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Characterization and potentiality evaluation
Soils developed in different land forms of north bank plain zone of Assam I. Characterization and potentiality evaluation

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Abstract: Four representative soil profiles collected from different landform units in North Bank Plain Zone of Assam were characterized for potentiality evaluation. The morphological characteristics of the soils showed considerable variations with dominant hue of 10YR. A chroma of =2 in soils of alluvial and flood plains indicated aquic characteristics. The soil texture showed wide variations which were related to land form units. Higher amount of soil organic matter was observed in alluvial (0-34.7 g kg^{-1}) and flood plains (2.1-38.3 g kg^{-1}) under grass vegetation. A difference in soil pH of 0.8 to 1.8 units was observed in water and 1*N* KCl suspension. Major portion (45-64 percent) of the exchange sites was saturated with exchangeable $H^{+}+Al^{3+}$. Clay and organic matter fractions were the main contributors to exchange acidity and CEC. Soils on low hill and monadnock were more developed as compared to those on alluvial and flood plain. Apparent constancy of Fe_d / clay ratio in soils of low hill and monadnock indicated co-migration of Fe_d with clay. The soils were classified as *Ultic Hapludalfs* (low hill and monadnock), *Humic Endoaquepts* (alluvial plain) and *Aquic Udifluvents* (flood plain). The soils on alluvial plain had the highest potentiality for crop growing and pasture while those on flood plain could be considerably improved for commercial trees.

Additional key words: *Pedogenic processes, land use, illuviation, land evaluation, soil classification*

Introduction

A landform comprises a geomorphological unit and is largely defined by its surface form and location in the landscape. Soil-landform studies are important to explore the relationship between soil properties and land form units. Such studies enable to extrapolate the soil properties on similar land forms under the same overhead climatic condition and thereby reduce time and efforts in soil resource management. This is because a land form unit is formed by the same geomorphic processes that are responsible for providing the substrate material of the soils (Gessler *et al.* 1995; Park and Burt 2002; Mini *et al.* 2007). Brubaker *et al.* (1993) studied soil properties in relation to landform positions and found significant differences among soil properties of sand, silt, pH and exchangeable Ca^{2+} and Mg^{2+}. The soils on relatively unstable landforms indicated young and immature A-C profiles whereas those from stable landforms showed distinct profile development having A-Bw-C and A-Bt-C horizons (Sawhney *et al*. 2000). Soils on different physiographic/land form units have been studied by Sen *et al.* (1997) across central Assam and Karmakar and Rao (1999) in lower Brahmaputra valley zone of Assam. But such studies are very meager in the North Bank Plain Zone (NBPZ) of Assam.

NBPZ of Assam is one of the six agro-climatic zones of Assam delineated on the basis of rainfall, terrain and soil characteristics (Anonymous 1981) and comprises of Darrang, Sonitpur, North Lakhimpur and Dhemaji districts of Assam. This zone occupies an area of 14,319 km^2 constituting 18.25 per cent of the state's total geographical area and consists of different land form units such as low hill, structural hill, piedmont, inselbergs or monadnocks, alluvial plain and flood plain. The northern part of this zone is a part of "Assam Himalayas" which forms the northern catchment of the Brahmaputra valley. This region is of Pre-Cambrian to Paleozoic period (Verma and Tandon 1976) and consists mainly of gneisses and schists (Dey 1968) which seems to be equivalent to the Dharwarian rocks of the Peninsula (Krishnan 1968). The alluvial and flood plains were formed from the sediments derived from Assam plateau in the south and Assam Himalayas in the north and brought down by the river Brahmaputra and its tributaries. The present paper is on the characterization and potentiality aspects of the soils of this region in relation to landform units.

Materials and Methods

The study area forms a transect in Sonitpur district in NBPZ of Assam and is situated in between 26^{o}41'42'' to 27^{o}13'54'' N latitude and 92^{o}43'45'' to 92^{o}47'45'' E longitude. The district covers an area of 5.324 lakh ha having 29.1 per cent forest area. The net cropped area of the district is 1.609 lakh ha with cropping intensity of 162 per cent. The area is characterized by humid climate with mean annual rainfall of 2370.9 mm and mean annual air and soil temperatures of 22.6^{o}C and 23.6^{o}C, respectively, mean maximum and minimum temperatures of 28.0^{o}C and 17.2^{o}C respectively, and mean annual potential evapo-transpiration (PET) of 1186.6 mm and length of growing period (LGP) of 275 days with water deficits in five months. The area qualifies for *Udic* soil moisture regime and *hyperthermic* temperature regime.

