacity values (Rawls *et al.,* 1991; Pachepsky *et al.,* 2006).

Since any soil's field capacity has no unique retention value, meaningful prediction of this property would require a careful evaluation of both laboratory and field data. Some pertinent laboratory data include particle size distribution, bulk density, pore size distribution, soil organic matter, and saturated hydraulic conductivity. The forbidding nature of labour and time consumption in *in-situ* determination, has made researchers use laboratory or other field methods for estimating field capacity. The magnitude of errors introduced by such substitution of techniques is unknown mainly (Salter and Williams, 1969; Van Looy *et al.,* 2017). Therefore, it is essential to choose the method that will most closely be related to the the need for prediction. The magnitude of these errors is expected to vary in different soils (Rawls *et al.,* 1991).

This study's objective was to develop a point-based pedotransfer function to predict the field capacity of the soilst in the Nsukka area, Southeast Nigeria. The specific objectives include determining field capacities in the field and laboratory, evaluate the relationships between specific soil properties and field capacity and recommend an easy way of predicting field capacity in the laboratory to limit the tedium of work involved in the field method.

2.0. Materials and Methods

2.1. Study site

This study was carried out at the University of Nigeria Teaching and Research Farm in Nsukka, Nigeria. The farm is located between Latitudes 06° 51' and 06° 53' N; Longitudes 07° 22' and 07° 26' E.; mean elevation 400 m above sea level). The soil is deep, porous and red to brownish red, derived from sandy deposits of false-bedded sandstone. It has an isohyperthermic soil temperature regime and is classified as Typic Paleustult (Nwadialor, 1989; Anikwe *et al.,* 2003). The soil is typical of agricultural soils of the area, which have suffered severe accelerated erosion by water due to careless management practices (Obi, 1982). The area is generally characterized by a humid tropical climate with wet and dry seasons with an average annual rainfall of 1700-2010 mm (Mbagwu, 1991). During the wet season with high rainfall, which begins in April and ends in October, there is a soil moisture recharge of 104 mm and a moisture surplus of about 260 mm; the dry season lasts from November to March, during which an average moisture deficit of about 650 mm occurs (Mbagwu and Adesipe, 1987). Mean annual temperatures vary from 26 to 31°C. Perennial bush burning has left the fire-resistant trees and grasses as the predominant vegetation. The floor canopy vegetation is dominated by *Imperata cylindrica, Andropogon spp, Chromoleanea odarata* and *Pennisetum spp.*

Samples were collected from three different locations in the University of Nigeria, Nsukka Farm. The first location comprising three plots designated as A, B, and C, with a deep permeable profile. The previously cultivated land was under vegetative fallow, with weeds [*Chromolina odorata*] being dominant. The second location comprising two plots designated as D and E, located on a piece of land under cultivation. The third location with one plot designated as F. The selected sites were about 200 m apart.

2.2. Field measurements

Each sampled area measured 1.5 x 1.5 m and was bound by a 5cm-deep furrow. The study area was saturated with water to a depth of 100 cm and covered with a black polythene sheet to reduce water evaporation from the soil's top layer. *The 100 cm soil depth interval was chosen to cover the complete root zone essential for available water for crop growth (*Sharma *et al*., 2006). Nine disturbed samples were collected from three different depths (0 cm - 30 cm, 30 cm – 60 cm, 60 cm – 90 cm) for three days, making a total of 162 soil samples. The samples were taken in the mornings to reduce the effect of sunlight as covers were removed before sampling. After day 3, undisturbed soil samples were collected from the three successive depths of 0 cm – 30 cm, 30 cm – 60 cm and 60 cm – 90 cm, each depth in triplicate. A total of 54 core samples were collected from all the locations.

