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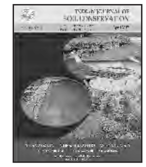

Assessment of fertility potential for the soils of Northern Brahmaputra valley zone using Principal Component Analysis

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ABSTRACT

An attempt is made to model relationships of soil physical-chemical-hydraulic parameters of 50 rice-growing soils for fertility potential classification under 6 physiographic units of Northern Brahmaputra Valley Zone (NBVZ) of Assam. The physiographic units studied were Old Flood Plain (OFP), Lower Alluvial Plain (LAP), Upper Alluvial Plain (UAP) Lower Piedmont Plain (LPP), Upper Piedmont Plain (UPP) and Structural Hill (SH) soils. Relationships of 27 soil parameters were established using Principal Component Analysis (PCA). The PCs identified are (i) Inherent Potentiality; (ii) Soil Loss; (iii) Nitrozinc; (iv) Cation Exchange; (v) Acidity; (vi) Copper; and (vii) Anionic factors which could explain 81% variability in soil parameters. Based on eigen vectors of PCs, component scores were determined for ranking soils and physiographic units. Dhullie (No. 32) soil ranked first for soil fertility, while OFP soils were most fertile. The ranking of soils was in agreement with analytical values of soil physical-chemical-hydraulic parameters. UPP soils had maximum values for CEC, acidity and anionic factors, compared to LPP soils for copper. The values were maximum for UAP for nitrozinc factor; LAP for soil loss factor; and SH for inherent potentiality. Among 27 soil parameters studied, silt, organic matter, CEC, manganese, field capacity, AWC and clay were found significant and contributed to the total variability. The soil classification would be useful for development of strategies for efficient management of crops under Northern Brahmaputra Valley Zone of Assam.

1. INTRODUCTION

Soil fertility refers to quality that enables soil to provide required nutrients in proper quantity and balance for growth of plants (Sharma *et al.,* 2011). The usefulness of a soil survey report is enhanced, if taxonomic units are grouped into management units for indicating potential and constraints of an area in terms of fertility. The fertility capability classification is a technical soil classification system that would focus quantitatively on soil physical, chemical and hydraulic properties important for soil fertility management (Mohanty and Filipovski, 1982). The fertility capability classification was designed to group soils having similar limitations of fertility management (Buol, 1972). The soil fertility capability classification system was developed as an attempt to bridge gap between soil classification and fertility, especially to interpret soil taxonomy and additional soil attributes in a way that is directly relevant to plant growth (Zehetner and Miller, 2006; Geissen *et al.,* 2009). It would lay maximum emphasis on component of soil fertility within 50 cm layer from surface. Norris (1971) observed that principal component analysis has an immense utility for quantitative evaluation of soil fertility to obtain fertility potential classification. PCA is a statistical device to reduce dimensionality of number of variables to a few indices (Dunteman, 1989; Jolliffe, 1986). The transformation of raw fertility data using PCA would result in new observations that are often better interpretable than original data (Norris, 1972).

The Principal Component (PC) model would compare information of number of fertility parameters into a few transformed factors. Anderson and Furley (1975) inferred that such a dimensionality reduction is an important economic consideration, especially if potential information recoverable from transformed data is as good as original data.

Mohanty and Filipovski (1981) developed a principal component model for quantitative classification of fertility potential for rice growing soils of Yugoslavia. They found that 4 principal components explained about 75% of total variability in the soil fertility parameters. They termed the factors as inherent potentiality, organic matter, phosphate and potassium in the order of importance. In a paper by Mohanty and Filipovski (1982), the authors evaluated 15 rice-growing soils for fertility potential considering 30 characters based on principal component analysis. They found that 5 principal components explained about 77% of variability in the soil parameters. Jagdish Prasad (2000) observed that the fertility capability classification was useful for relating the fertility limitation to crop yield response for tropical soils of semi-arid region. Rao and Jose (2003) found that the fertility capability classification system facilitated an addition or modification of management constraints under rubber growing soils. Mishra *et al.* (2012) assessed the soil physical, chemical and hydraulic properties after ameliorating Vertisols with sand for efficient crop and water management in south India. Ramteke *et al.* (2013) made an efficient crop planning after assessing the soil productivity under semi-arid Vertisols using MIKE SHE model. Adhikary *et al.* (2010) classified soils of different physiographic units in southern Haryana based on soil fertility capability classification and mapped them using Remote Sensing and GIS techniques. Ramachandran *et al.* (2016) used geostatistics for measuring agricultural sustainability and assessing the impact of watershed projects in Nalgonda district of Telangana. There is an immediate need to assess the soil fertility potential of rice-growing soils under Northern Brahmaputra Valley Zone in order to develop an efficient rice based cropping systems for efficient utilization of natural resources. Based on the observations collected on 27 soil physical, chemical and hydraulic parameters under 6 physiographic units, a principal component model has been developed for assessing the soil fertility potential of rice-growing soils under Northern Brahmaputra Valley Zone of Assam.

2. MATERIALS AND METHODS

The Brahmaputra valley of Assam is a part of Indo-Gangetic plain and covers large area of 56578 km^2. Due to differences in the sediment deposited by tributaries, wide variability in soil properties is noticed across Brahmaputra valley. The study area is a part of NBVZ of Assam and is situated between 93^{0}03' E to 93^{0}12' E longitude and 26^{0}41' N to 26^{0}56' N latitude. Six physiographic units *viz.*, SH, UPP, LPP, UAP, LAP and OFP were identified in the study (Deka *et al.*, 2009). About one kilogram soil each from 50 rice-growing soils representing different physiographic units were collected from 0-25 cm depth. Among the samples, 6 were from OFP, 19 from LAP, 10 from UAP, 11 samples from LPP and two samples each from UPP and SH. They were air-dried, grinded and sieved through 2 mm sieve and stored in polythene bags for laboratory analysis. The samples were analyzed for 27 soil parameters such as very fine sand (%); total sand (%); silt (%); clay (%); hydraulic conductivity (HC cm hr^{-1}); field capacity (FC, %); permanent wilting point (PWP, %); available water content (AWC, %); water holding capacity (WHC, %); cation exchange capacity (CEC) [cmol (p$^+$) kg^{-1}]; exchange capacity of clay [cmol (p$^+$) kg^{-1}]; apparent CEC [cmol (p$^+$) kg^{-1}]; bulk density (Mg m^{-3}); pH; base saturation (%); organic matter (OM, %); available N (kg ha^{-1}); P_2O_5 (kg ha^{-1}); K_2O (kg ha^{-1}); sulphur (kg ha^{-1}); iron (mg kg^{-1}); manganese (mg kg^{-1}); copper (mg kg^{-1}); zinc (mg kg^{-1}); relief (m); macro-aggregates (%); and micro-aggregates (%) using standard methods and procedures (Table 1). The collected samples belong to the order Entisols and Inceptisols.

