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PREDICTION OF SATURATED HYDRAULIC CONDUCTIVITY USING SOIL TEXTURE AND ORGANIC CARBON UNDER DIFFERENT LAND USE TYPES

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ABSTRACT
The aim of this study is to develop models for saturated hydraulic conductivity (Ks) in soils under different land use types in a tropical environment. The regression models were developed using the soil particle size fraction and organic carbon contents.The results indicated that the sand, clay and organic carbon content of the soils were sufficient in predicting the Ks. Also, there was a significant variation in the R^2 values of the prediction models resulting from variations in the soil properties used across the land use type. Thus a separate Ks is required for each land use type. The R^2 value of the models ranged from 37 % to 100 %.
Keywords: Soil texture, saturated hydraulic conductivity, land use types, organic carbon

INTRODUCTION

Tropical soils are usually characterized with weakly developed structure, crusting, compaction (Busari and Salako, 2014) and this observation has been linked to the intensity of the soil weathering and the low organic carbon content which in most cases have resulted into low water transmission rate. Apart from the inherent weakness of soil structure, rainfall intensity or erosivity is very high in the tropics, with intensities often exceeding 75 mmh^{-1} (Salako, 2008). Water transmission rate in soil is of great importance as it controls nutrient flow and invariably affects crop growth and productivity. Saturated hydraulic conductivity (Ks) is one of the most important soil properties controlling water infiltration, surface run-off, leaching of pesticides from agricultural lands, and migration of pollutants from contaminated sites to the ground water (Fasinmirin, 2011). Saturated hydraulic conductivity (Ks) of soils as reported by Debashis *et al.* (2006) as the most variable quantity, both spatially and temporally and this makes it difficult to determine. It is usually determined in the laboratory using constant head method (Klute and Dirksen 1936). This method is labourious, time consuming and data obtained may be often highly variable. In recent times, several attempts have been made to estimate indirectly soil properties from more easily measurable and more readily available soil properties especially the routinely determined parameters such as sand, silt, clay and organic carbon content (Larson and Pierce, 1991). Models for predicting Ks using soil properties such as clay, sand, and organic content, as well as bulk density using empirical equations and multivariate regression analysis had been proposed (Brakensiek *et al.* 1984, Cosby *et al.* 1984, Saxton *et al.* 1986, Vereecken *et al.* 1990).

Also, advanced correlation techniques for predicting Ks including fuzzy logic and neural network methods have been proposed (Schaap *et al.,* 1998). This method relates Ks to soil properties such as particle size distribution, porous structure, and water retention using physical and physio-empirical relationships (Bloemen 1980, *van Genuchten* 1980; Campbell and Shiozawa 1994). The limitation of the latter method is that it requires data that are not routinely determined in the laboratory (Hipple *et al.* 2003, Tugel *et al.* 2005). Also most of these models have been developed using data obtained from temperate soils. Therefore, there is need to develop models that will relate routinely determined soil properties in the laboratory to Ks. Research on developing such models for tropical soils is rare in South western Nigeria. The aim of this experiment was to develop regression models for predicting Ks using data obtained from different soil taxonomic classes and land use types.

MATERIALS AND METHODS

The study was carried out at the Federal University of Agriculture, Abeokuta, Ogun State (Longitude 3^0 21'E and Latitude 7^0 91'N) in the Derived Savannah Zone of South-western Nigeria. The soils under four different land uses viz Fadama (lowland), Agro forestry arboretum (Gmelina), Plantain and the Oil palm plantation were used (Table 1). Two (2) profile pits were dug per land use type. The profiles were described according to Food and Agriculture Organization (FAO) guideline on profile description (FAO, 2006) and sampled according to pedogenic horizons. Collected soil samples were air dried, and sieved using a 2 mm sieve. Particle size analysis was done using the hydrometer method (Buyoucous, 1962), organic carbon was determined using the wet oxidation method (Walkley–Black, 1934), and pH was determined using standard glass electrode pH meter (McLean, 1982). Core samples were taken using standard cores (5 cm in diameter and height). The core samples were used for the determination of the saturated hydraulic conductivity and bulk density. The Ks was determined using the constant head method (Klute and Dirksen, 1936). The data generated from the soil analyses were used to classify the soil type using the guidelines of Smyth and Montgomery (1962) and USDA taxonomy (2006) and developing the models for estimating the soil Ks.The linear models was used to estimate the Ks using the soil particle size and organic carbon. The resulting equation has the form:

$$Y = \text{intercept} \pm (a\times \text{sand}) \pm (b\times \text{silt}) \pm (c\times \text{clay}) \pm (d\times \text{OC})$$

Where Y is the dependent variable and a, b, c and d are regression coefficients for sand, silt, clay, and organic carbon respectively.