Using a physiographic map (1:50,000) as a base map, a transect was selected covering major land form units and four soil profiles were collected representing low hill (P1), monadnock (P2), alluvial plain (P3) and flood plain (P4). Location and site characteristics of the soil profiles are presented in Table 1 and Figure 1. The natural vegetation of the study area comprises of mixed semi-evergreen and deciduous forests, shrubs and short grasses. The dominant species are siris (*Albizzia leddek*), Indian laburnum (*Casisia fistula*), Indian redwood (*Dalbergia sisoo*), sal (*Shorea robusta*), mango (*Mangifera indica*), bamboo (*Bambusa tuida*), shrubs like fern (*Polypodium sp.*) and grasses (*Cynodon dactylon*, *Imperata cylindrical, Phragmites karka etc.*).

Table 1. Site characteristics of the study area

Pedon	Location	Latitude & Longitude	Landforms	Parent material	Present land use
P1	Gamani	27^{o}13'54" N 92^{o}46'15" E	Low hill	Gneisses, schists	Semi-evergreen and deciduous forest
P2	Balipara	26^{o}48'18" N 92^{o}43'45'' E	Monadnock	Quartzite sandstone	Tea
P3	Ghoramari	26^{o}42'54" N 92^{o}47'25" E	Alluvial plain	Alluvium	Grasses
P4	Na pam	26^{o}41'42" N 92^{o}47'45" E	Flood plain	Alluvium	Short mixed grasses

Morphological features of the profiles were studied in the field as per Soil Survey Manual (Anonymous 1970). Sieved soil samples (<2 mm) from each horizon were analyzed for mechanical composition (Jackson 1979; Piper 1950), bulk density by clod method (Black 1965), soil organic carbon (Walkley and Black 1934), exchangeable acidity (McLean 1965) and other physical and chemical properties (Jackson 1973). Soils were classified as per '*Keys to Soil Taxonomy*' (Soil Survey Staff 2010). Land evaluation for actual and potential productivity was carried out following the procedures of Riquier *et al.* (1970). The productivity (P) was calculated considering eight factors *viz*, soil moisture content (H), drainage (D), effective depth of soil (P), texture and structure of rooting zone (T), average nutrient content of A horizon (N), organic matter in surface horizon (O), nature of clay (A) and nutrient reserve (M): Productivity (P) = H x D x P x T x N x O x A x M