Statistical Analysis

The analyzed soil parameters were used for fertility potential classification using PCA. This technique would facilitate in reducing large number of inter-dependent variables to small set of meaningful and uncorrelated new variables known as principal components (Dunteman, 1989; Jolliffe, 1986). The PCA of soil parameters would provide scope to examine correlation matrix, eigen values and vectors with loadings of variables on PCs. The eigen values would explain amount of variance contributed by each component. The eigen vectors are coefficients of transformation equation of each component. The loadings would indicate degree of correlation among components and original variables.

A soil parameter is considered significant, if it has at least a loading of more than ± 0.4 (Maruthi Sankar *et al.,* 2014). We propose that a soil parameter could have (i) highly significant effect on a PC, if it has a loading of more or less than ± 0.7 (ii) significant effect on a PC, if it has positive loading in the range of 0.4 to 0.7 or negative loading in the range of - 0.7 to - 0.4; (iii) low and non-significant effect, if it has loading of less than + 0.4 or more than - 0.4. Each soil sample was assigned a 'Score' which is the computed value of the factor at that site and is referred as 'Component score'. The PC scores could be computed as a sum of products of loadings and values of soil parameters. The samples were ranked with respect to each PC. The mean value of ranks of soils was computed on soil physiographic unit basis which was subsequently used for ranking the physiographic units for soil fertility.

3. RESULTS AND DISCUSSION

Soil Parameters Observed in Different Physiographic Units

The soil samples were collected from 6 physiographic units of Ghiladhari watershed of Assam. The area, extent, land use of different physiographic units of the locations from where soil samples were collected in the watershed are given in Table 2. The soils of 6 physiographic units vary widely with respect to the analyzed soil parameters. The minimum Coefficient of Variation (CV) was observed as 5.1% for Bulk Density (BD) whereas the maximum CV of 70.1% was observed for very fine sand (Table 3).

The clay content ranged from 8.8 to 30.5% in SH and UAP soils respectively. The mean hydraulic conductivity of soils ranged from 0.99 to 5.32 cm hr^{-1} under UAP and LPP

Table: 1
Methods used in determining the physico-chemical and erosion related properties of soils in Ghiladhari watershed

S.No.	Parameters	Methods	References
1.	Very fine sand, total sand, silt, clay	International Pipette method	Piper (1966)
2.	Hydraulic conductivity	Constant head method	Klute (1965)
3.	Field capacity, permanent wilting point, Available water content	Pressure plate technique	Richards (1948)
4.	Water holding capacity	Keen-Rackzowski box method	Piper (1966)
5.	Cation Exchange Capacity (CEC)	Centrifuge method	Jackson (1973)
6.	Exchange Capacity of Clay (ECOC)	[CEC - (1.75 × organic matter)] x 100	Vadivelu (2002)
7.	Apparent CEC (ACEC)	(CEC/Clay) x 100	Vadivelu (2002)
8.	Bulk-density	Core method	Bodman (1942)
9.	Soil reaction (1:2.5)	Glass Electrode pH meter	Jackson (1973)
10.	Base saturation	[∑ Exchangeable bases/CEC] x 100	
11.	Organic matter	Walkley and Black's method	Jackson (1973)
12.	Available nitrogen	Alkaline $KMnO_4$ method	Subbiah and Asija (1956)
13.	Available phosphorus	Extracted with 0.03 N NH_4F in 0.025 N HCI (Bray's No.1 method)	Bray and Kurtz (1945)
14.	Available potassium	Flame photometric method	Jackson (1973)
15.	Available sulphur	Turbidimetric method	Ensminger (1954)
16.	Available micro nutrient (Fe, Mn, Cu, Zn)	DTPA method	Lindsay and Norvell (1978)
17.	Relief (metre)	Using Global Positioning System (GPS)	
18.	Macro-aggregates and Micro-aggregates	Wet sieving method	Yoder (1936)

Table: 2
Area, land use and name of the soil sampling sites in different physiographic units of Ghiladhari watershed

Physiographic unit	Area (ha)	No.	Land use	Name of location
Old Flood Plain	1325 (5.7)	6	Predominantly agricultural usage for paddy. Also mustard, jute and sugarcane are grown. Mostly double cropped.	(1) Bakrapatachapari (2) Digali Bil (3) Kadamani Bill (4) Dagaon (5) Bhirgaon (6) Garaihabi
Lower Alluvial Plain	7027 (30.4)	19	Agricultural usage for paddy. Also mustard and vegetables are grown. Some areas are under sugarcane and tea plantation	(7) Kadamani (8) Sakomata (9) Nilpur (10) Mahout (11) Bamgaon (12) Dagaon (13) Lehugaon (14) Kaldunga (15) Gereki (16) Pratapgarh (17) Kaldhoma (18) Petulibari (19) Borigaon (20) Jopoubari (21) Begunbari (22) Kamarijan (23) Barpathar (24) Dahatar (25) Bamuni Pathar
Upper Alluvial Plain	6386 (27.7)	10	Along with paddy, mustard and vegetables are also grown. Some areas are under tea plantation.	(26) Barpura (27) Kharasimalu (28) Phulchundari (29) Pabhoi (30) Missamari (31) Nihanchang (32) Dhullie (33) Lachaman Basti (34) Balichang (35) Majuli Pathar
Lower Piedmont Plain	5064 (21.9)	11	Agricultural crops like paddy, mustard and vegetables are grown. Also tea plantations are seen.	(36) Bhimajuli (37) Diring-I (38) Pabhoi tea garden (39) Mijikajan (40) Napamua (41) Mikir Block (42) Diring tea garden (43) Diring-II (44)Sariahbil (45) Madhupur Bongaon (46) Kachari Gaon
Upper Piedmont Plain	1699 (7.4)	2	Forest cover, paddy, mustard and vegetable cultivation.	(47) Majuli (48) Biswanath reserve forest
Structural Hills	1585 (6.9)	2	Forest cover, paddy and vegetable cultivation.	(49) Hill-I (50) Hill-II
Total	23086	50		