RESULTS

Soil Morphological Properties

Profile pits dug at agroforestry arboretum, oil palm and plantain plantation had plinthite at 110 cm, 94 cm and 83 cm depth (Table 2) respectively while the depth of the profile pits in the fadama were restricted by high water table which was encountered at 40 cm. The A and B horizons of all the profile pits except that of fadama that was 5 YR had colour hue ranging from 10 YR to 7 YR, colour value between 2 and 6 while the colour chroma ranged from 1 to 8 (Table 2). However, the lower horizons were subjected to seasonal water fluctuation resulting in mottling that were few medium common prominent and distinct. The mottles vary in colour hue from 2.5YR to 7.5 YR, colour value between 4 and

Table 1: Description of land use locations within the permanent site of the Federal University of Agriculture, Abeokuta.

LOCATION	LAND USE
Agroforestry arboretum	Consist of tree species such as *Treculia Africana, Acacia nilotica Tectona grandis,and Gmelina arborea*, established in 1990
Plantain plantation	Planted to plantain and was established in late 2007
Fadama (lowland)	In existence for about 11years with shrubs and grasses; Also consist of vegetables, lowland rice, and pepper
Oil palm	Established in late 2007, and planted to oil palm and sometimes intercropped with maize

7 while the colour chroma was 8 (Table 2). The lower horizons (B and C) were sticky because of the high clay content compared to the A horizon. The soil structure ranged from medium crumbs to sub angular blocky.

Soil Physical and Chemical Properties

The sand contents of all the profile pits were higher at the A- horizon but decreased with increasing soil depth (Table 2). Among the land use types, the average profile sand content was highest in the oil palm plantation. The clay contents increased with depth, with horizons between 89 and 110 cm depth at oil palm, 62 and 140 cm depth at agroforestry having higher clay content than other depth (Table 2). Silt content was similar at various depths of all the profile pits across the land uses. Bulk densities increased with depth in all profile pits of the land uses having mean value ranging from 1.52 gcm^{-3} at the agroforestry to 0.95 gcm^{-3} at the fadama and was lower in the A horizons of all land use types (Table 3). The soils under oil palm plantation had higher saturated hydraulic conductivity especially at upper horizons compared to that of fadama land use type (Table 3). The Ks was found to vary with soil depth across all the profile pits and ranged from 0.76 $cmhr^{-1}$ at 83-162 cm depth plantain 2 to 23.37 $cmhr^{-1}$ at 0-8 cm depth in the oil palm plantation 1(Table 3). The organic carbon content of soils from all land uses decreased with soil depth, with the A horizons having higher organic carbon content than all the subsoil horizons. The soil pH from all land use types ranges from 5.20 to 6.80 (moderately acidic to neutral).

Soil Classification

Based on the observed morphological, physical and chemical properties of the described profile pits, soils under the fadama, agroforestry arboretum and plantain plantation were classified as Hydra aquentic Humaquept, Typic Paulestalf and Arenic Hapludalf respectively while those under the oil palm plantation were classified from as Aquic Paleustalf and Oxyicaquic Paleustalf.

The Ks estimation models

The models developed were by linear stepwise regression using SPSS and was developed for each soil type (Table 4). Some of the models developed showed that the sand content of most of the soils from the land use types did not play a significant role for Ks. This could be supported with the fact that as sand content of the soil reduces down the profile, the silt and clay content increases, and the Ks also decreases.

