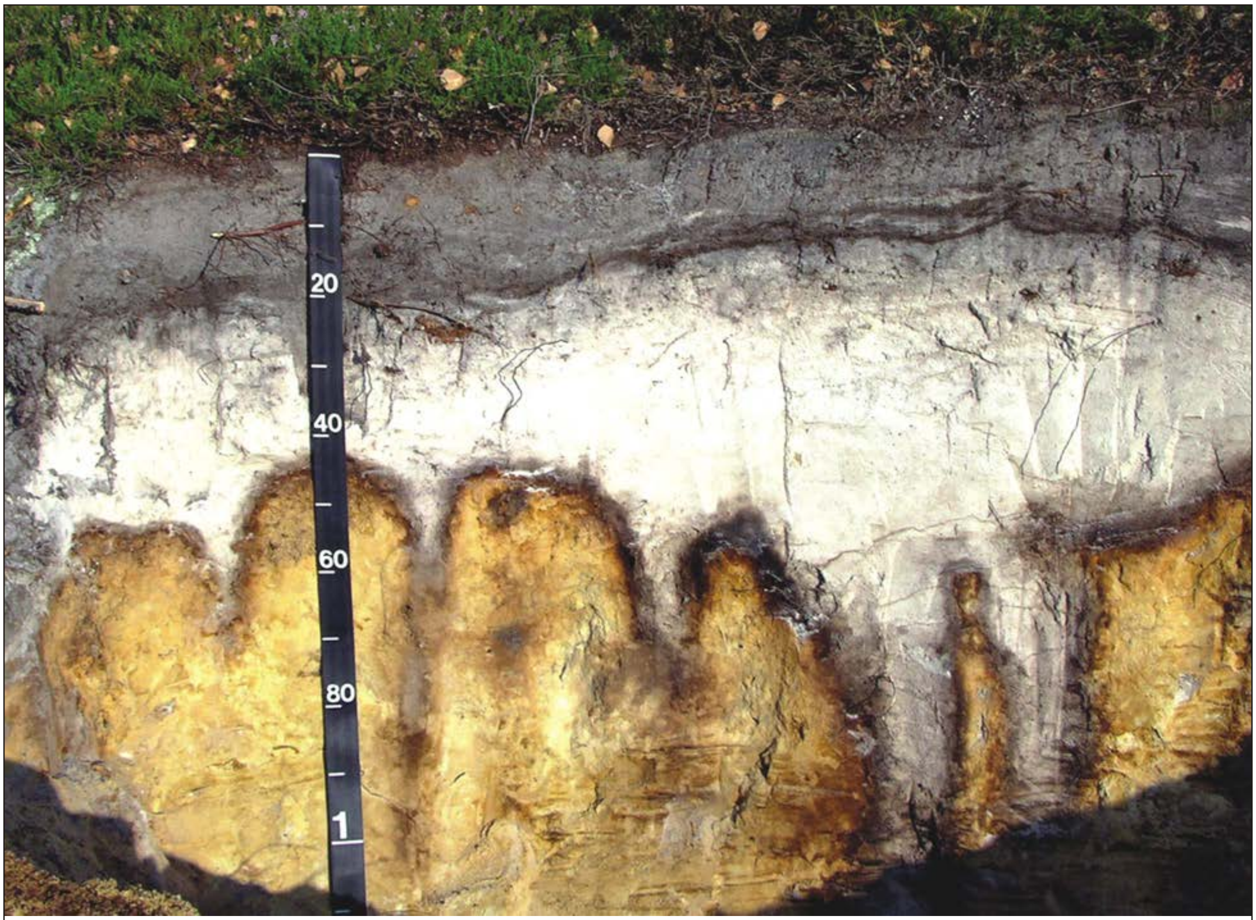

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Soil Wettability Characteristics of a Forested Catena in Relation to Organic Matter Fractions

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Abstract: This study was conducted from September 2005 and February 2006 to investigate wettability properties of soils on a catena in the humid tropics. A transect technique was used to align pedons on three identifiable forested physiographic positions. Soils were classified as Typic Paleustult/Dystric Nitisols. Soil samples were used to determine Soil Organic Matter (SOM), water [SOM (W)] and sodium pyrophosphate [SOM (PY)] soluble SOM fractions. Hydrophobic (A) and hydrophilic (B) functional groups of bulk soil SOM and soluble fractions were assessed with Fourier-Transform Infrared (FT-IR) spectroscopy. Soil wettability increased when Soil Organic Carbon (SOC) contents were less than 14 g kg^{-1} while it decreased for SOC contents greater than 14 g kg^{-1}. The Contact Angle (CA) of footslope soil was largest at Bt_3 horizon but with smallest SOC (1.6 g kg^{-1}) content.

