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Influence of slope positions on soil fertility index, soil evaluation factor and microbial indices in acid soil of Humid Subtropical India

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ABSTRACT

The slope positions can control the movement of water and nutrients in a hillslope and contribute to the spatial variation of soil properties. A study was conducted in acid soil of humid subtropical northeastern India with the objectives to examine the characteristics and spatial differences in soil fertility parameters and microbial properties. There were significant difference in sand, silt and clay with slope positions at 025 and 2550 cm depths except the clay fraction between middle and lower slope at both the depths. There was significant differences in soil pH under different slope position at 2550 cm but not at 025 cm depth. Cation exchange capacity (CEC) values exhibited significant difference at both the depths, with values in the order lower > middle > upper slope. Soil fertility index (SFI) and soil evaluation factor (SEF) increased from upper slope to lower slope as soil nutrients leached down from the upper catchments to lower catchments due to coarse texture of soil accompanied by high rainfall. Both SFI and SEF were higher in 025 cm as compared to 2550 cm depth at all three slope positions. Slope positions significantly affected the soil biological properties like microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP), acid phosphatase (APase) and dehydrogenase activity (DHA). MBC (506 mg kg^{-1}), MBN (31.21 mg kg^{-1}), MBP (6.51), APase (27.6 mg PNP g^{-1} h^{-1}) and DHA (33.12 µg TPF 24 h^{-1} g^{-1}) was highest in upper slope at 025 cm depth due to native forest landuse. MBC, MBN and MBP values were significantly different with respect to slope position, with values in the order upper slope > middle slope > lower slope. Activities of APase and DHA decreased markedly with soil depth.

1. INTRODUCTION

The spatial variation of soil properties is significantly influenced by the soil forming factors such as climate, topography, parent materials, vegetation and disturbance due to human activity (Ollinger *et al.*, 2002). Several studies have indicated that soil properties are related to topographic positions (Alemayehu, 2007; Yimer *et al.*, 2008). Soil moisture content is affected by the slope and aspect in the landscape (Yimer *et al.*, 2008) which leads to variations in microbial activity and microbial populations with variations in drainage class (Cavigelli *et al.*, 2005). Research works have also indicated that soil microbial properties vary with slope positions (Smith *et al.*, 2002; Khormali *et al.*, 2009). There is evidence for soil movement within small watersheds as soil erosion takes place in the back slope (BS) and shoulder (SH) and soil deposition in the footslope (FS) and toeslope (TS) positions (Moorman et al., 2004). Organic carbon (OC) and total nitrogen (TN) were found to be lower for the BS and SH and greater for the FS, TS and SU (summit) elements. Soil pH was also reported to be lower for the SU position relative to other landform elements. Temperature and precipitation variation with elevation has significant influence on the pedogenic processes as well. Slope and slope position significantly affect the movement and accumulation of soil solution leading variation in soil properties (Tsui *et al.*, 2004; Moges and Holden, 2008) which may lead to variation in soil fertility parameters.

Because of the complexity of soil properties, it is difficult to find an appropriate method to evaluate soil conditions. Soil scientists have made great efforts to develop methods to assess soil conditions. For example, soil quality is a combination of the physical, chemical, and biological properties that contribute to soil function (Knoepp *et al.*, 2000). An effective method to evaluate soil fertility is still lacking in the humid tropical region. Moran and Brondi´zio (1998) used a soil fertility index (SFI) and soil evaluation factor (SEF) to explore the relationship between soil fertility and crop choice. Several studies have been undertaken on assessment of soil quality using physico-chemical variables of soil under different land use types (Moran *et al.*, 2000; Lu *et al.*, 2002; Doi and Ranamukhaarchchi, 2009). The information on soil fertility status in relation to slope position using physico-chemical and biological variables in an integrated manner is generally lacking. Hence, the present study was attempt in Dholi catchment of Jorhat district of Assam covering an area of 990 ha. For this work, we hypothesized physicochemical, fertility and biological properties would vary by relative slope position in the catchment (upper, middle and lower). The objectives of the study were 1) to compare the influence of slope positions on selected soil fertility parameters and microbial indices and 2) to establish the interrelationship between soil fertility parameters and microbial indices.

2. MATERIALS AND METHODS

Study Area and Site Selection

The study was carried out in Dholi watershed, Jorhat district, Assam, extending between 26°35' to 26°38'N latitudes and 93°05' to 94°20'E longitudes covering an area of 990 ha. The climate of the area is humid subtropical. The mean winter and summer air temperatures are 17.0 °C and 28.7 °C respectively. The calculated mean annual soil temperature (MAST) is 24.5 °C, mean summer soil temperature (MSST) is 26.3°C and mean winter soil temperature (MWST) is 5.3 °C. Annual rainfall is 2250 mm. The rainfall is well distributed throughout the year, though major portion is received during March to September. 75 percent of rainfall is received during monsoon season.