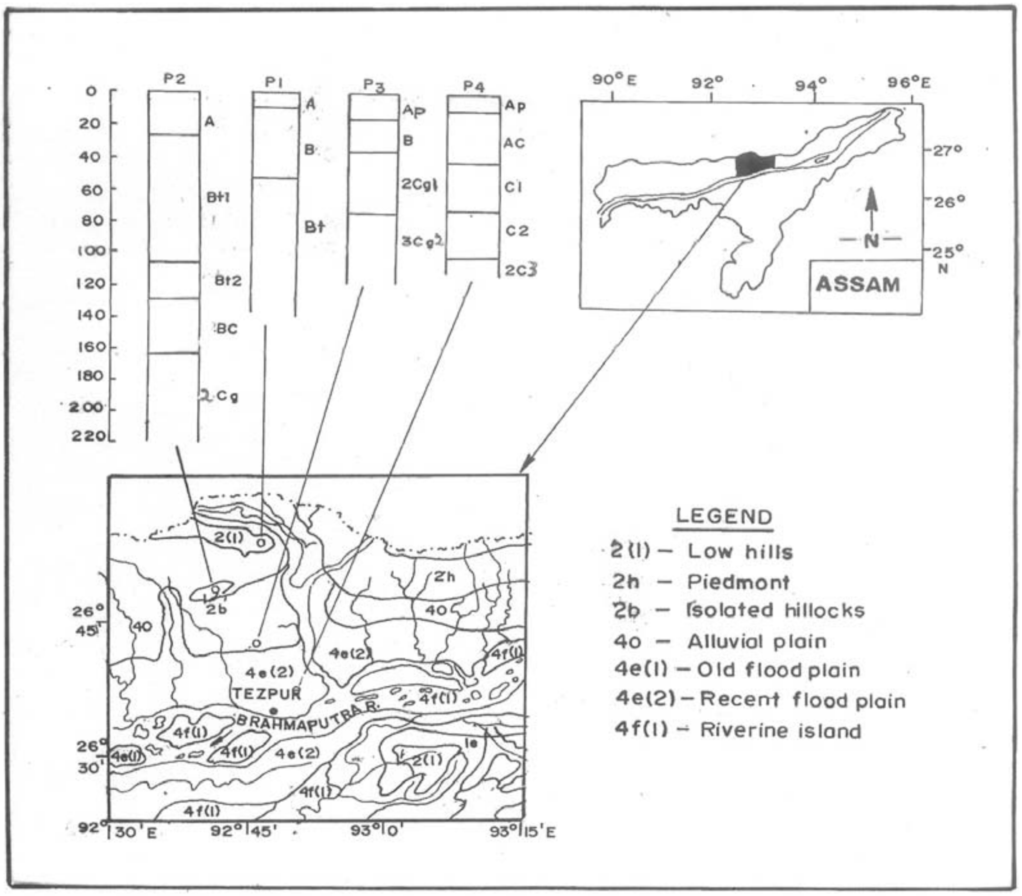

Fig. 1. Study area and profile locations

The actual factor-wise scores (on a scale of 0 to 100) for different land uses, expressed in percentage were multiplied to derive the final index. The potentiality (P') was calculated after a careful consideration of the probable improvement measures in different factors. The coefficient of improvement (CI) was calculated as follows:

$$\text{Coefficient of improvement (CI)} = \frac{\text{Actual productivity (P)}}{\text{Potential productivity (P')}}$$

The necessary statistical calculation was carried out as per Snedecor and Cochran (1967).

Results and Discussion

Morphological characteristics

The morphological characteristics of the soils showed considerable variations (Table 2). The dominant hue was 10YR except in upper two horizons of P2 (monadnock) where it was 7.5YR and in the lowermost horizon of P3 (alluvial plain) where it was 5Y. The redder hue in P2 may be due to more oxidative condition and yellower hue in P3 may be due to reduced condition. The value of the soil colour ranged from 3 to 7 and the chroma ranged from 1 to 8. The wide variation in chroma is related to topographic situation. Higher chroma (3-8) was observed in low hills (P1) and monadnock (P2). Low chroma (=2) observed in alluvial plain (P3) and flood plain (P4) soils indicates aquic characteritics associated with seasonal reducing conditions in these soils. Reddish yellow (7.5YR 6/8) to strong brown (10YR 5/8) mottles observed in subsurface horizons of monadnock (P2) and alluvial (P3) soils are indicative of oxidation and reducing conditions due to fluctuating ground water. The pedological features observed in the soils of low hill (P1) and monadnock (P2) were Fe-Mn glaebules which were formed due to prolonged alternate oxidizing and reducing conditions (Karmakar and Rao 1994).

Table 2. Morphological characteristics of the soils

Horizon	Depth (cm)	Colour (moist)	Mottles	Texture	Structure	Consistnce	Cutans	Other features
P1: Low Hill (Gamani) *: Ultic Hapludalfs*								
A	0-8	10YR 4/3		Scl	m3gr-sbk	ds, mfr, wss, wps		
Bt1	8-52	10YR 5/4		Scl	m2sbk	ds, mfr, wss, wps		Few medium subrounded Fe-Mn glaebules
Bt2	52-140	10YR 5/6		Scl	m2sbk	ds, mfr, wss, wps	Thin patchy argillans	
P2: Monadnock (Baliparai) *: Ultic Hapludalfs*								
Ap	0-25	7.5YR 5/4		scl	f-m2sbk	dsh, mfr, ws, wp		
Bt1	25-105	7.5YR 5/6		scl	m3sbk	dsh, mvfr, ws, wp	Thick continuous argillans on pore & ped faces	Few medium subrounded Fe-Mn glaebules
Bt2	105-128	10YR 5/8	f1f 7.5YR 6/8	scl	m3sbk	dsh, mvfr, ws, wp		Few Coarse subrounded Fe-Mn glaebules
BC	128-162	10YR 7/6	m2d, 7.5 YR 5/8	scl	m2sbk	dsh, mvfr, ws, wp		
2Cg	162-220	10YR 6/1		sl	massive	ds, mvfr, wss, wps		
P3: Alluvial plain (Ghoramari) : *Humic Endoaquepts*								
Ap	0-15	10YR 3/1		sl	m1gr-sbk	ds, mfr, wss, wps		
Bw	15-35	10YR 3/2		sl	m1sbk	ds, mfr, wss, wps		
2Cg1	35-70	10YR 6/1	f1f 7.5YR 6/8	fs	sg	dl, wso, wpo		
3Cg2	70-90	5Y 5/2		cs	sg	dl, wso, wpo		
P4 : Flood plain (Na-Pam) : *Aquic Udifluvents*								
Ap	0-9	10YR 4/1		cl	m2sbk	ds, fr, ws, wp		
AC	9-43	10YR 4/1		l	f1sbk	ds,fr, ws, wp		
C1	43-73	10YR 5/2		sl	Massive	ds, mvfr, wss, wps		
C2	73-101	10YR 5/1		sl	Massive	ds, mvfr, wss, wps		
2C3	101-108	10YR 6/2		fs	sg	dl, wso, wpo		