Values in parentheses indicate per cent of total geographical area

Table: 3
Weighted mean, weighted standard deviation and coefficient of variation of soil parameters in different soil physiographic units

Soil parameters	OFP	LAP	UAP	LPP	UPP	SH	μ	CV (%)
Very fine sand (%)	14.2	13.6	13.2	44.8	35.0	56.4	23.0	70.1
Total sand (%)	42.8	47.8	28.8	75.5	64.2	80.1	51.4	35.8
Silt (%)	27.2	27.1	40.7	12.8	18.1	11.1	25.7	41.2
Clay (%)	30	24.9	30.5	11.8	17.7	8.8	22.8	35.7
Hydraulic conductivity (cm hr^{-1})	2.34	2.22	0.99	5.32	4.52	1.11	2.72	62.8
Field capacity (%)	29.3	27.4	30.7	22.4	24.7	27	27.1	11.7
Permanent wilting point (%)	7.1	6.1	5.5	7.3	5.8	8.1	6.4	12.8
Available water content (%)	22.2	21.3	25.2	15.1	18.9	18.9	20.6	18.1
Water holding capacity (%)	36.9	33.7	33.2	24.6	25.5	19.5	31.1	17.1
Cation exchange capacity [cmol (p^+)kg^{-1}]	9.8	7.7	8.9	4.5	7.2	4.2	7.3	27.7
Exchange capacity of clay [cmol(p^+)kg^{-1}	21	21	20.6	26.8	23.6	30.6	22.7	14.1
Apparent CEC [cmol (p^+)kg^{-1}]	32.5	31.2	28.8	39.8	41.1	48.4	33.9	16.6
Bulk density (Mg m^{-3})	1.36	1.36	1.38	1.51	1.46	1.53	1.41	5.1
pH	5.1	5.1	4.7	5.3	4.3	5.3	5.0	5.5
Base saturation (%)	53	55	50	49	41	45	51	7.6
Organic matter (%)	1.89	1.38	1.39	0.88	1.3	0.88	1.31	25.3
Available N (Kg ha^{-1})	398	287	359	286	320	296	316	14.3
Available P_2O_5 (Kg ha^{-1})	28.5	25.1	25.6	16.7	13.8	22.2	23.2	20.5
Available K_2O (Kg ha^{-1})	186	183	113	53	97	61	132	45.6
Available S (Kg ha^{-1})	15.6	14.4	28.2	8.4	4.4	11.4	15.5	49.8
Available Fe (mg kg^{-1})	115	132	200	54	133	83	124	42.5
Available Mn (mg kg^{-1})	91	66	82	31	109	50	66	36.6
Available Cu (mg kg^{-1})	37	28	40	18	50	14	30	34.2
Available Zn (mg kg^{-1})	2.3	1.5	1.5	1.2	2.2	2.1	1.6	24.4
Relief (m)	46	66	84	116	157	292	91	59.3
Macro-aggregate (%)	71	59	57	44	42	25	55	20.5
Micro-aggregate (%)	29	41	43	56	58	75	45	24.9

μ : Weighted mean ; σ : Weighted standard deviation ; CV : Coefficient of variation (%)

soils; while FC was in the range of 22.4 to 30.7% and AWC was in the range of 15.1 to 25.2% under LPP and UAP soils respectively. Minimum PWP of 5.5% was observed in UAP soils, while maximum of 8.1% was observed in SH soils.

The WHC ranged from 19.5 to 36.9%; while CEC ranged from 4.2 to 9.8 [cmol (p^+) kg^{-1}] under SH and OFP soils. The exchange capacity of clay ranged from 20.6 to 30.6 [cmol (p^+) kg^{-1}]; while apparent CEC ranged from 28.8 to 48.4 [cmol (p^+)kg^{-1}] under UAP and SH soils. The OFP and LAP soils had a minimum BD of 1.36 Mg m^{-3}, while SH soils had maximum of 1.53 Mg m^{-3}. The pH of soils ranged from 4.3 under UPP soils to 5.3 under LPP soils. The base saturation ranged from 41 to 55% under UPP to LAP soils respectively. Minimum mean OM of 0.88% was found under SH and LPP soils compared to maximum of 1.89% under OFP soils.

The soil N ranged from 286 to 398 kg ha^{-1}; while available K and Zinc ranged from 53 to 186 kg $ha^{-1}$and 1.2 to 2.2 mg kg^{-1} under LPP and OFP soils respectively. The available P ranged from 13.8 kg ha^{-1} under UPP to 28.5 kg ha^{-1}under OFP soil; while sulphur ranged from 4.4 to 28.2 kg ha^{-1}under UPP and Upper Alluvial Plain soil. Iron ranged from 54 to 200 mg kg^{-1} while Manganese and Copper ranged from 31 to 109 mg kg^{-1} and 14 to 50 mg kg^{-1} under LPP and UPP soil. The mean relief ranged from 46 to 292 m and micro-aggregates ranged from 29 to 75% under OFP and SH soils; while macro-aggregates ranged from 25 to 71% under SH and OFP soils, respectively.

