

VARIABILITY IN PHYSICAL, CHEMICAL AND HYDRAULIC PROPERTIES OF AGRICULTURAL SOIL IN SOUTHWEST NIGERIA

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ABSTRACT

The properties of soil play significant roles in soil productivity. The study aimed at determining the variability in physical, chemical and hydraulic properties of agricultural soils and their implications for crop production in seven farmlands in the Southwest Nigeria. Textural class, bulk density at 0-30 and 30-60 cm, hydraulic conductivity, water repellency and contact angle were determined using standard techniques. The farmlands were predominantly sandy loam soil. Bulk density ranged from 1.14 g cm⁻³ in the upper 30 cm at Oyo to 1.53 g cm⁻³ in the lower 30-60 cm at Mokore. Organic matter ranged from 0.74 % in 30-60 cm at Mokore to 3.62 % in 0-30 cm at Oyo. Hydraulic conductivity was higher in the upper 30 cm of the soil than the lower layer. This implies that the soil in the area is well drained and water logging during rainy season will be minimal. Contact angles for sandy loam soil ranged from 20.8 to 72.2°. Repellency index ranged from 1.07 for NIHORT to 3.27 for Ijebu-Igbo. Most of the soils in the area were hydrophobic and had high sub-critical repellency for water. There was strong correlation between contact angle and repellency index ($r^2 = 0.98$, $p < 0.0001$), weak correlation between contact angle and organic matter ($r^2 = 0.14$, $p = 0.18$). Sustainable engineering measures and agronomic practices will be required to ensure optimum use of land resources in the areas.

Keywords: Soil property, sorptivity, repellency index, amelioration, crop,

INTRODUCTION

Physical, chemical and hydraulic properties of soil vary under different tillage systems, agronomic practices, types of fertilizer and rates of applications. Soil's physical properties are affected by depth, spatial variability of aggregates across the field and changes in climate (Swarowsky *et al.*, 2011). Soil physical properties such as soil structure, and soil texture differ from one soil to the other and these properties influence the movement and storage of

water through the soil (Haws *et al.*, 2004; Gupta *et al.*, 2006). Gerke and Kohne (2002) reported that hydraulic properties of soil can differ in many parts of soil aggregates and along landscape. Pires *et al.* (2008) and Alaoui *et al.* (2011) reported that pore structures and interstices affect hydraulic properties such as water retention and movement of water through the soil. The pore structures in the soil can be modified by tillage and cultivation practices (Dal Ferro-N, 2014). Compaction

of soil aggregates characterized with increased contribution of finer pores could reduce infiltration of water for roots growth and elongation. This is caused by the presence of more negative pore water pressures (Horn and Smucker, 2005). High pH above 6.5 reduces water repellency of some soils (Bayer and Schaumann, 2007).

Hydraulic properties of soil, such as infiltration and sorptivity, are crucial in modelling water and nutrient flow and for explaining physical characteristics of soils and their management for crop cultivation (Green *et al.*, 2003). Compaction of soil increased contact points or forces among soil aggregates, and is responsible for strength of internal aggregates and their stability and lower water penetration (Goebel *et al.*, 2004). Infiltration and sorptivity affect movement of water and solute in soil mass (Gerke and Kohne, 2002). Soil hydrophobicity, that is wettability and water repellency are important physical properties of soil. Wettability of soil is a measure of the ability of a soil to absorb water and can be measured using the cumulative rate of infiltration of water into unsaturated soil. Generally, hydrophilic soils are soils that are easily wetted by water (Anderson *et al.*, 1995). These properties of soil could affect soil water and production of crop and eventually hydrological cycles (Doerr and Thomas, 2000). Water repellency is a measure of resistance of soil to water. Therefore, water-repellent soils are soils that have the properties which include resistance against infiltration of water (Dekker *et al.*, 2001); lower water storage capacities and remain dry in the presence of water for weeks (Doerr and Thomas, 2000); low water retention that leads to surface runoff and overland flow and could cause widespread erosion of soils (Arbel *et al.*,

2005). Soil water repellency index is determined as the ratio of intrinsic sorptivity of ethanol to that of water in the soil. It is an index quantifying the relative decrease of water sorptivity in soil. For a hydrophilic soil, water repellency index is 1 and if greater than 1, especially greater than 1.95, the soil is termed hydrophobic (Hallett and Young, 1999). Water and ethanol are used for sorptivity test because ethanol can wet particles' surfaces completely and can be used to characterize the soil pore structure.