The soil texture varied widely and was related to landform situations. The soils on low hill (P1) and monadnock (P2) were medium (sandy clay to sandy clay loam) and those on alluvial (P3) and flood plains (P4) were coarser (sandy clay loam to coarse clay). Stratification was observed in the soils of unstable landforms (P3 and P4). The structure of the soils was mainly subangular blocky except in the C horizons where the structure was massive to single grain (Table 2). Thin patchy and thick continuous argillans were observed on the ped faces of low hill (P1) and monadnock (P2) respectively.

Physical and chemical characteristics

The texture of the soils showed wide variations (Table 3). Higher sand content (31.7- 91.4 per cent) was observed in alluvial (P3) and flood plain (P4) soils as compared to other two land forms . Fine sand constituted the major portion of the total sand. In general, the sand content increased with soil depth where as a reverse trend was observed in silt and clay distribution with few exceptions. Such type of distributions of soil separates in alluvial (P3) and flood plain (P4) reflects the fluvial characteristics of these soils (Karmakar and Rao, 1999). The amount of clay was higher (11- 34.5 percent) in soils of low hill (P1) and monadnock (P2) as compared to the other soils. In the soils of low hill (P1) and monadnock (P2), the clay increased with depth, reached a maximum and decreased thereafter indicating fairly well developed soils (Barshad 1964). On the other hand, the clay content decreased with depth in soils of alluvial and flood plains which reflect the initial stage of soil development.

Table 3. Physical and some chemical properties of the soils

Horizon	Depth (cm)	Coarse sand	Fine sand	Total sand	Silt	Clay	Org. matter ($g\ kg^{-1}$)	pH in		∆ pH	EC (dSm^{-1})
		---------- (%) ----------						H_2O	1*N* KCl		
P1: Low Hill (Gamani) : *Ultic Hapludalfs*											
A	0-8	8.3	46.4	54.7	18.5	26.8	31.7	5.1	4.1	1.0	0.30
B	8-52	5.2	42.7	47.9	21.7	30.3	11.4	4.8	3.4	1.4	0.16
Bt	52-140	6.4	51.3	57.7	10.0	32.3	5.2	4.8	3.2	1.6	0.09
P2: Monadnock (Baliparai) : *Ultic Hapludalfs*											
Ap	0-25	17.1	38.5	55.6	19.3	25.1	11.5	5.2	3.9	1.3	0.17
Bt1	25-105	17.9	31.0	48.9	19.8	31.3	6.7	4.6	3.4	1.2	0.07
Bt2	105-128	19.4	31.7	51.1	14.4	34.5	1.6	5.1	3.5	1.6	0.06
BC	128-162	17.3	42.1	59.4	14.9	25.7	0.5	5.3	4.7	1.6	0.04
2Cg	162-220	3.7	64.3	68.0	21.3	10.7	-	5.0	3.9	1.1	0.07
P3: Alluvial plain (Ghoramari) : *Humic Endoaquepts*											
Ap	0-15	30.3	46.0	76.3	13.1	10.6	34.7	4.9	3.8	1.1	0.20
Bw	15-35	25.2	49.4	74.6	12.8	12.6	29.0	5.1	4.0	1.1	0.15
2Cg1	35-70	8.6	77.4	86	12.4	1.6	1.6	5.4	4.3	1.1	0.09
3Cg2	70-90	49.6	41.7	91.4	6.1	2.5	0.8	5.6	4.8	0.8	0.07
P4 : Flood plain (Na-Pam) : *Aquic Udifluvents*											
Ap	0-9	6.8	24.9	31.7	40.0	28.3	38.3	5.8	4.5	1.3	0.32
AC	9-43	2.9	33.2	36.1	38.1	25.7	17.6	5.6	4.2	1.4	0.28
C1	43-73	1.4	62.6	64.0	23.3	12.7	5.9	6.3	4.5	1.8	0.08
C2	73-101	3.0	61.3	64.3	24.0	11.7	8.8	6.2	4.4	1.8	0.07
2C3	101-108	59.3	31.2	90.5	3.7	5.8	2.1	6.7	5.0	1.7	0.04