Key words: Catena, repellency, soil organic matter forms, soil moisture, humid tropics

INTRODUCTION

Knowledge of soil-water content is critical for the determination of local energy and water balance, transport of applied chemicals to plants and ground water, irrigation management and precision farming (Seyfried and Murdock, 2004). The aqueous wetting of soil solids is a precondition for processes of flow, transport and cation exchange in the soil milieu (Ermakova *et al*., 2001). But low levels of water repellency have been observed in many soils (Hallett *et al*., 2001) and though water appears to infiltrate in soils it has been postulated that slight and significant reduction in infiltration rates can cause an increase in soil aggregate stability and heterogeneity of overland flow and infiltration at field scale (Hallett *et al*., 2004; Lamparter *et al*., 2006).

The physicochemical nature of soils are profoundly determined by soil organic matter and clay minerals (Stevenson, 1994; Eynard *et al*., 2006) and these factors also influence soil wettability (Dekker and Ritsema, 1994; Regalado and Ritter, 2005). In addition to these factors, it has been reported (De Jonge *et al*., 1999) that the degree of water repellence decreases with moisture content and temperature and the repellency is positively correlated with organic matter (Mataix-Solera and Doerr, 2004) and this relationship affects microbial activity on organic matter (Goebel *et al*., 2005).

Soil organic matter controls not only tropical soil fertility (Fernandez and Sanchez, 1990) but soil moisture conservation (Juo, 1990). Soil organic matter as a solid or film at mineral surfaces affects wetting properties in unsaturated soils (Ellerbrock *et al*., 2005). Soil organic matter is composed of hydrophobic carbon backbone and functional groups ((Ellerbrock *et al*., 2005), which influence soil wettability in a characteristic manner (Hayes and Clapp, 2001). With increasing population on land, soil biomass declines (Scott, 2000) and this is a sensitive indicator of changing soil processes (Lamparter *et al*., 2006).

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In the study area, soils are intensively tilled and tillage influences soil organic matter content (Reicosky *et al*., 1995) and alters distribution and stability of aggregates (Six *et al*., 1998). Soil organic matter has an enormous surface area per unit weight and exerts a large influence on the composition of soil solution from which plants derive their nutrients. Soil organic matter contains waxes (Franco *et al*., 2000) and aliphatic constituents (Capriel, 1997; Scott, 2000) which influence soil wettability.

Considering the fact that soil organic matter in arable soils is greatly influenced by management (Gerzabek *et al*., 2001), a forested study site was chosen since Quideau *et al*. (2001) linked easy extraction of soluble soil organic matter fractions to vegetation. Based on the above, the major aim of the study was to assess wettability characteristics of soils on a forested catena with three identifiable physiographic positions, namely crest, midslope and footslope.

MATERIALS AND METHODS

Study Area

The study was conducted at Iyienyi Ibeku in Abia State, Southeastern Nigeria between September 2005 and February 2006. The study site was on latitude 5°48^{1}55^{11}. 520 N and longitude 7°45^{1}28^{11}.810 E and on an altitude of 141 m (Handheld Global Positioning System (GPS) Receiver (Garmin Ltd, Kansas, U.S.A.). Soils are formed over shale and are influenced by humid tropical climate. Rainforest vegetation dominates in the area. Farming and clay mining are major socio-economic activities.

Soils of the study site were classified as Typic Paleustults (Soil Taxonomy)/Orthic Nitisols (FAO/UNESCO legend) although most soils in the area are Typic Tropaquepts (USDA Soil Txonomy)/Dystric Gleysols (FAO/UNESCO legend) (Onweremadu, 2006).

Field Studies

A transect was used to link 3 main physiographic positions namely crest, midslope and footslope identified and used for the purpose of this investigation. Three pedons were aligned along the transect, with each pedon representing a physiographic land unit. The pedons were at an unequal interpedon distances as the distance between midslope and footslope was longer than that between crest and midslope. Soil profile pits were dug, sampled and described according to the procedure of FAO (1998). Soil samples were air-dried, crushed and passed through a 2 mm sieve in readiness for laboratory analysis. Roller tape was used in measuring depth of pedons.