Under field conditions, large inter-aggregate pores in the soil are drained off first. Transport of water and solute in soil are affected by physical and hydraulic properties and angle of contact (Horn and Smucker, 2005). Many studies have shown spatial relationship between saturated and unsaturated hydraulic conductivities, sorptivity and pore-size distribution parameters, saturated and residual soil water content (Hendrayanto *et al.*, 1999; Sobieraj *et al.*, 2002; Vogelmann *et al.*, 2010). Data and information on spatial variability of soil properties will lead to better decisions that will ensure higher soil physical and water productivity for crops and sustainability of the soils and environment (Schimel *et al.*, 2000; Özgöz, 2009). Knowledge of the variability of soil properties leads to informed decisions on agricultural management practices by identifying areas where remediation and other measures are needed in order to enhance productivity and sustainability.

In Ogun-Osun River Basin, Nigeria, agricultural lands are used for cultivation of annual and perennial crops. There is scanty data and information on physical and hydraulic properties of the soil such as hydraulic conductivity, sorptivity and water repellency of predominant tropical soils in

the area. Data on hydraulic and water repellency of soil planted with different crops will provide information on impact of agricultural land use on water and solute movement under rainfed and irrigated agriculture in the area.

Therefore, the objective of this study is to determine variability of physical, chemical and hydraulic properties of soils in selected farmlands in the Southwest Nigeria and their implications for sustainable land cultivation and environmental sustainability.

MATERIALS AND METHODS

Study Area

The study was conducted in selected agricultural farms in Ogun-Osun River Basin, Southwest Nigeria, where farmers cultivate annual and perennial crops (Table 1). Moisture contents, temperatures and

electrical conductivity of the soils in the areas were measured from 0 – 60 cm at intervals of 30 cm using TEROS 12 (Metre Group, USA) after calibration. Measurements were taken in triplicates in each farmland during the dry season in November 2015, day of the year (DOY) 320-335 to minimise interference with farming activities and to ensure reliability of data on hydraulic properties. Soil moisture contents were low because the measurements were taken during dry seasons (Table 2). Soil temperatures ranged from 30 to 31.4°C and falls within the range reported for soils in Southwest Nigeria (Alabi *et al.*, 2017). The electrical conductivities ranged from 0.01 to 0.08 dS m⁻¹. It indicates that soils in the selected farmland were non-saline and that the effects of salinity on productivity of crops in the area are negligible.

TABLE 1: GEOGRAPHIC LOCATIONS OF SELECTED FARMS FOR THE STUDY OF PHYSICAL AND HYDRAULIC PROPERTIES OF SOIL IN OGUN-OSUN RIVER BASIN, NIGERIA

S/n	Location Label	Name of the farm	Predominant crop	Longitude	Latitude
1	NIHORT	National Horticultural Research Institute of Nigeria (NIHORT) in Ibadan, Oyo State	Vegetables, plantain and Maize	07 22' 37"N	03 58' 54"E
2	MOKORE	Mokore Farm Settlement, Ikire, Osun State	Cassava and cocoyam	07 21' 09"N	04 10' 59"E
3	OAUTRF	Obafemi Awolowo University Teaching and Research Farms, Ile-Ife, Osun State	Maize and cassava	07 28' 21"N	04 34' 70"E
4	IJEBU-IGBO	Olowookere Farms Ijebu-Igbo, Ogun State	Tuber crops	07 41' 32"N	03 91' 24"E
5	OKE-AWO	Oke-Awo Farm, Modakeke, Osun State,	Maize and cassava	07 17' 32"N	04 28' 10"E
6	ILESHA	School of Nursing and Midwifery orchard in Ilesha, Osun State,	Banana and oranges	07 37' 13"N	04 40' 62"E
7	OYO	Oyo State College of Education, School Farm, Oyo, Oyo State	Maize and Vegetables	07 34' 94"N	03 94' 17"E