2.3. Laboratory methods

Soil auger samples were air-dried, gently crushed and sieved through a 2 mm sieve. Sieved soil samples were then analyzed in the laboratory for particle-size distribution and organic carbon. Particle-size fractions were determined by the Bouyoucos hydrometer method (Gee and Or, 2002) and separated according to the United States Department of Agriculture (USDA) particle-size classification system (FAO, 2006). Organic carbon was determined by the wet oxidation method of Walkley and Black (Nelson and Sommers, 1982). Undisturbed soil core samples were used to determine soil moisture at field capacity (FC) at 60 cm tension using the hanging column water method described by Veerman and Stolte (1997). The soil core samples were used to determine the bulk density (BD) and porosity after drying the soil core samples at 105°C for 24 hours (Blake and Hartge, 1986). The saturated hydraulic conductivity was determined using the method of Klute and Dirkson (1986) and was calculated as

$$K = Q/At.h/\Delta H \qquad [1]$$

Where;

K = Darcy coefficient (cm s^{-1})

Q = Steady-state volume of flow from an entire soil column (cm^3).

A = Cross-sectional area of the core (cm^2)

t = time of collection (sec).

h = Depth of soil (cm).

Δ H= Change in hydraulic head

2.4. Data analysis

The observed data were subjected to descriptive statistical analysis to determine the mean, standard error and coefficient of variation in the soil variables. Correlation coefficient and regression analysis were also performed to establish the relationship between field capacity and measured soil variables using SPSS.

3.0. Results and Discussion

3.1. Soil properties

The results of the particle size distribution are presented in Table 1. The percentage composition of sand ranged from 51.3 % to 89.3 % [Mean, 70.3%]. Silt fraction ranged from 1.2 % to 12.0 % [Mean, 6.6 %]. The percentage composition of clay fraction ranged from 6.9 % to 44.7 % [25.8%]. These results show a 70:30 % sand versus clay/silt %. These results also indicated that the sites had a 30 % higher clay content at 90 cm soil depth when compared to the surface layers. This is typical of Ultisols found in the study area. The silt fraction in the 90 cm soil depth was higher than that in the 0-30 cm soil depth by 27 %.

Conversely, the sand fraction was higher in the 0-30 cm soil depth by 9.3%. As O'Geen et al., (2010) noted, soil pedogenesis determines the chemical, morphological and physical properties of soil, such as the variation of texture with depth. The textures were loamy sand, sandy clay loam, sandy clay, sandy loam, and sand with sand as the dominant particle size fraction. The soil textural class significantly impacts water-holding capacity. Differences in soil properties (texture and structure) affect the water content at saturation, field capacity, and permanent wilting point. Texture and structure determine pore size distribution in soil, and therefore, the amount of plant available water content (PAW). In other words, soil with a lower percentage of silt and clay particles, which describes coarse-textured soil, has a lower water-holding capacity. Predominantly sandy soil tends to be porous and drains water rapidly (Ezechi, 2000).

The bulk density, total porosity, pore size distribution and the organic matter content of the study site's soil are shown in Table 2. The bulk density ranged from 1.28 g cm^{-3} to 1.80 g cm^{-3}. The bulk density decreased with depth by 4.5 %. The average organic matter content of the topsoil (0 -30 cm) layer of 6 sites was 2.07 %, and this was higher than the organic matter content of the 60-90 cm soil depth by 41 %. The results also show that topsoil (0-30 cm) total porosity for the six sites was between 40.5 – 56.43 %, and this was lower than that in the 60-90cm soil layer by 8.7 %. The samples' macro-porosity was generally lower than the microporosity, with values ranging from 8.04 -25.67 % in the 0-30 cm to 7.14 - 53.51 % in the 60 - 90 cm soil layer. Conversely, the samples' micro-porosity was generally higher when compared with the macro-porosity, with values ranging from between 28.16 - 39.28 % in the 0 - 30 cm to 28.16 - 42.87 % in the 60 - 90 cm soil layer. The water in the macro-pores drains rapidly. Rabot *et al.* (2018) identified porosity, macroporosity, pore distances, and pore connectivity as the most relevant indicators for several soil functions. *Water storage and redistribution, soil pore space and pore-size distribution are governed by texture and structure* (Childs 1940). Clay-rich soils have the largest pore space, hence the most significant total water holding capacity. The pore size distribution is one of the most critical indices of all the soil physical properties used to describe various soil structure aspects. Plant root growth, water holding capacity, water movement and aeration are all governed by it. The soil particle size distribution, structure characteristics, and densification define the soil pore size distribution and water characteristics (Wu and Vomocil, 1988).