Table 2: Soil Physical and Morphological Properties

Profile	Horizon	Depth (cm)	Sand	Silt	Clay	Gravel	Texture	Structure	Color (moist)
OP1	A_p	0-8	83.80	7.40	8.80	11.40	LS	wfc	brownish black (10YR2/3)
OP1	A_1	40-25	83.80	7.40	8.80	12.70	LS	wfc	dark brown (10YR3/4)
OP1	A2	25-48	81.80	7.40	10.80	19.90	LS	mmc	brown (10YR4/4)
OP1	AB	48-64	81.80	3.40	14.80	44.80	LS	wfsbk	Brown (7.5 YR 4/6)
OP1	B1	64-89	71.80	3.40	24.80	76.40	SCL	wcsbk	reddish brown (7.5 YR4/8)
OP1	B2	89-160	57.80	11.40	30.80	75.70	SCL	wcsbk	reddish brown (5 YR4/8) with yellow orange common medium distinct mottles (7.5YR7/8)
OP2	AP	0-15	83.80	7.40	8.80	2.60	LS	mmg	brownish black (10YR2/3)
OP2	B1	15-37	81.80	7.40	10.80	5.40	LS	mmc	dull yellow orange (10YR6/3)
OP2	B2	37-65	75.80	9.40	14.80	14.70	LS	fwsbk	dull yellow orange (10YR6/3) with medium common distinct bright brown (7.5YR 5/8)
OP2	BC	65-94	79.80	7.40	12.80	31.30	SC	wmsbk	dull yellowish brown (10YR5/4) with medium common distinct yellowish brown (10YR5/8)
PP1	Ap	0-21	79.80	9.40	10.80	20.90	LS	mcsbk	brown (7.5 YR 4/4)
PP1	Bt1	21-44	69.80	9.40	20.80	39.20	SCL	mcsbk	brown (7.5 YR 4/6) with orange common faint mottles (7.5YR 6/8)
PP1	Bt2	44-98	71.80	7.40	20.80	64.40	SCL	mcsbk	brown (7.5 YR 4/6) with bright reddish brown (7.5YR 5/8) common medium distinct mottles
PP1	Bt3	98-170	61.80	13.40	24.80	72.20	SCL	mmsbk	brown (7.5 YR 4/6) with bright reddish brown (5YR 5/8) common medium prominent mottles
PP2	Ao	0-11	83.80	3.40	12.80	48.90	LS	wmsbk	dark brown (7.5 YR ¾)
PP2	Bt1	11-46	63.80	9.40	26.80	64.90	SCL	mmsbk	bright brown (7.5 YR5/8) with bright brown (2.5YR 5/8) few faint mottles
PP2	Bt2	46-83	61.80	9.40	28.80	60.90	SCL	mmsbk	bright reddish brown (5YR 5/8) with bright yellowish brown (10YR 6/8) common fine faint mottles
PP2	Bt3	83-162	59.80	5.40	34.80	65.50	SC	mcsbk	bright reddish brown (5YR 5/8) with (2.5YR 4/8) reddish brown common fine distinct mottles
AA1	Ao	0-20	83.80	7.40	8.80	16.20	LS	fsbk	brownish black (7.5 YR 3/2)
AA1	A1	20-49	75.80	11.40	12.80	20.90	LS	msbk	brown (7.5YR4/6)
AA1	AB	49-62	65.80	13.40	20.80	77.60	SCL	csbk	reddish brown (5YR 4/8)
AA1	B1	62-110	53.80	11.40	34.80	78.90	SCL	csbk	dark reddish brown (2.5 YR 3/4)
AA1	B2	110-140	45.80	17.40	36.80	84.10	SC	csbk	dark reddish brown (2.5 YR 3/4) with few fine (7.5 YR 4/8) mottles
AA2	Ao	0-1	85.80	7.40	6.80	15.10	LS	gc	brownish black (5YR 2/1)
AA2	A1	11-33	79.80	11.40	8.80	43.50	LS	fsbk	dark reddish brown (2.5 YR 3/4)
AA2	A2	33-48	75.80	13.40	10.80	79.30	LS	msbk	dark reddish brown (2.5 YR3/4)
AA2	AB	48-83	73.80	7.40	18.80	81.70	LS	csbk	dark red (7.5 YR ¾)
AA2	B1	83-110	63.80	9.40	26.80	89.90	SCL	csbk	dark red (7.5 YR ¾)
F1	Ap	0-9	83.80	7.40	8.80	6.0	LS	mc	brownish black (5 YR 3/1)
F1	A1	9-40	79.80	9.40	10.80	11.60	LS	msbk	dull reddish brown (5 YR3/4)
F2	Ap	0-21	83.80	9.40	6.80	19.40	LS	wmc	brownish black (5YR2/1)
F2	A1	21-56	75.80	9.40	14.80	12.60	LS	wfc	dark reddish brown (5 YR3/3) with common medium faint dull reddish brown (5YR5/3) mottles