Soil Sampling and Analysis

Physical and chemical properties

Soil samples were taken by using 50 mm internal diameter and 5 cm depth core soil sampler (Eijkelkamp, Netherlands) at intervals of 30 cm from 0 cm to 60 cm. Particle size analysis of soil was determined by using the Bouyoucus hydrometer technique (Gee and Or, 2002). Textural class names of the soil were given based on the relative contents of the percent sand, silt, and clay separates using the soil textural triangle of the soil taxonomy. Soil bulk density was determined by using core sampling method (Blake and Hartge, 1986). Soil pH was determined using Calcium Chloride (CaCl_2) and pH meter

(Hendershot *et al.*, 2008). Soil organic matter was determined by oxidising soil in $\text{K}_2\text{Cr}_2\text{O}_7$ and H_2SO_4 (Nelson and Sommers, 1982). Potential acidity was determined using phenolphthalein indicator and titrated with 0.05 N NaOH (Page *et al.*, 1989). Active acidity was inferred by pH determined in distilled water in soil:water ratio of 1:2.5 (Walkley and Black, 1947). Cation Exchangeable capacity was determined by using NH_4OAC method at pH 7. In the leachate, exchangeable Ca^{2+} and Mg^{2+} were determined using Atomic Absorption Spectrophotometer (AAS) and Na^+ and K^+ by flame photometer (Senjobi and Ogunkunle, 2010; Fasinmirin *et al.*, 2018).

TABLE 2: MOISTURE CONTENTS, ELECTRICAL CONDUCTIVITIES AND TEMPERATURE OF SOIL IN THE SELECTED FARMS

Location Label	Moisture content ($\text{m}^3 \text{m}^{-3}$)	Temperature ($^{\circ}\text{C}$)	Electrical conductivity (dS m^{-1})
0 - 30 cm			
NIHORT	$0.152 \pm 0.07^*$	30.3 ± 0.6	0.02 ± 0.50
MOKORE	0.089 ± 0.09	30.1 ± 0.3	0.01 ± 0.65
OAUTRF	0.170 ± 0.02	30.3 ± 0.2	0.08 ± 0.14
IJEBU-IGBO	0.191 ± 0.04	30.5 ± 0.5	0.02 ± 0.50
OKE- AWO	0.113 ± 0.05	31.2 ± 0.2	0.01 ± 0.50
ILESA	0.094 ± 0.04	30.8 ± 0.5	0.01 ± 0.50
OYO	0.138 ± 0.02	31.2 ± 0.6	0.02 ± 0.25
30 – 60 cm			
NIHORT	0.056 ± 0.08	30.7 ± 0.5	0.01 ± 0.43
MOKORE	0.078 ± 0.07	30.0 ± 0.6	0.01 ± 0.57
OAUTRF	0.122 ± 0.04	30.4 ± 0.3	0.01 ± 0.43
IJEBU-IGBO	0.108 ± 0.05	30.9 ± 0.4	0.03 ± 0.49
OKE- AWO	0.072 ± 0.05	31.3 ± 0.4	0.01 ± 0.43
ILESA	0.146 ± 0.03	30.2 ± 0.2	0.02 ± 0.35
OYO	0.077 ± 0.08	31.4 ± 0.3	0.01 ± 0.43

*coefficient of variation of the measured data

Hydraulic Property

Unsaturated hydraulic conductivity of soil at the two depths were measured directly on the field using minidisk tension

infiltrometer (Metre Group, USA) for 3 replicates in each location at a suction rate of 2 cm ($h = -2$ cm). The method required measuring cumulative infiltration I (cm)

with time t (s) and the data were fitted using Eqns. (1) and (2) (Zhang, 1997; Ebel *et al.*, 2012):