The organic matter content of the soil ranged from 11.5 to 38.3 g kg^{-1} in the surface and 0.5 to 29.0 g kg^{-1} in the subsurface horizons (Table 3). The surface horizons of soils under grass vegetation (P3, P4) contained higher amount of soil organic matter (34.7-38.3 g kg^{-1}) as compared to those (11.5-31.7 g kg^{-1}) under forest (P1) and tea (P2). The soil organic matter content decreased regularly with depth in all soils except in the soils of flood plain (P4), wherein its depth distribution was irregular. The pH of the soil ranged from 4.6 to 6.7. The difference in pH values determined in water and 1*N* KCl ranged from 0.8 to 1.8 units and was found to be more than one-half unit in subsurface horizons of P1 (low hill) and P2 (monadnock). This indicates sufficient amount of exchangeable aluminium or complexed slowly exchangeable aluminium present in these soils (Boul *et al.* 1978). This is also corroborated by significant negative correlation (r= -0.555**) between exchangeable H^+ plus Al^{3+} and pH in 1N KCl.

The electrical conductivity (EC) of the soil was low (0.04-0.32 dSm^{-1}) indicating no salinity problem in these soils. The free Fe_2O_3 in soils ranged from 0.41 to 2.57 per cent (Table 4). The soils on low hill (P1) and monadnock (P2) contained higher amount (0.97-2.57 per cent) of free Fe_2O_3 as compared to those on alluvial (P3) and flood plain (P4) (0.41-0.89 per cent). The amount of free Fe_2O_3 increased with soil depth up to Bt horizons of P1 and P2 whereas in soils on flood plain (P4), its depth distribution was irregular. Higher amount of free iron oxide content in the soils of P1 and P2 indicates better development of these soils (Dey and Sehgal 1997) than others. The amount of free Al_2O_3 ranged from 0.17 to 0.98 per cent with narrow range of variation among the soils (Table 4).

Table 4. Exchange properties of soils

Hori-zon	Free		Exchangeable				Exch. Acidity (H^++Al^{3+})	CEC	PBS	Fe_d /clay	Exch.Ca^{2+} / Exch. Mg^{2+}
	Fe_2O_3	Al_2O_3	Ca^{2+}	Mg^{2+}	Na^+	K^+					
	< ….. % …>		< ………… cmol (+) kg^{-1} ……………….. >								
P1: Low Hill (Gamani) : *Ultic Hapludalfs*											
A	1.64	0.66	5.72	3.45	0.15	0.80	6.75	14.5	69.8	0.04	1.66
B	2.15	0.88	3.40	2.80	0.07	0.17	7.61	11.1	58.0	0.05	1.21
Bt	2.50	0.72	2.50	2.36	0.04	0.19	8.51	11.1	45.9	0.05	1.06
P2: Monadnock (Baliparai) : *Ultic Hapludalfs*											
Ap	1.97	0.94	4.08	3.32	0.07	0.22	5.70	11.2	68.7	0.05	1.23
Bt1	2.57	0.33	3.20	1.80	0.03	0.08	5.51	10.2	50.1	0.06	1.78
Bt2	2.22	0.72	2.80	2.27	0.05	0.06	7.12	9.1	56.9	0.05	1.23
BC	1.43	0.58	1.18	2.12	0.05	0.06	6.34	7.1	48.0	0.04	0.56
2Cg	0.97	0.36	1.50	1.80	0.05	0.06	5.89	6.7	50.9	0.06	0.83
P3: Alluvial plain (Ghoramari) : *Humic Endoaquepts*											
Ap	0.43	0.98	3.51	0.92	0.28	0.17	8.46	11.2	43.6	0.03	3.82
Bw	0.68	0.72	2.40	0.60	0.08	0.16	6.33	8.9	36.4	0.04	4.00
2Cg1	0.70	0.25	1.80	0.60	0.06	0.14	1.81	6.8	38.2	0.31	3.00
3Cg2	0.41	0.17	1.20	0.60	0.03	0.12	0.85	4.5	43.3	0.11	2.00

P4 : Flood plain (Na-Pam) : *Aquic Udifluvents*

Ap	0.86	0.25	4.74	3.06	0.54	0.09	9.68	17.8	47.4	0.02	1.55
AC	0.89	0.61	4.82	4.18	0.21	0.15	7.15	15.4	60.8	0.02	1.15
C1	0.63	0.19	2.77	2.63	0.12	0.09	4.98	10.0	56.1	0.03	1.05
C2	0.77	0.64	3.92	2.68	0.16	0.12	5.44	10.8	63.7	0.05	1.46
2C3	0.48	0.52	1.36	1.64	0.06	0.05	1.81	4.2	74.0	0.06	0.83

PBS = Percent Base saturation, CEC= cation exchange capapcity, Fed= dithinate extractable iron.