Table 1: Mechanical composition of the soils of the study area.

Site	Depth (cm)	Clay (%) Mean±SEM	Silt (%) Mean±SEM	Total Sand (%) Mean±SEM	Coarse Sand (%) Mean±SEM	Fine Sand (%) Mean±SEM	Texture
A	0-30	12.5± 0.7	4.6± 0.4	82.9±1.4	54.5±1.2	28.4±1.4	LS
	30-60	16.2± 0.3	4.2±0.3	79.6±1.7	47.5±1.7	32.1±1.2	SL
	60-90	12.7± 0.4	2.5±0.3	84.8±2.2	42.9±1.2	41.9±1.4	LS
B	0-30	11.4± 0.8	4.5±0.7	84.1±2.6	55.7±1.9	28.4±1.4	LS
	30-60	11.6± 0.4	3.8±0.5	84.6±2.5	47.3±1.1	37.3±1.3	LS
	60-90	11.0±0.7	7.9±0.3	81.1±2.1	45.3±1.9	35.8±1.7	LS
C	0-30	8.2±0.7	2.5±0.4	89.3±2.3	55.1±1.7	34.2±1.6	S
	30-60	10.2±0.5	3.8±0.7	85.9±1.8	45.4±1.2	40.5±1.2	LS
	60-90	6.9±0.6	7.2±0.5	85.9±1.5	38.5±1.4	47.5±1.5	LS
D	0-30	32.2±0.4	3.8±0.5	63.9±1.2	44.4±1.7	19.5±1.4	SCL
	30-60	37.5±0.5	01.2±0.2	61.3±1.1	41.9±1.2	19.4±1.6	SC
	60-90	42.2±0.7	4.5±0.4	53.3±1.4	37.4±1.6	15.8±1.1	SC
E	0-30	13.7±0.4	3.4±0.3	82.8±2.4	60.6±1.7	22.2±1.7	LS
	30-60	29.8±0.6	3.4±0.2	66.8±0.8	47.6±1.4	19.2±1.4	SCL
	60-90	34.7±0.4	2.0±0.4	63.3±1.6	44.0±1.2	19.3±1.3	SCL
F	0-30	28.0±0.6	12.0±0.6	60.0±1.1	39.7±1.6	20.3±1.4	SCL
	30-60	32.7±0.5	5.3±0.6	62.0±1.2	43.3±1.2	18.7±1.5	SCL
	60-90	44.7±0.7	3.3±0.2	51.3±1.4	35.4±1.6	15.9±1.5	SC
	CV(%)	58.50	56.31	17.44	14.86	36.29	

T.Sand = % Total sand, C.Sand = % Coarse sand, F.Sand = % fine sand, S = Sand, LS = Loamy sand, SCL = Sandy clay loamy, SL = Sandy loamy and SC = Sandy clay, SEM = Standard Error of the mean. CV(%) = Coefficient of variabilit

Table 2: Bulk density, porosity, pore size distribution and organic matter content of the soils of the study sites