Relationship Between Different Soil Parameters

A correlation matrix was derived for the analyzed soil parameters of 6 soil physiographic units (Table 4). Significantly higher positive correlation of >0.60 was observed for (i) very fine sand with total sand, relief and bulk density; (ii) clay with FC, AWC , CEC, WHC, iron, manganese and macro-aggregates; (iii) FC with available water content, CEC and manganese; (iv) base saturation with pH; (v) BD with total sand; (vi) AWC with CEC and iron; (vii) WHC with CEC, OM and macro-aggregates; (ix) CEC with manganese. Significantly higher negative correlation of >0.60 was observed for (i) very fine sand with silt and clay; (ii) total sand with silt, clay, AWC, FC, CEC, iron and manganese; (iii) BD with silt, clay, FC, AWC and WHC; (iv) micro-aggregates with clay and WHC; (v) pH with iron and manganese. The importance of soil physical, chemical and hydraulic parameters for explaining variability in soil fertility data was examined based on PC analysis. Similar results were reported by Adhikary *et al.* (2010), who made a soil fertility capability classification under semi-arid climate in India. Ensminger (1954) assessed the significance of different factors affecting

Table: 4
Correlation between soil physical, chemical and erosion related parameters

	VFS	TS	Silt	Clay	HC	FC	PWP	AWC	WHC	CEC	BD	pH	BS
TS	0.828**												
Silt	-0.749**	-0.924**											
Clay	-0.740**	-0.868**	0.612**										
HC	0.525**	0.584**	-0.480**	-0.582**									
FC	-0.547**	-0.792**	0.579**	0.885**	-0.576**								
PWP	0.353*	0.413**	-0.336*	-0.416**	0.509**	-0.352*							
AWC	-0.573**	-0.801**	0.596**	0.882**	-0.643**	0.962**	-0.595**						
WHC	-0.586**	-0.575**	0.388**	0.686**	-0.301*	0.579**	-0.312*	0.589**					
CEC	-0.589**	-0.713**	0.450**	0.888**	-0.443**	0.781**	-0.215	0.734**	0.615**				
BD	0.699**	0.690**	-0.632**	-0.603**	0.467**	-0.608**	0.329*	-0.618**	-0.657**	-0.501**			
pH	0.206	0.417**	-0.355*	-0.393**	0.309*	-0.407**	0.240	-0.420**	-0.244	-0.303*	0.365**		
BS	-0.368**	-0.025	0.009	0.045	-0.008	-0.105	-0.066	-0.070	0.125	0.016	-0.058	0.726**	
OM	-0.466**	-0.474**	0.333*	0.547**	-0.378**	0.495**	-0.249	0.498**	0.642**	0.451**	-0.581**	-0.384**	-0.035
Av.N	-0.116	-0.147	0.051	0.236	-0.228	0.216	-0.076	0.207	0.256	0.146	-0.122	-0.261	-0.080
Av.P_2O_5	-0.448**	-0.308*	0.174	0.410**	-0.328*	0.405**	-0.126	0.385**	0.435**	0.344*	-0.400**	-0.160	0.191
Av.K_2O	-0.531**	-0.305*	0.206	0.361**	-0.173	0.321*	-0.180	0.328*	0.335*	0.357**	-0.495**	0.185	0.564**
Av.S	-0.267	-0.323*	0.246	0.353*	-0.180	0.364**	-0.111	0.345*	0.434**	0.238	-0.240	-0.276*	-0.128
Av.Fe	-0.536**	-0.633**	0.504**	0.641**	-0.537**	0.582**	-0.377**	0.610**	0.420**	0.515**	-0.430**	-0.616**	-0.237
Av.Mn	-0.508**	-0.623**	0.481**	0.656**	-0.399**	0.618**	-0.204	0.591**	0.476**	0.609**	-0.490**	-0.670**	-0.361**
Av.Cu	-0.209	-0.058	0.010	0.110	-0.094	-0.002	0.139	-0.043	0.003	0.068	0.069	0.074	0.114
Av.Zn	-0.129	-0.179	0.024	0.333*	-0.266	0.343*	-0.106	0.326*	0.340*	0.324*	-0.280*	-0.257	-0.080
Relief	0.714**	0.468**	-0.366**	-0.494**	0.091	-0.188	0.160	-0.208	-0.465**	-0.412**	0.431**	0.000	-0.430**
MAG	-0.584**	-0.528**	0.362**	0.618**	-0.164	0.423**	-0.157	0.410**	0.627**	0.590**	-0.482**	-0.204	0.205
MIG	0.583**	0.527**	-0.361**	-0.618**	0.163	-0.422**	0.156	-0.408**	-0.628**	-0.590**	0.482**	0.204	-0.205

* Significant at p ≦ 0.05 probability level ; ** Significant at p ≦ 0.01 probability level

adsorption of sulphate in Alabama soils; whereas Geissen (2009) assessed effects of land-use on some properties of tropical soils in South-east Mexico. In a similar study by Vikas *et al.* (2015), the authors assessed the effect of soil tillage, mulching and rainfall by relating the factors with the performance of maize, apart from soil fertility and soil quality in Inceptisols at Jammu under dry sub-humid condition.

PC Analysis of Soil Parameters

The variability of 27 soil physical, chemical and hydraulic parameters was explained by 7 PCs with eigen values of more than 1 explaining 81% variability in soil parameters (Table 5). Based on factor loading matrix of 27 soil parameters, silt, clay, FC, AWC, WHC, CEC, OM, P, K, sulphur, iron, manganese, zinc, macro-aggregate had a positive loading; whereas very fine sand, total sand, HC, PWP, exchange capacity of clay, apparent CEC, BD, pH, relief and micro-aggregate had a negative loading on P1 (Table 5). Base saturation had a significantly higher negative loading as compared to the negative loadings of pH and K_2O and positive loading of manganese and relief on P2. Five parameters had a significant loading on P3 with PWP, apparent CEC, N and zinc with a positive loading and silt with a negative loading. In P4, 3 parameters had a significant positive loading which comprised of exchange capacity of clay; CEC and apparent CEC. The soil pH, base saturation and K_2O had a significant positive loading on P5; while copper had a significant positive loading on P6; P_2O_5 and sulphur had a significant positive loading on P7.

Component-wise grouping of soil parameters

The silt and clay content had a significant positive correlation with FC, AWC, WHC, OM, iron, manganese, macro-aggregate and mean weight diameter (Table 4). Very fine sand and total sand had a significant positive relation with HC, BD and micro-aggregate, while had a negative correlation with silt and clay parameters. Thus P1 was strongly influenced by the inherited mechanical components and chemical and fertility parameters were a set of related properties. Accordingly, the first factor was termed as 'Inherent Potentiality Factor'. P2 was significantly loaded by soil pH (-0.68), relief (0.64) and base saturation (-0.85) which were significantly correlated with each other and represented a set of related parameters. The second factor was termed as 'Soil Loss Factor'.