Geologically the area is formed from sediment derived from the Assam plateau carried by Brahmaputra river and its tributaries. According to the USDA Soil Taxonomy, the soil at the study region was classified into two orders viz., Entisols, Inceptisols (Gangopadhyay *et al.*, 2004). The native forest in the study area is dominated by Ajhar (Lagerstroemia flosreginae), Bot (Ficus bengalensis), Boga Koroi (Alvizzia procer), Khokon (Duabanga sonnertioides), Nahar (Mesua ferrea), Outenga (Dillenia indica), Sonari (Cassia fistula), Sisoo (Dalbergia sisoo), Simolu (Bombax malabaricum) and Bamboo (Bambusa sp.) etc. (Gangopadhyay *et al.*, 2004).

Soil sampling sites were selected within three major land uses located on varying slopes (upper, middle and lower) and soil sampling was carried out in October 2008. The slope gradient was found to be between 03% in the lower, 38% in the middle and 815% in the upper units dominated by cultivated land, tea plantation and native forest, respectively.

Soil Sampling and Analysis

A total of 108 soil samples were collected from eighteen randomly located in each slope position (18 locations × 3 slope positions × 2 depths) having major land use system of cultivated land, tea and native forest. Bulk soil samples were collected from excavated soil pits at 0-25 and 25-50 cm depth. Soil samples were air-dried and ground to pass through a 2-mm sieve. Particle size distribution was determined by the hydrometer method. A combined glasscalomel electrode was used to determine the pH of aqueous suspension (1:2.5 soil:solution ratio). Soil organic matter content (SOM) was estimated by loss on ignition at 550 C for 2h. Exchangeable cations (Ca, K, Mg and Na) were extracted with 1 *M* NH4OAc (pH 7.0). Potassium and Na contents were determined by flame photometer, while the Ca and Mg were determined by EDTA titration method. Exchangeable acidity was determined after extracting the soil with 1 *N* KCl solution, followed by titration with 0.1 *N* NaOH solution. Available phosphorus was determined by Bray II method. Cation exchange capacity (CEC) was determined by saturating soil with 1 *M* NH4OAc at pH 7 and subsequently subjecting it for the semi-micro distillation. Exchangeable Al was extracted with 1*N* KCl solution and titrated with 0.1*N* NaOH solution.

From each location the soil samples (108) were collected subsequently in separate plastic bags at the time of soil sampling for analysis of other soil parameters. The moist samples were sieved to 2 mm and analyzed for four parameters. Microbial biomass carbon (MBC) determination was made by chloroform fumigation method. Microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP) was according to procedure described by Brookes *et al.*, 1985 & 1982, respectively. The dehydrogenase activity (DHA) and Phosphatase activity (APase) was measured.

Values of soil fertility index (SFI) (Moran et al., 2000) and soil evaluation factor (SEF) (Lu *et al.*, 2002) were calculated to quantify soil fertility. The following equations were used to calculate values of soil fertility index and soil evaluation factor (Lu *et al.*, 2002):

SFI = pH + organic matter (%) + available P (mg kg^{-1}) + exch. K (c eq kg^{-1}) + exch. Ca (c eq kg^{-1}) + exch. Mg (c eq kg^{-1}) exch. Al (c eq kg^{-1})

SEF = [exch. K (c eq kg^{-1}) + exch. Ca (c eq kg^{-1}) + exch. Mg (c eq kg^{-1}) log (1 + exch. Al (c eq kg^{-1}) × organic matter (%) + 5

The use of the constant 5 while calculating SEF avoids negative values, if there are high Al amounts in the soil. An SEF value with less than 5 indicates extremely poor soil fertility and higher SEF indicates higher soil fertility (Lu *et al.*, 2002).

Statistical Analysis

All the statistical analyses were performed using SPSS 15.0 (SPSS Inc.). One-way analysis of variance was performed to test the effect of slope position and land uses on each soil properties. Fisher's least significant difference (LSD) *t*-test was performed to examine the significant differences between means. Two-way analysis of variance was performed to test the effect of slope and depth on each soil parameters. Turkey's HSD (honest significance difference) test was used for mean separation when the analysis of variance showed statistically significant difference ($P < 0.05$) between the soil properties.