Site	Depth (cm)	Org. C (%) Mean±SEM	BD (gcm^{-3}) Mean±SEM	TP (%) Mean±SEM	MaP (%) Mean±SEM	MiP (%) Mean±SEM
A	0-30	1.24±0.4	1.62±0.8	48.70±0.8	10.35±0.4	38.35±0.2
	30-60	0.94±0.2	1.62±0.5	45.92±0.5	10.95±0.2	34.97±0.7
	60-90	1.03±0.4	1.53±0.5	52.63±0.5	09.75±0.3	42.87±0.3
B	0-30	1.43±0.9	1.59±0.7	50.45±0.7	11.17±0.6	39.28±0.2
	30-60	1.09±0.5	1.57±0.6	51.20±0.6	11.08±0.2	40.12±0.4
	60-90	0.88±0.2	1.55±0.9	53.51±0.9	10.53±0.2	42.98±0.4
C	0-30	1.60±0.5	1.50±0.4	42.27±0.4	08.32±0.5	33.96±0.5
	30-60	1.06±0.4	1.58±0.5	49.94±0.5	07.68±0.7	42.25±0.7
	60-90	0.97±0.5	1.58±0.8	46.45±0.8	07.14±0.4	39.13±0.3
D	0-30	2.38±0.7	1.57±0.7	40.51±0.7	08.04±0.2	32.47±0.2
	30-60	1.52±0.2	1.49±0.7	44.53±0.7	07.26±0.3	37.27±0.2
	60-90	1.48±0.6	1.46±0.4	48.19±0.4	13.85±0.5	34.33±0.6
E	0-30	1.62±0.6	1.80±0.2	43.58±0.2	15.42±0.4	28.16±0.2
	30-60	1.36±0.7	1.80±0.9	44.79±0.9	13.07±0.4	31.73±0.8
	60-90	1.33±0.2	1.39±0.7	54.29±0.7	20.63±0.8	33.62±0.2
F	0-30	4.20±0.5	1.28±0.4	56.43±0.4	25.67±0.2	30.76±0.7
	30-60	1.98±0.4	1.60±0.7	48.45±0.7	15.47±0.2	32.98±0.4
	60-90	1.59±0.7	1.45±0.5	56.02±0.25	16.71±0.6	39.35±0.2
	CV(%)	49.8	8.02	8.02	39.89	12.13

BD = Bulk density, TP = Total porosity, MaP = Macro-porosity and MiP = Micro-porosity SEM = Standard Error of the mean. CV(%) = Coefficient of variability, SEM ± = SEM

Table 3 shows the saturated hydraulic conductivity of the representative soil samples. The soils exhibited significant differences in the saturated hydraulic conductivity (0.036 - 4.33cm h^{-1}) with a coefficient of variation of 126 % among all samples. This is relatively high. However, many researchers (Yang *et al.* 2020; Wang *et al.* 2008: Wang *et al.* 2012) reported very high spatial variability in soil hydraulic conductivity for different soil landscapes. The permeability class ranged from very slow to moderate. Hydraulic conductivity decreased with depth, and it was influenced by pore size distribution.

Table 4 showed the laboratory estimated field capacity compared with field values with respect to depth. The relative difference increased with time and depth so that at 0-30 cm depth, and on the first day, the values obtained from the field determined moisture content were closer to the values obtained in the laboratory. The percentage deviation at 0 -30 cm depth ranged from 6 to 44 %, 23 to 64 %, and 32 to 92 % on the first, second, and third days. Results showed a wide percentage deviation at 30 - 60 cm depth ranging from 16 % - 53 % on the first day, 25 % - 73 % on the second day and 33 % - 85 % on the third day. The 60 – 90 cm depth recorded the highest percentage deviation across the 3 days (33 % - 100 %, 40 % - 100 % and 44 % - 116 %). The laboratory estimated values showed an upper limit of 26 % and a lower limit of 16 % across the six plots.

3.2. Correlation between field capacity and other soil properties.

The correlation coefficients for the linear relationships between field capacity [FC] estimated at 60 cm tension and soil properties are shown in Table 5. The major soil properties influencing the amount of water retained in the studied soil can be ascertained. The FC estimated at 0.06 bar [Y] correlated negatively [$p<0.05$, $r = -0.493$] with coarse sand [X_1] and positively [$p<0.05$, $r = 0.529$] with