Significant loadings on P3 were expressed by positively correlated soil N (0.53) and zinc (0.56), indicating contribution towards chemical potentiality. Thus P3 was termed as 'Nitrozinc Factor'. P4 was significantly loaded by CEC (0.52), exchange capacity of clay (0.78) and apparent CEC (0.52) which were significantly correlated with each other. Hence, P4 which determined the contribution of exchangeable cations was termed as 'Cation Exchange Factor'.

Table: 5
Eigen values, cumulative variance (%) and matrix factor loading of soil parameters

Principal component	P1	P2	P3	P4	P5	P6	P7
Eigen value	12.15	3.31	2.29	1.98	1.50	1.22	1.04
Cumulative variance (%)	41.9	53.3	61.2	68.0	73.2	77.4	81.0
Very fine sand	-0.85	0.31	0.22	-0.02	0.07	-0.21	-0.06
Total sand	-0.88	-0.07	0.27	-0.22	0.12	-0.14	0.07
Silt	0.69	0.07	-0.40	0.17	-0.21	0.15	-0.04
Clay	0.92	0.05	-0.03	0.24	0.03	0.09	-0.10
Hydraulic conductivity	-0.59	-0.30	0.31	-0.02	-0.36	-0.22	0.08
Field capacity	0.80	0.28	-0.06	0.34	0.22	0.00	-0.05
Permanent wilting point	-0.46	-0.14	0.54	0.21	-0.16	0.18	0.14
Available water content	0.82	0.28	-0.21	0.23	0.24	-0.05	-0.09
Water holding capacity	0.77	-0.11	0.18	0.02	0.03	-0.27	0.07
Cation exchange capacity	0.77	0.00	0.20	0.52	0.06	0.08	-0.15
Exchange capacity of clay	-0.43	-0.13	0.29	0.78	0.02	0.20	0.03
Apparent CEC	-0.59	0.03	0.50	0.52	0.06	-0.05	0.01
Bulk density	-0.77	0.03	0.13	-0.04	-0.05	0.23	0.01
pH	-0.45	-0.68	-0.02	0.05	0.41	0.11	-0.05
Base saturation	0.09	-0.85	-0.13	-0.09	0.40	0.09	0.00
Organic matter	0.73	0.13	0.33	-0.36	0.11	-0.16	-0.15
Nitrogen	0.31	0.22	0.53	-0.35	0.11	0.06	-0.08
Phosphorus	0.51	-0.06	0.10	-0.04	0.36	-0.01	0.60
Potassium	0.47	-0.51	-0.02	0.04	0.44	-0.16	0.09
Sulphur	0.46	0.19	0.26	-0.09	-0.06	0.00	0.60
Iron	0.70	0.38	-0.03	-0.01	-0.12	0.20	0.32
Manganese	0.73	0.40	0.23	-0.02	-0.08	0.07	-0.04
Copper	0.14	-0.09	0.32	-0.32	0.04	0.80	-0.08
Zinc	0.42	0.27	0.56	-0.30	0.35	0.04	-0.27
Relief	-0.57	0.64	0.04	0.08	0.34	-0.08	0.00
Macro-aggregate	0.72	-0.32	0.38	0.01	-0.22	-0.22	-0.10
Micro-aggregate	-0.72	0.32	-0.38	-0.01	0.22	0.22	0.10
Highly significant (more than $\pm$ 0.70)	13	1	0	1	0	1	0
Moderately significant ($\pm$ 0.40 to $\pm$ 0.70)	11	4	5	2	3	0	2
Non-significant (less than $\pm$ 0.40)	3	22	22	24	24	26	25
Positive and significant loadings	14	2	4	3	3	1	2
Negative and significant loadings	10	3	1	0	0	0	0

P5 was significantly loaded by pH (0.41), base saturation (0.40) and exchangeable K (0.44). The base saturation, which is influenced by exchangeable K, had a significantly higher correlation with pH that influences the soil acidity. The fifth component was termed as 'Acidic Factor'. Copper (0.80) had a significant positive loading on P6 indicating the contribution of copper. Accordingly, P6 was termed as 'Copper Factor'. P7 was significantly loaded by soil P (0.60) and sulphur (0.60). These two anions were significantly correlated with each other and P7 was termed as 'Anionic Factor'.

The factors were ranked based on coefficient of variation observed within a physiographic unit and rank sum of each factor was derived over physiographic units. Based on the rank sums, 'Inherent Potentiality Factor' was superior with lowest rank sum of 16, followed by 'Soil loss factor' with rank sum of 19, 'Acidic factor' with rank sum of 22, 'Cation Exchange factor' with rank sum of 25, 'Copper factor' with rank sum of 27, 'Nitrozinic factor' with rank sum of 28 and 'Anionic factor' with rank sum of 31. The study has clearly indicated that a watershed could be efficiently assessed based on the 7 factors in the order of importance as described above.

Similar observations were made by Anderson and Furley (1975) in assessing the surface properties of chalk soils based on PCA. In another study by Prasad (2000), the soil parameters of a semi-arid watershed and fertility capability classification of soils was made for growing suitable crops. Our results are in agreement with those observed by Rao and Jose (2003) on fertility capability classification of soils in Kerala.

Fertility Ranking of Soils Based on PC Scores

Since the 7 PCs were interpretable, the 'component or factor scores' for individual 50 soils with respect to components were computed using PCA (Table 6). Based on factor scores, ranks were assigned to soils with respect to 7 PCs (Table 7). Among different soils, soil No. 32 'Dhullie' was ranked first for P1, P6 and P7 due to significantly higher measurements for inherent soil characteristics along with

Table: 6
PC scores of soils for first seven PCs under different physiographic units