3. RESULTS AND DISCUSSIONS

Effect of Land Uses and Slope Positions on Soil Physio-chemical Properties

The clay fraction was invariably lower compared to sand and silt in all three positions. There were significant difference in sand, silt and clay with slope positions and land uses at 025 and 2550 cm depths, but the clay fraction between middle and lower slope were non significant (Table 1). There were not much difference in sand, silt and clay content with variation in soil depth. Sand content (75.9%) at 025 cm depth in upper slope (native forest), silt content (53.1%) at 2550 cm depth in lower slope (cultivated) and clay content (20.3%) at 2550 cm depth in lower slope (cultivated) were highest as compared to other slope and land uses. The results were in accord to the trend in soil texture over landscape for increased fine particles on lower slopes (Deka *et al.*, 2009). Furthermore, the much significant difference in silt but not clay content between middle and lower slope indicated non-selective removal of the clay particles from the soil surface and transported to the lower slope position (Table 1). It has long been documented that slope is one of the most important abiotic factors that control the pedogenic process on a local scale (Buol *et al.*, 1997). Steeper slopes contribute to greater runoff, as well as to greater translocation of surface materials downslope through surface erosion and movement of the soil mass. Soil pH showed significant difference with respect to slope position at 2550 cm but not at 025 cm depth and pH increased with distance from 4.8 to 5.1 and 4.7 to 5.4 at 025 cm and 2550 cm depth, respectively from middle to lower slope (Table 2). The highest pH value was found in middle slope as compared to lower and upper slopes may be ascribed due to presence of tea plantation in middle slope then the native forest and cultivated land in upper and middle slope, respectively.

Table : 1
Soil texture (0-25 and 25-50 cm depths) in relation to land uses on different slope positions

Parameter	Depth (cm)	Land uses (% slope)		
		Forest (>15)	Tea plantation (3-8)	Agriculture (<3)
Sand (%)	0-25	75.9^{a}	36.1^{b}	29.1^{c}
	25-50	69.9^{a}	38.3^{b}	26.7^{c}
Silt (%)	0-25	13.1^{a}	48.2^{b}	53.0^{c}
	25-50	17.3^{a}	47.5^{b}	53.1^{c}
Clay (%)	0-25	11.0^{a}	15.7^{b}	17.9^{bc}
	25-50	12.8^{a}	14.2^{ab}	20.3^{b}

Means within a row followed by a different letter are significantly different according to LSD 0.05.

Table : 2
Soil fertility parameters (0-25 and 25-50 cm depths) in relation land uses on different slope positions

Parameter	Depth (cm)	Land uses (% slope)		
		Forest (>15)	Tea plantation (3-8)	Agriculture (<3)
pH	0-25	5.0^{a}	4.8^{b}	5.1^{a}
	25-50	5.0^{a}	4.7^{b}	5.4^{c}
Cation exchange	0-25	5.82^{a}	10.37^{b}	10.63^{bc}
capacity (c mol kg^{-1})	25-50	5.55^{a}	9.37^{b}	12.29^{c}
Exchangeable Ca	0-25	0.68^{a}	1.45^{b}	2.43^{c}
(c mol kg^{-1})	25-50	0.66^{a}	1.19^{b}	2.91^{c}
Exchangeable Mg	0-25	0.84^{a}	0.39^{b}	0.34^{bc}
(c mol kg^{-1})	25-50	0.93^{a}	0.53^{b}	0.73^{ab}
Exchangeable K	0-25	0.22^{a}	0.17^{a}	0.10^{b}
(c mol kg^{-1})	25-50	0.20^{a}	0.13^{b}	0.07^{c}
Exchangeable Na	0-25	0.16^{a}	0.22^{a}	0.18^{a}
(c mol kg^{-1})	25-50	0.14^{a}	0.22^{b}	0.22^{b}
Exchangeable Al	0-25	2.48^{a}	1.91^{b}	1.20^{c}
(c mol kg^{-1})	25-50	2.11^{a}	2.94^{b}	1.68^{a}
Exchangeable H	0-25	0.47^{a}	0.26^{b}	0.29^{bc}
(c mol kg^{-1})	25-50	0.58^{a}	0.17^{b}	0.20^{bc}

Means within a row followed by a different letter are significantly different according to LSD 0.05.

CEC values were significantly different at both the depths, with values in the order lower > middle > upper slopes. Relatively fine textured soils from middle and lower slopes showed higher CEC which suggests that clay was the main contributor of CEC in these soils. The strong dependence of CEC on clay content was also observed by Wild (1993).