Table 3: Saturated hydraulic conductivity of the study area

Site	Depth (cm)	K (cms^{-1}) x 10^4	Permeability Index	Class
A	0-30	12.05	4	Moderate
	30-60	2.97	3	Moderately Slow
	60-90	1.24	3	Moderately Slow
B	0-30	7.36	4	Moderate
	30-60	1.43	3	Moderately Slow
	60-90	0.18	1	Very Slow
C	0-30	3.86	3	Moderately Slow
	30-60	2.13	3	Moderately Slow
	60-90	0.94	2	Slow
D	0-30	2.61	3	Moderately Slow
	30-60	1.09	2	Slow
	60-90	0.13	1	Very Slow
E	0-30	6.43	4	Moderate
	30-60	1.51	3	Moderately Slow
	60-90	13.99	4	Moderate
F	0-30	0.31	2	Slow
	30-60	0.25	1	Very Slow
	60-90	0.10	1	Very Slow
	CV(%)	126.69%.		

Table 4: Laboratory estimated field capacity compared with field values concerning depth.

		Gravimetric water content (%)						60cm tension vol. water content (%)
Site	*Depth (cm)*	*1*	*% D*	*2*	*% D*	*3*	*% D*	*L M*
A	0-30	18	33	15	60	13	85	24
	30-60	19	16	17	29	15	41	22
	60-90	20	40	20	40	18	56	28
B	0-30	18	39	14	64	13	92	25
	30-60	19	27	15	60	14	85	26
	60-90	21	33	17	53	16	75	28
C	0-30	16	44	14	64	13	77	23
	30-60	17	53	15	73	14	85	26
	60-90	19	53	17	71	17	71	29
D	0-30	18	17	14	50	15	40	21
	30-60	17	47	15	67	15	67	25
	60-90	16	44	16	44	16	44	23
E	0-30	15	06	13	23	11	45	16
	30-60	12	50	12	50	12	50	18
	60-90	13	100	13	100	12	116	26
F	0-30	22	14	19	32	19	32	25
	30-60	17	18	16	25	15	33	20
	60-90	19	42	19	42	18	50	27
	CV(%)	14.5	56.4	14.2	37.3	15.3	37.1	

FM = Field method LM = Laboratory method %D = Percentage deviation.

Table 5: Correlation coefficients for the linear relationships between field capacity and soil properties.

Variables	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y	-0.493*	0.529*	0.192	-0.188	0.611**	-0.142	0.807**	-0.601**	-0.196	-0.096

Y = water content at 0.06 bar [Field capacity], X1 = Coarse sand, X2 = Fine sand, X3 = Silt, X4 = Clay, X5 = Total porosity, X6 = Macro-porosity, X7 = Micro-porosity, X8 = Bulk density, X9 = Organic carbon and X10 = Hydraulic conductivity. *Significant at $p<0.05$ ** Significant at $p<0.01$

fine sand [X_2].The FC correlated positively [$p<0.01$] with each of total porosity [r = 0.611] and micro-porosity [r=0.807] but negatively [$p<0.01$] with bulk density [r = -0.601]. There was a poor correlation between FC and silt, clay, macro-porosity, organic matter, and hydraulic conductivity, with r being 0.192, -0.188, -0.142, -0.196 and –0.096 respectively.

This point-based pedotransfer function, calibrated for water content at field capacity, was successfully tested. Hence, the results indicate that this point based PTF can be used to model field capacity water content. The use of this kind of PTF in estimating field capacity water content is valuable in developing countries where soil data of adequate quality and reasonable quantity is critically essential for sustainable management

3.3. Soil properties influencing FC of the studied soils.

The moisture content at FC [estimated in the laboratory] mainly depends on soil texture and structure, especially the sand fraction and pore size distribution. Bulk density also correlated significantly with moisture content at FC.

The correlation between moisture retention and sand fraction at 60cm tension was significant because the soil structure was most effective within a textural class. In strongly structured soils, any observed textural differences would be considered less critical. Also, the poor correlation observed between silt, clay and moisture retention could be attributed to the fact that moisture retention would increase with silt content and decrease with clay content (Mbagwu, 1989). Nevertheless, in this study, the silt content was low across the locations with corresponding higher clay content. Hence, poor correlations obtained. So, in soils where there is relatively high silt content, the possibility of this high silt content correlating significantly with moisture retention values is there.