LS=Loamy sand; SCL=Sandy clay loam; SC= Sandy clay; wfc=weak fine crumbs; mmc= moderate medium crumbs; wfsbk= weak fine sub-angular blocky; wcsbk= weak coarse sub-angular blocky; mmg= moderate medium granular; fwsbk=fine weak sub-angular blocky; wmsbk=weak medium sub-angular blocky; mcsbk=moderate coarse sub-angular blocky; mmsbk= moderate medium sub-angular blocky;gfsbk; csbk; gc;fsbk;gc; msbk

DISCUSSSION

The particle size distribution indicated that the soils of the different land use examined were predominantly sandy in the surface and sub-surface layers. The implication of this is that soils would be well drained in the surface, but may have poor water and nutrient holding capacity (Hillel, 1980). The soils reported in this study had coarse to moderate texture, and this resulted in poor soil aggregation (Salako *et al.*, 1999; Salako and Hauser, 2001).

It was also observed from the study that the bulk density increased with depth for soils from all the land use. However, it should be noted that the bulk density at the lower depth of each of the profiles was significantly higher than that obtained from upper depth. This presumably reflects decreased biological activity. It could be linked to the fact that the organic carbon content at surface soils is high, which enhances the

Table 3: Some Chemical Properties of the soils from each of the Land Use

LAND USE	DEPTH (cm)	% SAND	% SILT	% CLAY	TEXTURE	BD gcm^{-3}	Ks $cmhr^{-1}$	pH (H20)	% OC
OILPALM1	0-8	83.80	7.40	8.80	loamy sand	1.21	23.37	6.80	2.35
	40-25	83.80	7.40	8.80	loamy sand	1.37	17.74	6.20	2.11
	25-48	81.80	7.40	10.80	loamy sand	1.55	3.07	6.20	2.03
	48-64	81.80	3.40	14.80	loamy sand	1.61	10.27	5.90	0.34
	64-89	71.80	3.40	24.80	sandy clay loam	1.53	32.15	5.80	2.07
	89-110	57.80	11.40	30.80	sandy clay loam			6.40	0.34
OILPALM2	0-15	83.80	7.40	8.80	loamy sand	1.43	3.39	6.20	3.87
	15-37	81.80	7.40	10.80	loamy sand	1.37	9.34	6.20	0.34
	37-65	75.80	9.40	14.80	loamy sand	1.52	10.00	6.20	1.74
	65-94	79.80	7.40	12.80	loamy sand	1.51	7.62	5.90	1.84
Mean		78.20	7.20	14.60		1.46	13.00	6.20	1.70
Standard Deviation		8.15	2.40	7.45		0.12	9.66	0.29	1.11
AGROFORESTRY1	0-20	83.80	7.40	8.80	loamy sand	1.37	14.19	6.00	9.10
	20-49	75.80	11.40	12.80	loamy sand	1.33	4.89	6.20	6.30
	49-62	65.80	13.40	20.80	sandy clay loam	1.66	4.17	6.10	13.50
	62-110	53.80	11.40	34.80	sandy clay loam	1.62	10.49	6.20	2.30
	110-140	45.80	17.40	36.80	sandy clay	1.63	16.78	6.40	2.20
AGROFORESTRY2	0-11	85.80	7.40	6.80	loamy sand	1.17	9.10	6.70	11.80
	11-33	79.80	11.40	8.80	loamy sand	1.61	0.96	6.40	9.10
	33-48	75.80	13.40	10.80	loamy sand	1.66	5.21	6.50	7.40
	48-83	73.80	7.40	18.80	loamy sand	1.68	29.80	6.40	4.30
	83-110	63.80	9.40	26.80	sandy clay loam	1.53	5.66	6.50	10.40
Mean		70.40	11.00	18.60		1.52	10.13	6.34	1.87
Standard Deviation		13.00	3.24	11.01		0.20	0.21	0.21	1.29
FADAMA1	0-9	83.80	7.40	8.80	loamy sand	1.30	0.87	5.90	2.89
	9-40	79.80	9.40	10.80	loamy sand	1.35	2.51	5.70	1.94
FADAMA2	0-21	83.80	9.40	6.80	loamy sand	0	7.96	5.50	2.73
	21-56	75.80	9.40	14.80	loamy sand	1.14	9.40	6.40	2.27
Mean		80.80	8.90	10.30		0.95	5.19	5.88	2.46
Standard Deviation		3.83	1.00	3.42		0.64	4.13	0.39	0.43
PLANTAIN 1	0- 21	79.80	9.40	10.80	loamy sand	1.22	2.68	5.30	3.83
	21-44	69.80	9.40	20.80	sandy clay loam	1.57	2.00	5.30	2.01
	44-96	71.80	7.40	20.80	sandy clay loam	1.53	2.48	5.50	2.01
	96-170	61.80	13.40	24.80	sandy clay loam	1.51	8.24	5.20	1.92
PLANTAIN 2	0-11	83.80	3.40	12.80	loamy sand	1.25	2.48	5.90	3.07
	11-46	63.80	9.40	26.80	sandy clay loam	1.25	8.62	5.50	0.22
	46-83	61.80	9.40	28.80	sandy clay loam	1.67	2.48	5.80	2.03
	83-162	59.80	5.40	34.80	sandy clay	1.54	0.76	5.90	1.84
Mean		69.05	8.40	22.55		1.44	3.72	5.55	2.12
Standard Deviation		8.94	3.02	8.03		0.17	2.97	0.28	1.04
Mean		73.80	8.90	17.30		1.41	8.67	6.03	3.76
Standard Deviation		10.49	3.05	9.13		0.31	8.03	0.41	3.48