Laboratory Studies

Soil particle size distribution was estimated by hydrometer method as described by Gee and Or (2002). Soil pH was determined electrometrically using 1:1 soil solution ratio (Hendershot *et al*., 1993). Soil Organic Carbon (SOC) was computed as a difference of total carbon and carbonate carbon. Carbonate carbon was determined after application of phosphoric acid by gas chromatographic analysis of carbon dioxide evolution. Total carbon was measured by elemental analysis (CNS 2000, LECO Ltd., Monchengladbach, Germany) as CO_2 via infrared detection after dry combustion at 1250° in duplicate. Two detection limits, namely 0.1 and 0.09 g kg^{-1} were used for SOC and nitrogen, respectively.

The sieved soil samples from the 3 physiographic positions were sequentially extracted. Five grams of soil were mixed with 0.05 dm^3 of deionised water (Nierop and Buurman, 1998). This mixture was shaken for 24 h using roller mixer (SRT2, Steward Scientific, United Kingdom) at a room temperature. Solid residues were separated by centrifuging at 1400 x g for 35 minutes. The solution was filtered through a 0.45 μm membrane filter (Schleicher and Schuell, Dassel, Germany). This represented the water extraction (SOM/W) while in the second step, the sodium pyrophosphate (SOM/PY) extraction was mixed with 0.05 dm^3 of 0.1 M $Na_2P_2O_7$ solution in deionized water

(Ellerbrock *et al*., 1999) and shaken at room temperature for 6 h. The solid residue was separated by centrifuging at 1400 x g for 35 min and filtered using 0.45 μm membrane filter. Remaining solution was adjusted with 1 M hydrochloric acid to pH 2, in order to enhance the precipitation of SOM (PY). Precipitation lasted for 12 h and this was followed by centrifuging the mixture at 1400 x g for 30 min. Water and sodium pyrophosphate extracts were washed free of salts by using a dialysis membrane with a pore size of 2.5 to 3 nanometres and freeze-dried.

Infra-Red Analysis

A BiaRad FTS 135 (BioRad Corp., Hercules, CA) was used to determine organic matter fractions in the soil. Absorption spectra of organic matter was obtained using the KBr technique (Celi *et al*., 1997) in a range of wave numbers between 3900 and 400 cm^{-1}. In this analysis, 0.5 mg of air-dried finely ground soil (for total soil organic matter analysis) and freeze-dried water-soluble and Na_2BO_7-soluble extracts [for SOM (W) and SOM (PY) analysis] was mixed with 80 mg of KBr and finely in an agate mortar. The mixture obtained was dried for 12 h over silica gel in a dessicator. The dessicator treatment was meant to standardize water content. Sixteen scans were performed at a resolution of 1 cm^{-1} for all spectra according to the procedure of Ellerbrock *et al.* (1999). Two absorption bands that indicated hydrophobic (CH-group) and hydrophilic (CO-group) functional groups were analyzed in the Fourier-Transform Infra spectra. The CH-bands of Hydrophobic methyl and methylene groups occur at 2920 cm^{-1} and at 2860 cm^{-1} describing asymmetric and symmetric stetches, respectively (Capriel *et al*., 1995) and both bands were combined to form a single type: 3020-2800 cm^{-1} and this was denoted as absorption Band A. Bands ranging from 1640-1620 and 1740-1710 cm^{-1} were used in order to exclude overlap with C = C and amide bands and both were denoted as Band B and this represented the hydrophilic group.

The A/B ratios in the Fourier-Transform spectra were calculated using BioRad WINIREZ (BioRad Corp, Krefeld, Germany) computer software. Soil wettability was estimated using the capillary rise method according to the procedure of Adamson (1990).

Data Analysis

Soil data were subjected to regression analysis.

RESULTS

Soil Properties

Results of particle size distribution (Table 1) show that clay-sized particles dominated soils of the site. However, soils increased in clay content downslope. In all pedons, clay content increased with depth silt-caly ratio values were very low (0.04-0.29) and generally decreased with depth. Argillation was prominent in all the pedons irrespective of physiographic position. Argillation occurred at lower depths (80-186 cm) in crest soil when compared with 60-190 and 40-197 cm for midslope and footslope soils, respectively.