Pore size distribution played a role in moisture retention at 0.06 bar. Salter and William (1965) also reported that structure had a more significant effect on the quantity of water held at low tension than at high tension. Macro-aggregates will only influence moisture release characteristics at low tension, but micro-aggregates exert dominant influence at high tension. At high tension, all the inter-aggregate water controlled by the larger pores had been drained from the samples; hence macro-porosity was not significant as a moisture retention factor within 0.06 bar. Also, large pores retained little water, and more air at low tension explains why macro-porosity was not significantly correlated with moisture content (Petersen *et al.,* 1968).

The bulk densities of the studied soils played a major role in the soil's moisture content, but SOM did not. Petersen *et al.* (1968) noted that the most significant bulk density effect on soil water was on moisture content at FC. This is because, at very high bulk density, water penetration into the soil is hindered due to compaction, hence the moisture retained. The organic matter did not influence the moisture content of the studied soil. Even though, in other literature, SOM had a high influence on moisture content (Rawls *et al.* 2003, Klute, 1986). This is probably because of their very low values in the studied soils. Therefore, if the level of organic matter in the studied soils would be increased, it might improve the soil's water retention capacity as the ability of SOM to form stable micro-aggregates that approximates the size of coarse will be harnessed.

3.4. Simple regression equations relating FC at 60cm tension with significantly correlated soil properties

These regression equations were obtained from the correlation FC results at 60 cm tension and the studied soil properties. The FC was then regressed on only significantly correlated soil properties. The regression equations are as follows:

$$Y = 35.716 - 0.255X_1 \qquad [2]$$

$$Y = 18.852 + 0.187X_2 \qquad [3]$$

$$Y = 1.575 + 0.460X_5 \qquad [4]$$

$$Y = 0.538 + 0.645X_7 \qquad [5]$$

$$Y = 50.472 - 17.030X_8 \qquad [6]$$

where: X_1 = Coarse sand, X_2 = Fine sand, X_5 = Total porosity, X_7 = Micro-porosity, X_8 = Bulk density

From the above regression equation, it could be deduced that as coarse sand increases, moisture content at field capacity reduce but increases with fine sand. Field capacity increased with an increase in total porosity. This also explains the macro-porosity effect on moisture contents since the total porosity comprises micro and macro- porosity. Micro-porosity also significantly influences moisture content such that field capacity increases with an increase in moisture content. This is because more water and less air were retained at the micro-porosity level. As O'Geen et al. (2010) discussed, the mechanism of flow by the force of gravity occurs mainly in macropores. As the soil dries, field capacity is reached after free drainage of macropores has occurred. Field capacity represents the soil water content retained against the force of gravity by matric forces (in micropores and mesopores) at a tension of -0.033 MPa. As water content decreases, soil matric potential decreases, becoming more negative. As a result, water is held more firmly to mineral surfaces due to cohesive forces between water molecules and adhesive forces associated with water and mineral particles (capillary forces). Bulk density decreased with an increase in field capacity because as bulk density decreases, the ability of the water to penetrate the soil will reduce, hence influencing the amount of water retained.

3.5. The predictabilities of the regression models

Table 6 shows a summary of the regression parameter for estimating the reliability of the regression models. The coefficient of determination [r^2] was generally low with the corresponding high standard error of estimation. This means that in the prediction of FC using determined laboratory parameters, many factors will significantly influence moisture content.

The lowest value of r^2 is 24.3% at X_1, with the corresponding highest error of 3.167. This was followed by X_5 [r^2 = 28.0%, S.E = 3.089]. This is because coarse-textured soil drains water more rapidly than fine-textured soil. Thus the low value of r^2 at X_1 could be attributed to texture. Total porosity had a lower value of r^2 [37.3%, S.E = 2.882] than micro-porosity, which had the highest r^2 value [65.1%] and the least S.E [2.150]. This can be explained by the fact that more water was retained at micro-pores. Also, total porosity encompasses both micro-porosity and macro-porosity. Because the macro-porosity was not significant, its low value influenced moisture retained at 60cm tension, affecting the r^2 value. The FC decreased as bulk density increased with an r^2 value of 32.3% and an S.E value of 2.909. The predictability of field capacity as a factor influenced by bulk density largely depends on its value.