Sample no.	P1	P2	P3	P4	P5	P6	P7
Old Flood Plain							
1	14.38	0.65	1.79	2.95	-0.83	0.77	-1.62
2	7.72	-0.20	2.93	4.37	-0.98	-0.01	0.22
3	5.55	-6.20	1.36	-0.80	0.13	-1.39	-0.37
4	9.34	-2.10	4.67	-2.78	1.91	0.51	-0.10
5	11.30	1.15	2.96	-2.77	1.73	-0.68	-0.12
6	8.70	-2.09	1.16	-2.21	-0.53	0.19	-0.57
Lower Alluvial Plain							
7	1.44	-4.96	-0.87	-0.06	1.72	1.14	0.67
8	8.05	-1.68	-2.24	1.03	-0.47	-0.55	-0.26
9	11.32	-1.22	-0.39	2.13	-0.82	0.08	-0.81
10	-2.96	-5.19	1.93	-0.34	-0.59	1.30	0.74
11	0.82	-2.54	-0.25	1.68	-1.11	-1.07	0.02
12	7.38	-1.03	-0.05	-2.70	0.16	0.24	-0.64
13	9.60	0.18	-2.02	1.93	-0.05	-0.39	-0.74
14	-3.89	-7.95	-2.47	3.66	4.31	-0.14	1.34
15	4.07	-5.26	2.02	-2.95	-0.27	-2.09	0.40
16	-0.26	-1.56	-0.60	-1.42	0.22	0.74	0.17
17	11.38	0.72	-0.73	-0.64	0.60	-0.06	-0.75
18	8.29	-2.65	-2.23	0.64	1.45	-0.58	-0.76
19	12.59	-0.91	-1.09	1.79	-0.02	-0.78	-0.90
20	1.89	-0.94	-3.33	0.55	0.61	-1.20	-0.33
21	-8.57	-3.97	-2.73	-1.93	3.54	0.53	-0.22
22	2.22	-0.04	2.34	-2.47	0.03	-0.28	2.62
23	0.17	-1.65	-1.48	-2.32	0.88	-1.19	0.26
24	-0.12	2.42	-2.35	-0.31	-1.96	1.24	1.75
25	15.13	2.94	4.30	1.74	0.41	0.03	-0.36
Upper Alluvial Plain							
26	8.46	-0.11	-1.93	1.17	-0.76	0.25	-0.76
27	10.88	0.35	0.83	-0.27	3.32	-0.22	0.28
28	13.69	1.91	0.32	0.45	0.30	0.54	-0.02
29	21.27	2.43	2.76	2.32	0.89	1.08	-1.01
30	10.35	1.82	-0.75	4.34	-0.99	0.59	0.53
31	-3.77	0.69	-2.16	0.80	-1.63	1.26	1.17
32	23.81	5.37	2.51	-2.40	-1.18	6.08	3.77
33	2.01	3.38	-5.23	-0.68	-1.25	1.29	0.30
34	3.21	2.94	-4.40	-0.01	-1.75	0.66	0.09
35	0.78	2.16	-3.41	-0.83	-0.75	1.59	0.23
Lower Piedmont Plain							
36	-23.95	-3.87	2.33	-1.08	0.45	-0.12	0.63
37	-14.81	0.16	0.64	1.58	-0.11	-0.57	0.76
38	-6.42	2.40	-0.74	-1.79	-0.12	-0.29	-1.39
39	-13.60	0.44	1.11	0.36	-2.47	-0.69	-0.11
40	-19.21	-1.90	3.07	0.44	-1.42	-0.84	-0.03
41	-14.00	0.58	-1.17	-2.33	-1.00	-1.34	-1.96
42	-22.71	-2.36	2.18	1.71	-1.37	-0.44	0.07
43	-21.67	-1.04	1.72	1.47	-1.95	-1.24	-0.09
44	-11.96	-0.75	-3.19	-1.33	1.46	-0.97	-0.35
45	-10.54	2.08	-3.90	-0.65	0.66	-1.03	1.11
46	-15.76	2.52	2.32	1.22	-1.78	-1.44	0.78
Upper Piedmont Plain							
47	-5.44	3.67	0.73	-2.51	-0.72	-0.51	-0.53
48	-1.19	5.40	1.62	-3.41	-2.95	0.37	-2.30
Structural Hills							
49	-24.72	5.65	-0.17	2.71	-1.48	-0.12	0.69
50	-18.62	7.17	2.29	1.09	-1.57	-0.26	-0.30

soil copper, P and sulphur. Soil No. 14 'Buldonga' was ranked first for 'Acidity factor' (P5) due to high soil pH, base saturation and soil K. Because of high contribution from CEC, exchange capacity of clay and apparent CEC, soil No. 2 'Digalibil' could be ranked first for P4 (Cation Exchange factor). High contribution of soil N and zinc made soil

Table: 7
Ranking of soils for seven PCs based on scores derived under different physiographic units

Sample site no.	P1	P2	P3	P4	P5	P6	P7
Old Flood Plain							
1	4	20	15	4	32	9	48
2	18	28	5	1	33	22	18
3	20	49	18	33	19	48	35
4	13	40	1	48	4	15	26
5	9	17	4	47	5	37	28
6	14	39	19	40	27	19	37
Lower Alluvial Plain							
7	26	46	33	26	6	7	11
8	17	37	41	18	26	34	30
9	8	34	28	7	31	20	44
10	33	47	14	29	28	3	9
11	31	42	27	12	36	43	22
12	19	32	25	46	18	8	39
13	12	24	38	8	22	31	40
14	35	50	43	3	1	26	4
15	21	48	13	49	25	50	13
16	30	35	29	37	17	10	19
17	7	18	30	30	13	23	41
18	16	43	40	19	8	36	42
19	6	30	34	9	21	39	45
20	25	31	46	20	12	45	32
21	38	47	44	39	2	14	29
22	23	26	8	44	20	29	2
23	28	36	36	41	10	44	16
24	29	11	42	28	48	6	3
25	3	8	2	10	15	21	34
Upper Alluvial Plain							
26	15	27	37	16	30	17	43
27	10	23	21	27	3	27	15
28	5	15	24	21	16	13	23
29	2	10	6	6	9	8	46
30	11	16	32	2	34	12	12
31	34	19	39	24	43	5	5
32	1	3	7	43	37	1	1
33	24	6	50	32	38	4	14
34	22	7	49	25	45	11	20
35	27	13	47	34	29	2	17
Lower Piedmont Plain							
36	49	44	9	35	14	25	38
37	43	25	23	13	23	35	8
38	37	12	31	38	24	30	47
39	41	22	20	23	49	38	27
40	46	38	3	22	40	40	24
41	42	21	35	42	35	47	49
42	48	41	12	11	39	32	21
43	47	33	16	14	47	46	25
44	40	29	45	36	7	41	33
45	39	14	48	31	11	42	6
46	44	9	10	15	46	49	7
Upper Piedmont Plain							
47	36	5	22	45	44	33	36
48	32	4	17	50	50	17	50
Structural Hills							
49	50	2	26	5	41	24	10
50	45	1	11	17	42	28	31

No. 4 'Dagaon' as superior in P3. High score in SH soils 'Hill-I' and 'Hill-2' (No. 49 and 50) for P2 was contributed by relief and soil loss parameters and hence had an adverse effect on available soil fertility. Mohanty and Philipovski (1982) emphasized that parameters which affect soil fertility adversely should not be considered since they would significantly inflate score values.