Table 2 indicates soil chemical properties in the study site. All soils in the area showed strong acidity which reduced with depth. Soils of the crest were more acidic than other physiographic positions. High pH values were recorded at argillic (Bt) horizons. Soil Organic Carbon (SOC) increased spatially downslope but decreased with depth in all the pedons. The same trend was exhibited by total nitrogen in the study. Higher carbon-nitrogen values occurred in the middle horizons of all the pedons.

Infra-red Analytical Results

Heights of absorption bands A relative to B Bands as well as contact angles are shown in Table 3. Bulk soils indicated relatively small intensities at Bands A and B in the spectral analysis.

Table 1: Particle size distribution of soils of the study site

Horizon	Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Silt/clay ratio
Crest					
A	0-15	370	140	490	0.29
AB	15-46	390	80	530	0.15
BA	46-80	410	100	490	0.20
Bt_1	80-119	440	50	510	0.10
Bt_2	119-186	450	30	520	0.06
Midslope					
A	0-9	400	100	500	0.20
AB	9-60	400	90	510	0.18
Bt_1	60-90	400	90	510	0.18
Bt_2	90-141	440	40	520	0.08
Bt_3	141-190	460	20	520	0.04
Footslope					
A	0-20	380	110	510	0.22
AB	20-40	400	80	520	0.15
Bt_1	40-93	370	110	520	0.21
Bt_2	93-136	230	50	720	0.07
Bt_3	136-197	220	70	710	0.10

Table 2: Some chemical properties of the study site

Horizon	Depth (cm)	pH (KCl)	SOC (g kg^{-1})	TN (g kg^{-1})	C/N
Crest					
A	0-15	3.9	14.0	2.8	9:1
AB	15-46	3.8	8.0	0.8	10:1
BA	46-80	4.9	3.5	0.1	35:1
Bt_1	80-119	4.5	1.3	0.4	3:1
Bt_2	119-180	4.6	0.9	0.1	9:1
Midslope					
A	0-90	4.0	14.7	1.3	11:1
AB	90-60	3.8	5.8	0.6	10:1
Bt_1	60-90	4.3	2.6	0.2	13:1
Bt_2	90-141	4.5	1.1	0.6	2:1
Bt_3	141-190	4.3	1.0	0.2	9:1
Footslope					
A	0-20	4.6	29.9	3.2	9:1
AB	20-40	4.1	19.1	1.2	16:1
Bt_1	40-93	4.5	9.3	0.4	23:1
Bt_2	93-136	4.7	5.5	0.1	6:1
Bt_3	136-197	4.4	1.6	0.1	16:1

However, Band A for sodium pyrophyosphate soil organic matter [SOM (PY)] was relatively larger than water soluble soil organic matter [SOM (W)] and bulk soil. There was hardly any relation between the spectra of SOM (W) and soil depth with respect to Band A while Band B decreased with depth. In the four outermost horizons of the crest soil, the A/B ratios of SOM (W) had an average of 0.2 while the A/B ratios of SOM (PY) from the same soil are higher than SOM (W) values. The whole or bulk soil showed least A/B ratios in crest soil. The A/B ratios increased with depth except at subsurface horizons in midslope soil. Largest A/B ratios were found in Bt_1 and the least value in A horizon for SOM (PY) as shown in Table 3. Differences in A/B ratios among horizons are higher in SOM (PY) when compared with SOM (W) in midslope soil. Largest A/B ratios occurred in the Bt_3 horizon for both SOM (W) and SOM (PY). The contact angle for crest soil ranges from 50.8 to 76.8°. In the Bt_2 horizon with low SOC content (0.9 g kg^{-1}), the CA was high (72.1°) while the smallest CA was recorded in AB transitional horizon with 8.0 g kg^{-1} of SOC content.

In the midslope soil, CA varied between 60.3 to 90.1°, corresponding to AB and A horizons, respectively. Earlier laboratory determinations showed that their SOC contents were 5.8 g kg^{-1} and 14.7 g kg^{-1}, respectively. The CA of footslope soil showed highest recorded value at 86.6° (Bt_3) and least value of 59.0° at Bt_2. This result implied that the largest CA was obtained in the subsoil horizon with the smallest SOC content (1.6 g kg^{-1}).