The result obtained generally agrees with the works of Lal (1978), Botula *et al.* (2013), Zacharias and Wessolek (2007). They suggested excluding OM or OC as a predictor in PTFs with a proposal of using only physical properties such as soil texture, structure, and BD. Though, Vereecken *et al.* (2010), Nemes *et al.* (2003), and Weynants *et al.* (2009) observed that including OM or OC as a predictor in "temperate" PTFs improved predictions. This can be explained by the substantial amount of OC found in the temperate areas compared to the low content in tropical soils due to the rapid decomposition rate under high temperatures and abundant rainfall. Therefore, OM or OC is not an essential variable in estimating water retention for soils in the tropics. PTFs, according to Van Looy et al. (2017), connect easy-to-measure soil properties to less-accessible Earth system process parameters. PTFs are developed based on basic textural and structural properties to capture the biogeochemical processes context (this sums the four groups of parameterization dealt with: hydraulic, solute, thermal fluxes, and biogeochemical processes).

Table 6: Statistical parameters for testing the reliability of the models.

Dependent Variable [Y]	**Independent Variable [X]**	**P**	**R**	**r^2[%]**	**Adjusted r^2[%]**	**S. E**
	X_1	<0.05	-0.493	24.3	19.6	3.167
Y	X_2	<0.05	0.0529	28.0	23.5	3.089
	X_5	<0.01	0.611	37.3	33.4	2.882
	X_7	<0.01	0.807	65.1	62.9	2.150
	X_8	<0.01	-0.601	36.1	32.2	2.909

p = probability level at which the independent variables were significant. r = correlation coefficient r2 [%] = Coefficient of determination S.E = Standard error of estimation.

4.0. Conclusions

Three locations were studied to predict field capacity using both laboratory and field methods. Some soil properties were ascertained: bulk density, pore size distribution, particle size distribution, organic matter content and hydraulic conductivity. The soils were of the soil classification called ultisol, and the dominant textural class was loamy sand with sand as the least. Using 60cm tension as the field capacity and 15bar tension as the permanent wilting point measured in the laboratory, it was found that there was slight variation between laboratory and field estimated field capacity; clay and organic matter influenced these differences. The influence of organic matter on the field capacity appeared to be small.

Field capacity correlated with some of the measured soil properties, which included: coarse sand, fine sand, total porosity, micro-porosity and bulk density. So in predicting the field capacity of the soils of the studied area, these parameters should be considered. Also, if the organic matter of the studied area is improved, it will improve the soil's ability to retain water at field capacity.

In predicting the field capacity of the studied locations, laboratory-measured field capacity at -6 KPa matric potential was more significant than measured in the field. Laboratory estimated field capacity values varied least with field-determined field capacity on the first day of determination. Thus field capacity should be determined about twenty-four hours following soil saturation. Structure and texture influenced the prediction of field capacity. Bulk density mainly exerted a significant influence on-field capacity. Hence more research will be needed to determine the exact relationships between field capacity [measured both in the laboratory and in the field] on the one hand and soil properties [physical and chemical] on the other hand.

This point-based pedotransfer model variant can be used as a modest alternative to more classical, equation-based PTFs due to the water retention estimation's correctness. This kind of PTF in estimating field capacity water content is valuable in developing countries where soil data of adequate quality and reasonable quantity is critically essential for sustainable land management.

By providing prediction models for water content at FC, this work sets the stage for a quick and accurate determination of field capacity water content. It provides the opportunity to generate large datasets that can produce a new generation of high-resolution maps of FC water content, given that soil attribute is key to sustainable land management.

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