$$I = C_1 t + C_2 \sqrt{t} \quad (1)$$

$$C_1(h_o) = A_1 k(h_o) \quad (2)$$

where C_1 (m s^{-1}) is related to hydraulic conductivity $k(h_o)$ and C_2 ($\text{m s}^{-1/2}$) is related to soil sorptivity $s(h_o)$. The hydraulic conductivity of the soil (k) was computed using Eqn. (3)

$$k = C_1 / A \quad (3)$$

where C_1 is the slope of the curve of the cumulative infiltration vs. the square root of time, and A is a value relating the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk (van Genuchten, 1980; Decagon, 2006). A is computed using Eqn. (4):

$$A = \frac{11.65 (n^{0.1} - 1) \exp [2.95 (n - 1.9) \alpha h_o]}{(\alpha r_o)^{0.91}}, n \geq 1.9$$

(4)
where n and α are the van Genuchten parameters for the 12 textural classes obtained from Carsel and Parrish (1988). The soil, r_o is the disk radius, and h_o is the suction at the disk surface.

Water repellency index

Water repellency, (R), was determined from the sorptivities of 95% ethanol and water. The minidisc infiltrometer reservoir was filled with 95% ethanol to determine the sorptivity of ethanol and water. The measurements were taken at suction rate of 2 cm. Sorptivities of ethanol and water were determined using Eqn. (5) established for one-dimensional horizontal infiltration (Sepaskhah *et al.*, 2005; Moody *et al.*, 2009):

$$I = S_e \sqrt{t} \quad (5)$$

where,

I = cumulative infiltration (cm)

S_e = the sorptivity of ethanol or water ($\text{cm s}^{-1/2}$)

t = time (s)

Repellency index (R) of soil was determined using Eqn. (6) (Tillman *et al.*, 1989):

$$R = 1.95 \times \left(\frac{S_e}{S_w} \right) \quad (6)$$

where S_w is the sorptivity of water ($\text{cm s}^{-1/2}$)
Angle of soil-water contact was determined using Eqn. (7) (De Gryze *et al.*, 2006):

$$\theta = \arccos \left(\frac{1}{R} \right) \quad (7)$$

where θ is the angle of soil water contact and R is the index of repellency. When water infiltration into soil or the soil-water contact angle is greater than 0 but lower than 90° , the soil water repellency is termed sub-critical (Tillman *et al.*, 1989). A soil is actually water-repellent when the soil-water contact angle is greater than 90° , preventing water absorption by the soil for a period of time (Hallett *et al.*, 2001).

Statistical Analysis

Coefficients of variation of hydraulic conductivity, sorptivity, contact angle and repellency index were determined from means and standard deviations of the triplicate samples. Correlations between contact angle, organic matter and repellency index of the hydraulic properties were determined using linear regression analysis in Sigma Plot 12 at $\alpha = 0.05$.

3. RESULTS AND DISCUSSION

3.1 Physical and chemical properties

There were wide variations in the particle size compositions of collected soil samples. All soil samples except the upper 30 cm for OAUTRF were characterized by high sand

content of greater than or equal to 57% (Table 3). At OAUTRF, 30-60 cm had the lowest sand contents while the others were well over 65% for 30-60 cm. Soils in OKE-AWO and OAUTRF at 00-30 cm had the highest clay contents with over 22%, while soils in OKE-AWO at 30-60 cm and 00-30 cm at OAUTRF were also high in clay contents in the subsurface soil horizon. Aborishade *et al.* (2008) reported similar observation that soil in South West of Nigeria is characterized by a relatively low level of clay content. Agricultural soils in the area will not impede soil water movement and redistribution because the clay contents were below 40%, which is the maximum threshold for adequate water infiltration (Soil Science Division Staff, 2017).

The high sand contents of the soils with annual rainfall of about 2000 mm suggests that the finer particles in the soils may have been eroded with sediment deposited in water channels. The particle size distribution also shows that in the upper 30 cm, 71% of the soils are sandy loam while 29% are sandy clay loam. In the lower 30 – 60, 85% were sandy loam while 15% were sandy clay loam. NIHORT, OAUTRF and OKE-AWO had the highest dispersible clay (DC) of 15% at the lower 30-60 cm while at upper 30 cm, the DC was less than 15%. This indicates that denser soil particles are in the top soil in the area and that appropriate tillage systems need to be put in place to break soil clogs and ensure productive cultivation of land in the area.