Table 4: Pedotransfer models for soil from all the land use types

Land Use Type	Taxonomy	Steps	Regression Equation	R^2	Parameter Removed
Oil Palm	Aquic paleustalf	1	Ks = 22.087 - 2.521 sand + 0.286 clay + 2.100 organic carbon	40%	Silt
Oil palm	Oxyic paleustalf	1	Ks = 0.677 + 0.830 silt + 0.282 clay – 1.526 organic carbon	100%	Sand
Agroforestry	Typic paleustalf	1	Ks = 42.810 – 2.820 silt + 0.422 clay – 5.079 organic carbon	59%	Sand
		2	Ks = 41.885 – 2.042 silt – 4.966 organic carbon	37%	Sand, Clay
Fadama	Hydraaquentic Humaquept	1	Ks = -76.186 + 5.216 silt + 0.802 clay + 10.854 Organic Carbon	100%	Sand
Plantain plantation	Arenic haplustalf	1	Ks = 8.986 + 0.503 silt – 0.202 clay – 2.331 organic carbon	72%	Sand
		2	Ks = 1.878 + 0.524 silt – 1.211 organic carbon	57%	Sand, Clay
		3	Ks = - 1.509 + 0.622 silt	40%	Sand, Clay & Organic Carbon

K_s- Saturated Hydraulic Conductivity

Table 5: Regression Model for all the classified soil

Model	Regression equation	R^2	Parameter removed
1	Ks = 4.872 + 0.053 silt + 0.208 clay – 0.096 organic carbon	9%	Sand
2	Ks = 4.598 + 0.053 silt + 0.213 clay	9%	Sand, Organic Carbon
3	Ks = 7.923 + 0.49 silt	4%	Sand, Organic Carbon & Clay
4	Ks = 9.618	0%	Sand, Organic Carbon, Clay & Silt

aggregate stability and thus the soil particles were well arranged and could still be further influenced by the high content of organic carbon in such soils as compared to others, as organic carbon enhances aggregate stability as reported by Caravaca *et al.*, 2004; Pinheiro *et al.,* 2004.

The saturated hydraulic conductivity of the soil of the oil palm plantation was significantly higher than other land uses especially that of fadama soils which shows very low ease of flow of water. Also, the saturated hydraulic conductivity decreased with depth but this differs from what was observed in fadama soils as it increased with depth. The reason for this was the low activity clay present in the soil (Oosterbaan and Nijland, 1994) and that the area is water logged.

The parameters used for the development of the regression models have been found to be largely interdependent such as the silt, sand, clay, and organic carbon; this is because they play significant role in the ease of flow of water and aggregate stability. This is as a result of the inverse relationship between the particle size classes. From the model developed for Oxyaquic Paleustalf, it could be observed that the coefficient of determination (R2) did not change. This implies that the Ks such soil largely depends on silt, clay and organic carbon. In addition to this, the coefficient of determination for hydraaquentic humaquept remained at 100 %, an indication that the silt and clay fraction of the soil played a significant role in the ease of flow of water. The model also reflected that a universal Ks cannot be developed for all the land use types in this study as the coefficient of determination was 0 %, thus suggesting that regression model for predicting Ks should be based on soil type.

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