Fertility Ranking of Physiographic Units

The soils of OFP unit ranked top in P1 with mean score value of 13.0 as compared to P3 with mean score value of 10.3. These soils ranked second in P5 with mean score value of 20.0 compared to P6 with 24.98 (Table 8). The OFP received 5th rank and these soils were superior from soil fertility point of view. The UAP soils received 6th rank. However, soils of UAP unit which ranked first for P6 with mean score value of 10.0 compared to P7 with 19.6; second in P1 with 15.1 and P4 with 23.0 could be considered as second best from soil fertility point of view. The soils of LAP which received first rank in P5 with mean score value of 18.9 have also received third rank in P1 with 21.4; P4 with 25.0; and P7 with 25.0. Hence, could be ranked third for soil fertility. The soils in LPP unit are ranked fourth for fertility of soils in the watershed area although LPP unit received 2nd rank. Although UPP unit received 1st rank, soils of UPP could be ranked fifth due to only two samples. Similarly, SH soils showed highest ranking in P2 with mean score value of 1.5 and P4 with 11.0. In fact, P2 (Soil Loss Factor) was negatively correlated with soil fertility, while high scoring in P4 (Cation Exchange Factor) was due to low clay content in soils. Although SH soils received 4th rank, SH unit could be considered as least fertile in the NBVZ and could be ranked sixth with regard to P1 with mean score value of 47.5. The ranking of factors based on coefficient of variation with in a physiographic unit and rank sums derived over physiographic units indicated the superiority of 'Inherent Potentiality Factor' with lowest rank sum, followed by 'Soil loss factor', 'Acidic factor', 'Cation Exchange factor', 'Copper factor', 'Nitrozinic factor' and 'Anionic factor' with increasing rank sums among the different physiographic units studied.

Our results are in conformity with those observed by Mohanty and Filipovski (1981, 1982), based on assessment of

Table: 8
Mean and variation of scores of PCs in different physiographic units

Principal factors	OFP	LAP	UAP	LPP	UPP	SH
Factor 1 : Inherent Potentiality factor						
Mean	13.00	21.42	15.10	43.27	34.00	47.50
Standard deviation	5.87	10.55	11.26	3.90	2.83	3.54
CV (%)	45.1	49.2	74.6	9.0	8.3	7.4
Rank based on CV	4	5	6	3	2	1
Factor 2 : Soil Loss factor						
Mean	32.17	33.96	13.90	26.18	6.45	1.50
Standard deviation	12.54	12.35	7.68	11.92	0.71	0.71
CV (%)	38.9	36.4	55.2	45.5	11.0	47.3
Rank	3	2	6	4	1	5
Factor 3 : Nitrozinc factor						
Mean	10.33	30.16	31.20	22.90	19.50	18.50
Standard deviation	7.89	12.83	16.30	15.04	3.54	10.61
CV (%)	76.4	42.5	52.2	65.7	18.1	57.3
Rank	6	2	3	5	1	4
Factor 4 : Cation Exchange factor						
Mean	28.83	25.00	23.00	25.46	47.50	11.00
Standard deviation	21.12	14.69	12.50	11.34	3.54	8.49
CV (%)	73.3	58.8	54.3	44.5	7.4	77.2
Rank	5	4	3	2	1	6
Factor 5 : Acidic factor						
Mean	20.00	18.90	28.40	30.46	47.00	41.50
Standard deviation	13.00	11.89	14.39	15.30	4.24	0.71
CV (%)	65.0	62.9	50.7	50.2	9.0	1.7
Rank	6	5	4	3	2	1
Factor 6 : Copper factor						
Mean	24.98	26.26	10.00	38.64	25.00	26.00
Standard deviation	14.66	14.41	7.90	7.54	11.31	2.83
CV (%)	58.7	54.9	79.0	19.5	45.2	10.9
Rank	5	4	6	2	3	1
Factor 7 : Anionic factor						
Mean	32.00	25.00	19.60	25.90	43.00	20.50
Standard deviation	10.37	15.04	14.65	15.10	9.90	14.85
CV (%)	32.4	60.2	74.7	58.3	23.0	72.4
Rank	2	4	5	3	1	6
Over-all Rank sum	31	26	33	22	11	18
Rank	4	3	6	5	1	2

OFP = Old Flood Plain ; LAP = Lower Alluvial Plain ; UAP = Upper Alluvial Plain ; LPP = Lower Piedmont Plain ; UPP = Upper Piedmont Plain ; SH = Structural Hills soil characteristics and fertility potential classification of rice soils of Yugoslavia. Similar results were reported by Zehetner and Miller (2006) with respect to climatic gradient in an Andean agro-ecosystem.

Based on CV of PC scores for soil parameters representing the inherent potentiality factor, the physiographic unit SH has minimum CV of 7.4%, while UAP has variation of 74.6%. UPP has variation of 11.0% compared to UAP with maximum of 55.2% in soil loss factor. UPP has minimum variation of 18.1% compared to OFP with maximum of 76.4% in nitrozinc factor; while UPP has minimum of 7.4% compared to maximum of 77.2% by SH in cation exchange factor. SH has minimum variation of 1.7% and OFP has maximum variation of 65.0% in acidic factor; while SH has minimum variation of 10.9% and UAP has maximum variation of 79.0% in copper factor. In anionic factor, UPP has minimum variation of 23.0%, whereas SH has maximum of 72.4% based on soil parameters observed in 6 physiographic units.