The bulk densities in the soil profiles showed minimal differences because the coefficient of variation was 10.5% in the upper 30 cm, while in the lower 30 – 60 cm, it was 8%. MOKORE had the highest bulk density of 1.53 g m^{-3} at 30-60 cm. There is

adequate root-soil contact and water retention for the agricultural land because the bulk density is within $0.9 - 1.2 \text{ Mg m}^{-3}$ (Reynolds *et al.*, 2003). Although a bulk density of about 1.6 g cm^{-3} is considered to be a threshold for an impaired soil, however, with bulk density higher than 1.2 g cm^{-3} , there is tendency for impediment of root elongation and reduction of soil aeration (Reynolds *et al.*, 2003). Deep-rooted tuber crops such as cocoyam, yam, and cassava are cultivated in the area. Therefore, soil productivity could be improved with effective tillage technique to ensure proper aeration and water infiltration in the soil.

The organic matter at 0-30 cm in NIHORT, OAUTRF and OYO were more than 3%, whereas the 0-30 cm at NIHORT had the highest with around 6.5% and the smallest at 30-60 cm at MOKORE in the two horizons. Generally, organic matters in the top soil were higher than those of the sub-surface and this could be attributed to accumulation of litters and residues over years in the areas. NIHORT had the lowest pH of 4.6 at 0-30 cm, which shows that the soil is acidic, and could only support crops that require relatively acidic soil. High annual rainfall of 2014 mm in NIHORT, Ibadan in 2015 could have induced leaching of basic cations leading to the reduction in the soil pH. The low soil pH could affect productivity of crops in the area. Therefore, there will be a need for soil amelioration in the area in order to improve crop yields and use the land for sustainable farming activities.

TABLE 3: PHYSICAL AND CHEMICAL PROPERTIES OF SOIL SAMPLED AT 0 -30 CM AND 30 – 60 CM DEPTH

Location Code	Particle size distribution			Textural Classification	BD (g cm ⁻³)	OM (%)	AA (c molkg ⁻¹	PA (c mol kg ⁻¹)	CEC at PH of 7 (c mol kg ⁻¹)	BS (%)	DC (%)	pH	Al3 ⁺ (c mol kg ⁻¹)	Dissolved cations (c mol kg ⁻¹)		
	Sand (%)	Clay (%)	Silt (%)											Ca ²⁺	Mg ²⁺	K ⁺
0 – 30																
NIHORT	67	16	17	Sandy Loam	1.29	6.5	0.3	0.20	5.06	90.12	9	4.6	4.39	2.9	0.84	0.58
MOKORE	81	13	6	Sandy loam	1.51	2.75	0.2	0.50	3.47	79.83	5	8.2	18.05	2.1	0.34	0.13
OAUTRF	49	24	27	Sandy Clay Loam	1.16	4.03	0.1	0.30	7.33	94.54	9	7.3	4.33	6.1	0.41	0.21
IJEBU- IGBO	66	13	21	Sandy Loam	1.28	2.15	0.3	0.40	10.13	96.05	8	8.0	4.11	8.5	0.61	0.36
OKE-AWO	57	28	15	Sandy Clay Loam	1.31	1.34	0.1	0.20	6.37	95.60	15	7.6	3.29	5.2	0.44	0.25
ILESA	72	11	17	Sandy Loam	1.45	0.87	0.2	0.20	2.79	84.43	6	7.1	8.37	1.8	0.30	0.15
OYO	70	16	14	Sandy Loam	1.14	3.62	0.5	0.20	3.65	80.82	7	6.8	6.78	2.3	0.35	0.14
30 – 60																
NIHORT	67	18	15	Sandy loam	1.46	1.21	0.2	0.30	2.83	82.33	15	6.8	12.88	1.8	0.26	0.11
MOKORE	65	22	13	Sandy loam	1.53	0.74	0.7	0.35	4.12	75.73	1	7.9	11.22	2.1	0.54	0.24
OAUTRF	37	31	32	Clay loam	1.17	2.82	0.6	0.30	6.54	86.24	15	7.3	5.32	5.0	0.32	0.11
IJEBU- IGBO	73	12	15	Sandy Loam	1.43	2.01	0.1	0.20	10.18	97.05	4	8.3	2.02	8.6	0.65	0.40
OKE-AWO	66	27	7	Sandy Clay Loam	1.47	1.74	0.2	0.5	6.48	89.20	1	8.1	8.65	4.5	0.66	0.42
ILESA	74	14	12	Sandy Loam	1.50	0.87	0.1	0.30	3.10	87.10	1	7.6	11.11	2.1	0.31	0.15
OYO	74	15	21	Sandy Loam	1.38	2.08	0.1	0.10	4.78	90.41	3	6.8	2.23	3.6	0.45	0.27