Effect of Land Uses and Slope Positions on Exchangeable Nutrient and Fertility Indices

Among the exchangeable cations, Ca and Mg were the most dominant, followed by Na and K. Lower content of Na and K than divalent cations in the studied soils. which corroborates to the fact that leaching causes preferential losses of monovalent ions. There were inconsistent variation of exchangeable Mg, K and Na with respect to slope position. Only Ca showed a significant difference with slope positions. The base saturation indicated that the soil was potentially less fertile with a possible Al toxicity. The soil in the upper slope had higher exchangeable Al (2.3 c mol kg^{-1}) followed by middle (2.9 c mol kg^{-1}) and lower slope (1.4 c mol kg^{-1}) soils. There were significant differences (Table 2) for all the soil physico-chemical properties with slope. Significant differences among slope positions and soil depths for soil properties were also observed by Tsui *et al*. (2004) and Yimer *et al*. (2008). The combination of slope and depth also had a significant interactive effect on pH, exchangeable Ca and exchangeable Al. At 0-25 cm soil depth, available P was significantly different by slope, but variation in soil organic matter (SOM) was non significant. At 25-50 cm depth SOM was significantly lower but available P was significantly higher (Table 3). Generally SOM had higher values on upper slope (1.8%) than middle (1.4%) and lower slopes (1.3%) may be attributed to vegetation effect. The forest soils are expected to contain a greater SOM as compared to intensive cultivation in the middle and lower slope due to the mineralization of SOM. Higher available phosphorus at 25-50 cm depth as compared to 0-25 cm depth may be ascribed due to higher pH at lower depth as compared to upper depth in all the slope positions of the study area.

Soil fertility index (SFI) and soil evaluation factor (SEF) increased from upper slope to lower slope (8.4 to 10.0 and 7.5 to 9.1, respectively) as soil nutrients leached down from the surface layer to deeper layers due to coarse texture and high rainfall. This observation is in agreement with the findings of Lu *et al.* (2002) and land uses also showed significant influences on soil nutrient conditions (Carpenter *et al.*, 2001; Giovannini *et al.*, 2001). Both SFI and SEF were high in 0-25 cm as compared to 25-50 cm depth at all three slope positions. There were significant differences (Table 3) for all the soil fertility parameters with slope except available P. The combination of slope and depth also exhibited a significant interactive effect on SOM and SEF.

Table : 3

Soil fertility index and soil evaluation factor (0-25 and 25-50 cm depths) in relation land uses on different slope positions

Parameter	Depth (cm)	Land uses (% slope)		
		Forest (>15)	Tea plantation (3-8)	Agriculture (<3)
Organic matter	0-25	2.02^a	1.91^a	1.98^a
(%)	25-50	1.49^a	0.99^b	0.65^c
Available P	0-25	2.36^a	2.25^{ab}	1.42^b
(mg kg^{-1})	25-50	5.0^a	4.7^b	5.4^c
Soil fertility	0-25	8.65^a	9.02^a	10.21^a
index	25-50	8.09^a	6.44^{ab}	9.79^{ac}
Soil evaluation	0-25	7.80^a	8.56^a	10.84^b
factor	25-50	7.21^a	6.46^a	7.36^a

Means within a row followed by a different letter are significantly different according to LSD 0.05.

Effect of Land Uses and Slope Positions on Soil Biological Properties

Slope positions significantly affected the soil biological properties like microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP), acid phosphatase (APase) and dehydrogenase activity (DHA). MBC, MBN and MBP showed significant difference with respect to slope (Table 4), with values in the order: upper > middle > lower slope. Addition of organic matter and better nutrient cycling in forest in upper slope position might have increased the biological activity of the soil (Min *et al.*, 2003). Both SOM and available P content followed the same trend as did the MBC, MBN and MBP of the soils. It is consistent with the fact that microbial biomass should positively correlate with increasing soil organic carbon (Smith and Paul, 1990). The value of MBC obtained in the study (306- 506 mg kg^{-1}) is well within the reported range (61-1900 mg kg^{-1}); Srivastava and Singh, 1988). There was no significant difference in APase and DHA between slope positions at 025 and 2550 cm (Table 4), but a significant difference for APase at 025 cm soil depth. There is strong relationship between SOM content and enzyme activities (Gracia *et al.*, 1994). Soil enzyme is highly related with soil biological properties and is often used to reflect biological properties (Cavigelli *et al.*, 2005; Jadia and Fuleker, 2009). Activities of APase and DHA decreased markedly with soil depth. This might be attributed to the enzyme properties. APase and DHA hydrolase in soils and are mainly extracellular, their activities endure despite the lysis of the cells. Additionally, these enzymes are released by microorganisms in response to their substrates. When organic matter and total N is increased, the activity of these enzymes is also increased. Profile distribution of APase was found and DHA was therefore influenced by organic matter and total N in soils.