Exchangeable Ca^{2+} was the dominant cation in these soils ranging from 1.18-5.72 cmol (+) kg^{-1} followed by exch. Mg^{2+} (0.60-4.18 cmol (+) kg^{-1}), exch. K^+ (0.05-0.80 cmol (+) kg^{-1}) and exch. Na^+ (0.03-0.54 cmol (+) kg^{-1}) (Table 4). The soils of low hill (P1) contained the highest amount of exchangeable bases with a decreasing trend with soil depth. The exchangeable acidity (H^++Al^{3+}) ranged from 0.85-9.68 cmol (+) kg^{-1} soil. The data on cation saturation (Fig. 2, Fig. 3) showed that major portion of the exchange sites was saturated with exchangeable (H^++Al^{3+})ranging from 42.6 to 64.5 per cent in the surface horizons of P2 and P3 respectively, and 41.62 to 59.6 per cent in the series control section (SCS) of P3 and P1 respectively. This was followed by exchangeable Ca^{2+} ranging from 25.82 to 30.47 per cent in the surface horizons of P3 and P2 respectively and 20.48 to 39.02 per cent in the SCS of P1 and P3 respectively; exchangeable Mg^{2+} ranging from 6.65 to 24.79 per cent in the surface horizons of P3 and P2 respectively and 14.88 to 23.84 per cent in the SCS of P3 and P4 respectively; exchangeable K^+ ranging from 0.76 to 2.34 per cent in the surface horizons of P4 and P1 respectively and 0.75 to 3.29 per cent in the SCS of P2 and P3 respectively; exchangeable Na^+ ranging from 0.52 to 1.89 per cent in the surface horizons of P2 and P4 respectively and 0.28 to 1.23 per cent in the SCS of P2 and P4 respectively (Fig. 2, Fig. 3).

The exchangeable acidity (H^++Al^{3+}) was positively and significantly correlated with clay (r=0.721**) and organic matter content (r=0.589**). The step-wise multiple regression analysis showed that clay content alone accounted for 72.1 percent of the variability in exchangeable acidity (H^++Al^{3+}); clay and organic matter together explained for 86.4 percent of the variability. Inclusion of silt could slightly increase (0.7 percent) the predictability. This indicates that clay and organic matter are the main contributors to exchange acidity in these soils.

Exch. Acidity (H^++Al^{3+}) = 2.839 + 0.157 clay R^2 =0.721

Exch. Acidity (H^++Al^{3+}) = 2.084 + 0.140 clay + 0.090 OM R^2 =0.864

Exch. Acidity (H^++Al^{3+}) = 1.776 + 0.131 clay + 0.081 OM + 0.032 silt R^2 =0.871

The cation exchange capacity (CEC) of the soils varied from 4.2 to 17.8 cmol (+) kg^{-1}. The CEC was positively and significantly correlated with silt (r = 0.803**), organic matter (r= 0.727**) and clay (r = 0.599**). This suggests that silt fraction also carries sufficient negative charge which may be due to weathering and/or finer silt fraction nearer to 0.002 mm size. Many workers (Caravaca *et al.* (1999; Leinweber *et al.* 1993) also reported contribution of fine silt fraction towards CEC. The step-wise multiple regressions showed that silt fraction alone accounted for 80.3 percent of the variability in CEC. The silt and organic matter together explained for 91.0 percent of the variability. Inclusion of clay increased only 5.0 per cent in the predictability. This indicates that silt, organic matter and clay are the main contributors to cation exchange capacity in the studied soils.

Fig. 2. Cation saturation on surface soils (0-25 cm)