TC- Textural classification, BD- Bulk density, OM- Organic matter, AA- Active acidity, PA- Potential acidity, BS- Base saturation, DC- Dispersible clay, The first and second set of values for each location represents data for 0-30 and 30-60 cm respectively.

IJEBU-IGBO had the highest soil pH of 8.3 at 30-60 cm and indicates slightly alkaline soils which have better natural fertility and low aluminium saturation. The lower aluminium saturations were due to their high pH because pH is inversely proportional to aluminium saturation. However, the trend is reversed at MOKORE at 00-30 and 30-60 cm. The CEC at pH 7.0 vary from 2.79 to 10.73 cmol kg⁻¹, a low to very low range (Adepetu *et al.*, 2014). Samples with higher CEC were found having high levels of organic matter and pH. Therefore, addition of organic materials as soil amendment is necessary to boost the CEC and productivity of these soils. The CEC at pH 7 was higher mostly in the 30-60 than 0-30 cm, an indication of the importance of clay to CEC in these soils. The base saturation ranges from 76% to 97% demonstrating a small variation of this feature in the sampled soils. The lower 30-60 cm had the least CEC except for IJEBU-IGBO, ILESA, and OYO. In the study areas, higher base saturations were associated with very high pH and low Al³⁺ saturation. MOKORE had the highest active acidity of with 0.65 cmol kg⁻¹, at 30-60 cm. This could be attributed to cultivation of cassava and cocoyam in the area. IJEBU-IGBO and ILESA at 30-60 cm, OAUTRF and OKE-AWO at 00-30 cm had the lowest active acidities of 0.1 Cmol kg⁻¹. There was little variation in the potential acidity in the horizons in the study area. OKE-AWO had the highest of 0.5 cmol kg⁻¹ while few other agricultural soils had 0.2 cmol kg⁻¹, which was the lowest. This shows that potential acidity is relatively higher in horizons with high Al³⁺ saturation. Exchangeable cations such as Ca⁺ were

higher compared with Mg⁺, K⁺ and Na⁺. This means that dissolved cations are higher in the subsurface horizon compared to the top surface, an evidence of rainfall induced leaching of soil in the area. Deep-rooted crops such as root and tubers could utilize this. Therefore, this allows for higher productivity of root and tuber crops in the area.

3.2 Hydraulic conductivity, sorptivity, repellency, and angle of contact

Sorptivity of water ranged from 0.0033 for upper 30 cm at NIHORT to 0.060 for 30-60 cm at MOKORE. Similarly, sorptivity for ethanol ranged from 0.033 for 30-60 cm at Ijebu-Igbo to 0.2715 for 0-30 cm at OYO (Table 4). Soil repellency index ranged from 1.07 (Sandy loam) in NIHORT to 3.74 (Sandy clay loam) at OKE-AWO in the upper 30 cm. A wide range of repellency indices in this study testifies to the effects of land use on wettability and formation of soil aggregates in area. Soils in most of the studied area were hydrophobic with $R > 1.95$ and this means that they are not easily wetted by water (Table 3). High repellency index could be attributed to agronomic and management systems such as crop rotations, manuring, fertilization and zero tillage because these practices could induce high sub-critical water repellency in soils (Jarvis *et al.*, 2008). Hydrophobicity of the soil decreased with increasing depths except for NIHORT at 30-60 cm whose repellency index was higher. This suggests the influence of high organic matters in all the soil considered. Doerr *et al.* (2006) and Vogelmann *et al.* (2010) reported a similar situation in which the decrease in water