Table : 4
Soil biological properties (0-25 and 25-50 cm depths) in relation land uses on different slope positions

Parameter	Depth (cm)	Land uses (% slope)		
		Forest (>15)	Tea plantation (3-8)	Agriculture (<3)
Microbial biomass carbon (mg kg^{-1})	0-25	506^{a}	425^{b}	321^{c}
	25-50	485^{a}	395^{b}	306^{c}
Microbial biomass nitrogen (mg kg^{-1})	0-25	31.21^{a}	26.67^{b}	21.37^{c}
	25-50	29.50^{a}	25.52^{b}	18.56^{c}
Microbial biomass phosphorus (mg kg^{-1})	0-25	6.51^{a}	3.06^{b}	3.87^{b}
	25-50	4.24^{a}	3.00^{b}	3.01^{b}
Acid phosphatase (mg PNP g^{-1} h^{-1})	0-25	27.6^{a}	22.9^{b}	18.00^{c}
	25-50	23.2^{a}	18.3^{b}	15.01^{c}
Dehydrogenese activity (mg TPF g^{-1} dry soil)	0-25	33.12^{a}	30.05^{a}	27.39^{a}
	25-50	31.07^{a}	28.23^{a}	22.15^{a}

Means within a row followed by a different letter are significantly different according to LSD 0.05

Correlation between Soil Properties and Soil Microbial Indices

To examine the relationships between soil properties and soil microbial indices, Pearson's correlation matrix was established. Table 5 revealed that SFI and SEF are 1) highly significant and positive correlation with OM, CEC, P, K, Na, MBC and MBN 2) significant and positive correlation with MBP, APase and DHA. Among the soil biological parameters like MBN, MBP, APase and DHA showed significant and positive relationship with OM but MBC showed highly and positive correlation with OM. With increase in CEC of the soil, microbial activity increased significantly, as evidenced from very high positive values of correlation coefficients.

4. CONCLUSIONS

Land uses and slope position affected soil parameters further leads to variation in soil fertility and soil microbial indices. Significant differences with respect to slope positions and land uses were found for most of the soil properties studied. The contents of exchangeable cations, CEC, clay fractions, SFI, SEF and pH value were highest on lower slope position. However, the contents of SOM, MBC, MBN, MBP, APase and DHA were generally higher on the upper slope positions (native forest) than those of middle (tea plantation) and lower slope (agriculture). A highly significant correlation of SFI and SEF with soil chemical and biological properties indicates that these two indices can successfully be used as indicators of soil quality.

Table : 5
Pearson correlation coefficients between soil fertility parameters and soil microbial properties

	SFI	SEF	pH	OC	CEC	Ca	Mg	K	Na	Al	P	MBC	MBN	MBP	APase	DHA
SFI	1.00															
SEF	0.85^{**}	1.00														
pH	NS	NS	1.00													
OC	0.50^{**}	0.45^{*}	NS	1.00												
CEC	0.59^{*}	0.61^{**}	NS	NS	1.00											
Ca	NS	NS	NS	NS	NS	1.00										
Mg	NS	NS	NS	NS	NS	NS	1.00									
K	0.71^{**}	0.75^{**}	NS	0.21^{*}	-0.11^{*}	NS	NS	1.00								
Na	0.51^{**}	0.61^{**}	NS	NS	NS	NS	NS	NS	1.00							
Al	NS	NS	NS	NS	NS	NS	0.57^{*}	NS	NS	1.00						
P	0.62^{**}	NS	0.31^{*}	NS	NS	NS	NS	NS	NS	NS	1.00					
MBC	0.58^{**}	0.65^{**}	NS	0.51^{**}	0.24^{*}	NS	NS	0.77^{**}	NS	NS	NS	1.00				
MBN	0.60^{**}	0.61^{**}	NS	0.41^{*}	0.29^{*}	NS	NS	NS	NS	NS	0.41^{*}	0.74^{**}	1.00			
MBP	0.42^{*}	0.31^{*}	NS	0.48^{*}	0.21^{*}	NS	NS	NS	NS	NS	0.56^{**}	0.71^{**}	0.58^{**}	1.00		
APase	0.31^{*}	0.25^{*}	NS	0.45^{*}	0.31^{*}	NS	NS	0.61^{**}	NS	NS	0.64^{**}	0.61^{**}	0.51^{**}	0.63^{**}	1.00	
DHA	0.49^{*}	0.21^{*}	NS	0.31^{*}	0.12^{*}	NS	NS	0.67_{**}	NS	NS	0.47^{*}	0.57^{**}	0.42^{*}	0.58^{**}	0.41^{*}	1.00

*Significant at the 0.05 level, **Significant at the 0.01 level

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