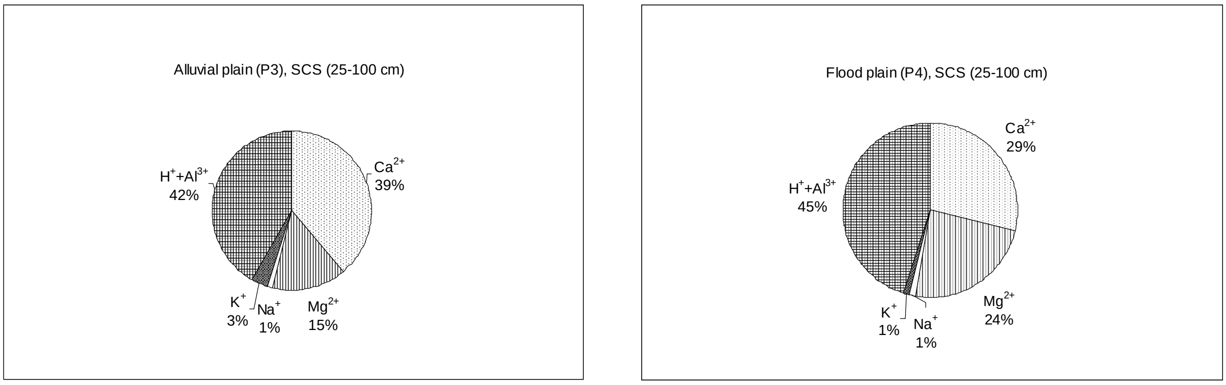

Fig. 3. Cation saturation on soils of series control section (25-100 cm)

CEC = 4.4624 + 0.302 silt R^2 =0.803

CEC = 4.249 + 0.227 silt + 0.131 OM R^2 =0.910

CEC = 3.066 + 0.178 silt + 0.131 OM + 0.109 clay R^2 =0.960

The base saturation of the soils varied from 36.4-74.0 per cent. The base saturation was maximum (47.4-74.0 per cent) in the soils on flood plain (P4) in which it increased with soil depth.

The Fe_d/clay ratio varied narrowly in P1 (0.04-0.05) and P2 (0.04-0.06) as compared to that in P3 (0.03-0.31) and P4 (0.02-0.06). Apparent constancy of Fe_d / clay ratio in P1 (low hill) and P2 (monadnock) indicated migration of Fe_d with clay. This is also supported by the significant positive correlation (r = 0.840**) between Fe_d and clay.

Soil classification

All the soils have ochric epipedon. The soils on low hill (P1) and monadnock (P2) have argillic horizons characterized by having more than 1.2 times clay content as compared to eluvial horizons and presence of thin patchy and thick continuous clay cutans on ped faces, respectively. The base saturation in these soils at a depth of 125 cm from top of argillic horizons is more than 35 per cent but less than 60 per cent. The soil moisture regime is *udic*. Therefore, these two soils, P1 and P2, qualify for *Ultic Hapludalfs* at subgroup level. The soils on alluvial plain (P3) have cambic horizon and within 50 cm of soil surface, chroma of = 2 with characteristics of redox concentration. These soils have endosaturation condition and colour value moist of 3 throughout the upper 15 cm of the soil surface but the base saturation is <50 per cent. So these soils qualify for *Humic Endoaquepts* at subgroup level. The soils on flood plain (P4) have no diagnostic horizon other than ochric; slope of less than 25 per cent and soil organic carbon irregularly decreased with soil depth. The soils are water saturated during monsoon. So these soils qualify for *Aquic Udifluvents* at the subgroup level.

Pedogenic consideration

The studied soils have developed in different land form units and have varying degree of pedogenic development as indicated by process of horizonation. The soils on relatively unstable landforms (P4: flood plain) are young and immature with Ap-AC-C1-C2-2C3 horizons whereas those on alluvial plain (P3) have Ap-Bw-2Cg1-3Cg2 horizonation. The soils on relatively old land form units (low hill and monadnock) are more developed with A-B-Bt horizons and Ap-Bt1-Bt2-BC-2Cg horizons respectively. The process of illuviation is operative in the soils of low hill (P1) and monadnock (P2). The ratio of exchangeable Ca^{2+} to Mg^{2+} was less and decreased with soil depth in P1 (low hill) and P2 (monadnock) as compared to the other two soils (Table 4). This suggests that the soils on low hill and monadnock are more developed. Boul *et al.* (1978) also reported that, in humid and subhumid regions, exchangeable Mg^{++} increases with respect to exchangeable Ca^{++} with increasing soil age and degree of development. Lower values and irregular depth distribution of this ratio in soils of flood plain (P4) suggests that flood plain was formed by deposition of pre-weathered materials. Apparent constant Fe_d/clay ratio with soil depth observed in low hill (P1) and monadnock (P2) indicates movement of iron and clay in these soils (Table 4).