TABLE 4: HYDRAULIC CHARACTERISTICS OF THE SELECTED AGRICULTURAL SOILS IN THE SOUTHWEST, NIGERIA

Location of sample	Hydraulic conductivity (cm s ⁻¹)	Sorptivity of water, S_w (cm s ⁻¹)	Sorptivity of ethanol, S_e (cm s ⁻¹)	Repellency index (R)	Contact angle, Θ (degree)
0 – 30 cm					
NIHORT	0.0033	0.2983±0.103*	0.1638±0.032	1.0707±0.01	20.83±0.02
MOKORE	0.0022	0.1600±0.076	0.1043±0.087	1.2711±0.01	38.12±0.02
OAUTRF	0.0004	0.1539±0.068	0.1068±0.077	1.3532±0.01	42.35±0.02
IJEBU-IGBO	0.0004	0.1063±0.075	0.1783±0.031	3.2707±0.02	72.20±0.02
OKE-AWO	0.0012	0.0297±1.263	0.0570±0.137	3.7424±0.02	74.50±0.01
ILESA	0.0024	0.1483±0.034	0.1541±0.068	2.0263±0.01	60.43±0.01
OYO	0.0031	0.1931±0.018	0.2715±0.073	2.7417±0.01	68.61±0.01
30 – 60 cm					
NIHORT	0.0017	0.2024±0.094	0.1326±0.073	1.2770±0.01	38.46±0.02
MOKORE	0.0004	0.0600±0.038	0.0360±0.041	1.1700±0.01	31.27±0.02
OAUTRF	0.0006	0.1104±0.153	0.0390±0.075	1.2681±0.01	37.95±0.02
IJEBU-IGBO	0.0009	0.1148±0.070	0.0332±0.052	2.8134±0.02	69.18±0.02
OKE-AWO	0.0003	0.2382±0.054	0.0462±0.179	3.1821±0.01	71.68±0.01
ILESA	0.0023	0.1429±0.073	0.1170±0.029	1.5966±0.01	51.22±0.02
OYO	0.0021	0.4164±0.115	0.2632±0.047	1.2326±0.01	35.78±0.05