Table 3: Contact angles and heights of absorption bands A related to B bands using Fournier-Transferom Infra-red Analysis of organic matter of water and sodium pyrophosphate soluble fractions of soil samples

Horizon	Depth (cm)	CA (o)	SOM (W) A/B	SOM(PY) A/B	Whole soil A/B
Crest					
A	0-15	76.8	0.15450	0.24906	0.13542
AB	15-46	50.8	0.14913	0.33208	0.08010
BA	46-80	69.1	0.15961	0.33949	0.12002
Bt_1	80-119	56.8	0.15990	0.20112	0.09941
Bt_2	119-180	72.1	0.43490	0.46169	0.14069
Midslope					
A	0-9	90.1	0.27991	0.10186	0.22164
AB	9-60	60.3	0.13281	0.21962	0.16966
Bt_1	60-90	78.6	0.15418	0.33684	0.18916
Bt_2	90-141	79.9	0.16996	0.23118	0.22979
Bt_3	141-190	77.2	0.21346	0.29186	0.24049
Footslope					
A	0-20	71.6	0.32038	0.31782	0.41976
AB	20-40	82.1	0.22637	0.10512	0.16136
Bt_1	40-93	66.3	0.09857	0.18961	0.27608
Bt_2	93-136	59.0	0.13956	0.19061	0.21058
Bt_3	136-197	86.6	0.23941	0.23169	0.23151

CA = Contact angles, AB = Heights of absorption bands A relative to B bands, SOM (W) = Soil organic matter of water, SOM (PY) = Soil organic matter of sodium pyrophosphate soluble fraction

Table 4: Relationship between contact angles and soil organic carbon at three physiographic positions ($p \leq 0.05$)

Physiographic position	Relationship
Crest	CA = 69.9-39.0. SOC + 25.0. SOC r^2 = 0.05
Midslope	CA = 77.6-45.2. SOC + 29.1. SOC r^2 = 0.89
Footsope	CA = 88.2-70.1. SOC + 32.6. SOC r^2 = 0.83

CA = Contact angle SOC = Soil organic carbon

Table 5: Relationship between CA, A/B ratios and SOC in soils of the study site

Physiographic position	Properties	r^2-value
-	A/B versus SOC	0.16
-	A/B versus CA	0.71
Crest	CA versus A/B (SOM (PY)	0.86
Midslope	CA versus A/B (SOM (PY)	0.84
Footslope	CA versus A/B (SOM (PY)	0.85

CA = Contact angle, SOC = Soil organic carbon SOM (PY) = Sodium pyrophosphate soluble soil organic matter

In relating these CA values with SOC contents (Table 4), results indicated that highest r^2-value (r^2 = 0.89; $p \leq 0.05$) was obtained in midslope soils and least in crest soils (r^2 = 0.50, $p \leq 0.05$). Good relationships were established between CA and A/B SOM(PY) values in all physiographic positions as there was also a high r^2 value when CA was regressed with A/B values (Table 5).

DISCUSSION

The CA values obtained in crest soil (50.8-76.8°) are subcritical water repellence values according to Hallett *et al.* (2001) showing that the soil sample was partially wettable but not hydrophobic. Soils are said to be hydrophobic when CA values are greater than 90° (Goebel *et al.*, 2004), suggesting that only A-horizon of soils of the midslope are susceptible to hydrophobicity. This may be attributed to low clay content of the horizon as well as land use history, since land use could alter aggregate sizes. There were differences in behaviour between topsoils and subsoils in wettability. Soil wettability increased with SOC content for low SOC contents but decreased for SOC greater than 14 g kg^{-1}. Generally wettability did not decrease with reduced SOC content, suggesting the SOC was not the only determining factor in soil wettability characteristics. These results are consistent with the findings of Chenu *et al.* (2000). It is also possible the degree of stabilization of encapsulated SOC has effects on soil wettability.

The CH-/CO-groups ratio, that is, A/B ratio was less than 0.5, showing more hydrophilic properties of the soil organic matter. A CA range of 50.8 to 90.1 suggests reduced wettability of soils of the study site and this could be due to substantial proportion of sand in these soils. Poor wettability is caused by low surface free energy resulting in a weak attraction between solid and the liquid phase (Roy and McGill, 2002). The r^2 value of 0.71 existing between A/B ratios and CA (Table 5), implies a coefficient of alienation of 0.29. By this result, it suggests other independent variables may have influenced wettability although not assessed in this study. Such outliers could be due to the presence of sesquioxides in these highly weathered soils as suggested by the low silt-clay ratios (<0.30).

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