Potentiality evaluation

The productivity index (P), potentiality index (P') and coefficient of improvement (CI) of the soils for different land uses are presented in Table 5. The productivity of the soils varied from 32.3 per cent in P2 to 39.5 per cent in P4. The productivity rating class was good (35.9 per cent) in P1 (low hill) and P4 while it was average in P2 (monadnock) and P3 (alluvial plain). With agronomic practices like moisture conservation and nutrient management, the productivity of these soils could be improved to good in P2 (54.7 per cent) and P3 (58.5 per cent). For pastures, the productivity index (P) of the soils varied from 27.7 per cent in P2 to 52.0 per cent in P4 with productivity rating class of good in P3 (40.9 per cent) and P4 (52.0 per cent) and average in P1 (32.8 per cent) and P2 (29.5 per cent). Adopting agronomic practices like moisture conservation and nutrient management, the productivity of these soils could be improved to good in P1 (43.1 per cent), P2 (43.1 per cent) and to excellent in P3 (65.8 per cent), P4 (73.1 per cent) with irrigation facility. For commercial crops (forestry and non-forestry), the productivity index (P) of the soils varied from 7.3 per cent in P4 to 30.8 per cent in P1 with productivity rating class of average in P1, P2, P3 and extremely poor in P4. The potentiality (P') of these soils could be improved to good in P1, P2 and P4.

Table 5. Assigned scores of soil characteristics for specific land use (SLU) and productivity index (P), potentiality index (P') and coefficient of improvement (CI) of the soils

Pedon No.	SLU	H	D	P	T	N	O	A	M	Productivity		CI
										P	P'	
	C	70	100	100	100	60	100	95	90	35.9	54.7	1.52
		(80)	(100)	(100)	(100)	(80)	(100)	(95)	(90)	(2)	(II)	
P1	P	60	80	100	100	80	100	95	90	32.8	43.1	1.31
		(70)	(80)	(100)	(100)	(90)	(100)	(95)	(90)	(3)	(II)	
	T	40	100	100	100	90	100	95	90	30.8	53.9	1.75
		(70)	(100)	(100)	(100)	(100)	(100)	(95)	(90)	(3)	(II)	
	C	70	100	100	100	60	90	95	90	32.3	54.7	1.67
		(80)	(100)	(100)	(100)	(80)	(100)	(95)	(90)	(3)	(II)	
P2	P	60	80	100	100	80	90	95	90	29.5	43.1	1.46
		(70)	(80)	(100)	(100)	(90)	(100)	(95)	(90)	(3)	(II)	
	T	40	100	100	100	90	90	95	90	27.7	59.8	2.16
		(70)	(100)	(100)	(100)	(100)	(100)	(95)	(90)	(3)	(II)	
	C	90	90	100	100	50	100	95	95	32.9	58.5	1.78
		(100)	(90)	(100)	(100)	(80)	(100)	(95)	(95)	(3)	(II)	
P3	P	80	90	100	100	70	100	95	95	40.9	65.8	1.61
		(100)	(90)	(100)	(100)	(90)	(100)	(95)	(95)	(2)	(I)	
	T	90	40	100	100	80	100	95	95	23.4	32.5	1.39
		(100)	(40)	(100)	(100)	(100)	(100)	(95)	(95)	(3)	(III)	
	C	100	80	100	100	60	90	95	95	39.5	65.0	1.65
		(100)	(90)	(100)	(100)	(80)	(100)	(95)	(95)	(2)	(II)	
P4	P	100	80	100	100	80	90	95	95	52.0	73.1	1.41
		(100)	(90)	(100)	(100)	(90)	(100)	(95)	(95)	(2)	(I)	
	T	100	10	100	100	90	90	95	95	7.3	36.1	4.95
		(100)	(40)	(100)	(100)	(100)	(100)	(95)	(95)	(5)	(III)	

*SLU = Specified land use : C= Crop, P= Pasture, T= Trees (Forest or non-forest); ** Figures in the parenthesis represent potentiality rating scores.

Classes of productivity (P) and potentiality (P')

P	Classes	Rating	P'
1	Excellent	65 – 100	I
2	Good	35 – 64	II
3	Average	20 – 34	III
4	Poor	8 – 19	IV
5	Extremely poor	0 – 7	V

The coefficient of improvement (CI) varied from 1.52 in P1 (low hill) to 1.78 in P3 (alluvial plain) for growing crop, 1.31 in P1 to 1.61 in P3 for pasture and 1.39 in P3 to 4.95 in P4 (flood plain) for commercial trees. The results indicate that the soils on alluvial plain (P3) have the highest potentiality for crop growing and pasture while the soils on flood plain (P4) could be considerably improved for commercial trees.

Conclusion

From the present study it can be concluded that distinct relationship exists between soil properties and landform units. The soils on different landforms are at varying degree of pedogenic development and have different productivity and potentiality for specified land uses. The soil resource data generated in the present investigation could be well utilized for general crop planning of the area with specific situations management practices. However, more study is needed on pedogenic development of these soils.

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