*Coefficient of variation of the measured data

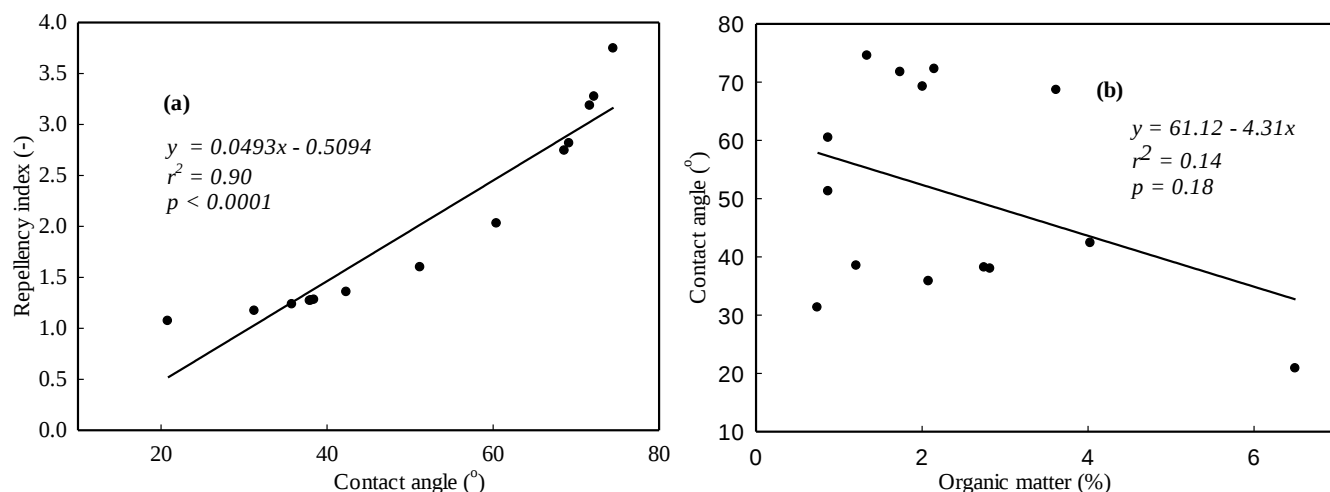


FIGURE 1: Relationships of the contact angle with (a) repellency index, (b) organic matter for soils in selected agricultural farms in Southwest Nigeria

repellency with increased soil depth was caused by the decrease in organic matter contents (OMC) down the soil profile. Generally, water repellency was more pronounced in soils with higher organic matter content, except for ILESA at 0-30 and 30-60 cm, which had low organic matter contents and higher repellency index. Our findings are in agreement with Wallis and Horne (1992) who reported that severity of repellency in soil is related to the quantity of organic matter present. However, increased soil water repellency with higher soil organic matter was reported in García-Moreno *et al.* (2013). However, sandy soil has extreme water repellence due to the low specific surface area of soils and the ease of coating of sand by hydrophobic substances. De Gryze *et al.* (2006) reported that smaller fractions of the sandy soil showed the highest degree of repellency and this is attributed to higher organic carbon contents in the soil. However, OKE-AWO has slightly high repellency indices down to 60 cm because of their high clay contents. The hydraulic conductivities also show that some samples have higher conductivity at 30 – 60 cm relative to 0 – 30 cm. For example, samples at 30 – 60 cm at OAUTRF and IJEBU-IGBO.

Hydraulic conductivity decreases down the soil profile except for OAUTRF and IJEBU-IGBO that are characterised by clay loam and sandy loam respectively at 30-60 cm. Our finding is similar to Sepehrnia *et al.* (2017). Sorptivity for water also reduced down the soil profile except for IJEBU-IGBO and OYO that were characterized by sandy loam in the two horizons. Similarly, Sorptivity of ethanol decreased down the group without any exception for all the

horizons. Repellency index reduced down the soil profile except for NIHORT. This is similar to the results earlier reported by Sepehrnia *et al.* (2017). Sandy clay loam mostly found in OKE-AWO had the highest contact angle. Contact angle and hydro repellency were significantly related (Fig. 1a). This could be attributed to higher proportion of sand, which had been observed to enhance water repellency compared to clay (Bachmann *et al.*, 2000). Generally, the higher the decomposed organic substance in soils, the greater the contact angle (Ellerbrock *et al.*, 2005). However, in this study, there was weak correlation between contact angle and organic matter (Fig. 1b). The relatively lower sand and clay contents may have masked the effects of organic matter leading to the weakness in their relationship. OAUTRF had the highest organic matter experienced lower contact angle (Table 3).

4. CONCLUSIONS

Soil samples were collected at seven agricultural farms in Ogun-Osun River Basin, Nigeria. The physical, chemical and hydraulic properties of the samples were determined using standard field and laboratory methods. Lower 30-60 cm layer of the soil profile had higher bulk density. This can be attributed to series of compaction, tillage equipment and intensive land cultivation in the area. Thus, further use of this equipment requires caution and appropriate soil management practices that prevent compaction need be put in place. Upper 30 cm of the soil layers in the basin is richer in organic matter and therefore had the potentials to sustain productive farming with

minimum amelioration. Exchangeable cations were higher in the subsurface horizons than the upper soil surface. Soils in most of the agricultural land had higher repellency indices and contact angles. Therefore, they were hydrophobic and were not easily wetted by water. This could initiate high surface runoff and seasonal flooding in the areas. Therefore, efficient water drainage systems are required in the basin to prevent flooding of farmlands. Highly acidic soil in certain areas could lower water quality and soil productivity especially for crops that are sensitive to high acidity. This calls for caution in the use of fertilizer that may induce acidity and there may be need for liming. Therefore, suggested land amelioration may be required in order to improve the soil and ensure sustainable use of land in the areas.

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