Factor loadings of soil parameters in P1 and P2; P1 and P3; and P2 and P3 are depicted in Fig. 1, significant parameters occurred in 4 quadrants (Table 9). The 1st quadrant had parameters with positive loadings of both PCs; while 2nd quadrant had negative loadings on P1 and positive loadings on P2; 3rd quadrant had negative loadings of both PCs; and 4th quadrant had positive loadings on P1 and negative loadings on P2. When loadings of P1 and P2 were compared, silt, OM, CEC, iron, manganese, FC, AWC and clay occurred in 1st quadrant. In a comparison of loadings of P1 and P3, 8 parameters occurred in 1st quadrant. Majority of parameters were positively loaded on leading components and contributed to total variability. The significant parameters could be used to assess soils under similar physiographic units. Although soil physiographic units received different ranks based on grades, considering watershed area and number of samples of each unit, LPP and LAP were superior from soil fertility point of view. The assessment of soil physiographic units would become a relevant basis for development in the watershed area.

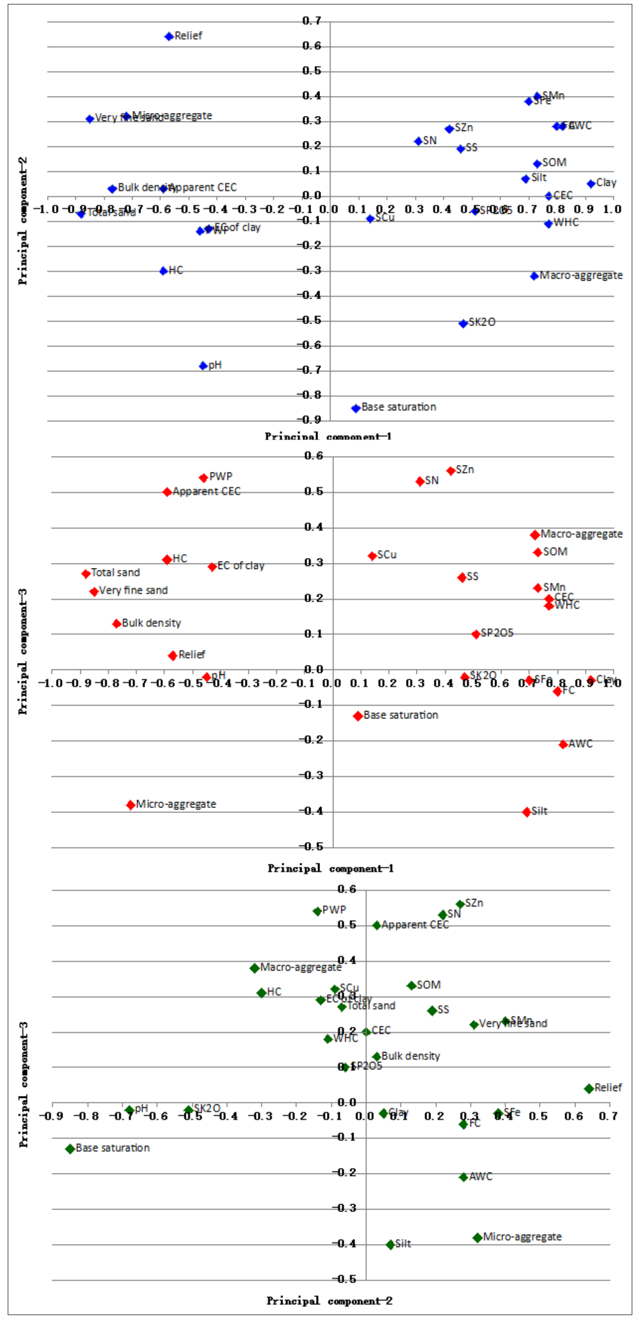

Fig. 1. Relationship between loadings of soil parameters on first 3 PCs P1, P2 and P3

Table: 9
Significant soil parameters identified based on the relationship of loadings of leading 3 PCs

Principal components		I Quadrant (+, +)	II Quadrant (-, +)	III Quadrant (-, -)	IV Quadrant (+, -)	Total
P1	P2	Silt, Soil organic matter, CEC, Iron, Manganese, Field capacity, Available water content, clay (8)	Bulk density, Micro aggregate, Very fine sand, Total Sand (4)		Macro- aggregate, Water holding capacity (2)	14
P1	P3	Silt, Soil organic matter, CEC, Iron, Manganese, Field capacity, Available water content, clay (8)	Bulk density, Very fine sand, Total Sand (3)	Micro aggregate (1)	Available water content (1)	13
P2	P3			Base saturation (1)		1
	Total	16	7	2	3	28

Values in parentheses indicate total number of soil parameters occurred in the quadrant

4. CONCLUSIONS

An assessment of 50 rice growing soils in 6 landscape units of NBVZ in Assam is made in the paper. Based on principal component analysis, the soils were assessed for fertility potential using 27 physical and chemical parameters. Seven PCs explained 81% variability of soil parameters and were identified as (i) Inherent Potentiality; (ii) Soil Loss; (iii) Nitrozinc; (iv) Cation Exchange; (v) Acidity; (vi) Copper; and (vii) Anionic factors for assessing soils. Based on ranking of individual soils and physiographic units, Dhullie (No. 32) received first rank from soil fertility point of view. Among physiographic units, OFP soils were most fertile. The fertility potential classification reduced the dimensionality from 27 correlated soil parameters to 7 uncorrelated PCs, which would help for efficient fertility management in the watershed area. Based on ranking of factors with in a physiographic unit and rank sums derived over physiographic units, the 'Inherent Potentiality Factor' was superior with lowest rank sum of 16, followed by 'Soil loss factor' with rank sum of 19, 'Acidic factor' with rank sum of 22, 'Cation Exchange factor' with rank sum of 25, 'Copper factor' with rank sum of 27, 'Nitrozinic factor' with rank sum of 28 and 'Anionic factor' with rank sum of 31. The study has clearly indicated that a watershed could be efficiently assessed based on the 7 factors in the order of importance as described above. Among 27 soil parameters studied, silt, organic matter, CEC, manganese, field capacity, AWC and clay significantly contributed to the total variability. These parameters could be used to assess soils under similar watersheds in the country.

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