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Characterization, genesis and classification of rice soils of Eastern Region of Varanasi, Uttar Pradesh

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Abstract : Rice growing soils of eastern U.P. have developed from the Quaternary Gangetic alluvium of the Holocene period into very deep, well to imperfectly drained soils with strong horizon differentiation. These soils showed clay illuviation. Micromorphological study of thin sections of Bt horizons of pedons 1 and 3 showed that there was a moderate plasma separation along voids and grains. The CEC values were low to medium and consistent with clay fractions dominated by the illite and kaolinite minerals. The dominant basic cation was Ca which influenced the development of the soil. The pedons 1 and 3 were classified as Typic Hapludalfs whereas pedon 2 as Dystric Eutrudepts and pedon 4 as Typic Ustifluvents.

Additional key words: Alluvial parent material, mineralogy, alkalization, micromorphology

Introduction

Rice is an important staple food crop of tropical and subtropical climatic regions. In eastern India, rice is dominantly grown as rainfed *kharif* crop with the onset of south-west monsoon. Due to variation in physiography, the study area has all three types of rice cultivation, *i.e.* upland rice, mid-upland rice and lowland rice. Rice has got a potential to grow in various types of soils and under a wide range of climatic conditions. The wide variety of ecological conditions under which rice is growing is matched by the diversity of soils which support this crop, so that in reality there is probably no such thing as a 'rice soil'. The natural drainage varies from good to poor. The parent materials range from recent alluvium to well weathered residual materials in upland sites. Soil texture varies from heavy clay to sand; organic matter from less than 1% to more than 50%; salt content from near 0 to 1%; and pH from less than 3 to more than 10 (De Datta 1981). Thus it is likely that the crop can also be grown under various soil water regimes, which vary from near saturation to about 10-50 cm of standing water (Mandal 1984). The continuous submergence of soil causes changes in physical and chemical characteristics of the soils and these changes are distinctly different from those of mid-upland and upland rice growing soils (Mandal 1984). Puddling in rice growing soils affects physical properties of soil. This results in breaking the natural larger aggregates into finer ones, with considerable expenditure of energy (Ghildyal 1978). The bulk density is decreased, the capillary pore space is destroyed and hydraulic conductivity is reduced, as is the free percolation of water. Soil aeration is minimised in the major upper tilled layers of the soil. Sharma and De Datta (1985, 1986) also reported the drastic changes in pore- size distribution of the soil as a result of puddling. Information on characterization of rice growing soils of U.P. is available in literature but only sporadic attempts (Agarwal and Mehrotra 1952; Agarwal 1961; Shankarnarayana and Hirekerur 1972 and Singh *et al.* 1989) have been made to classify such soils using Soil Taxonomy. In view of the above facts, the present investigation was undertaken in part of eastern Uttar Pradesh India to understand the characteristics and genesis of the soil in relation to physiography and distance from the river flowing in the region.

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Materials and Methods

The study area lies between 25° 10' and 25° 30' North latitudes and between 83° 0' and 83° 30' East longitudes covering part of Chandauli (erstwhile Varanasi) district of eastern Uttar pradesh. The area has a semi-arid and subtropical monsoonic type climate with a mean annual rainfall of 1060 mm. The mean annual summer and winter temperatures are 32° and 19.3°C respectively. The temperature regime of the area is *hyperthermic* whereas the moisture regime is *udic*. Four observations were made which are representative of the selected landforms in village; Dhanapur (P_1), Shahjaur (P_2), Sakaldiha (P_3), and Hardhanjura (P_4). Morphometric observations were made as per Soil Survey Division staff 1995; I.A.R.I. Manual 1970). The soils were analysed for their physical and chemical properties following methods described by (Black 1965; Jackson 1950). Separation of clay and chemical composition of soils (MgO, CaO, SiO_2, R_2O_3, Fe_2O_3) was determined according to Jackson (1950, 56). Elemental analysis of the soil was done by fusing the soils with anhydrous sodium carbonate (Jackson 1967). XRD study of whole clay of the P_1 and P_3 pedons for the identification of layer silicates was done according to the procedures outlined by Jackson (1979). Micromorphological investigations were carried out at National Bureau of Soil Survey and Land Use Planning, Nagpur for the selected B horizons of P_1 and P_3 pedons. The thin sections were prepared following methods described by Jongerius and Heintzberger (1963). Description of the plasmic fabrics was done as per the terminology of Brewer (1964) and Bullock *et al.* (1985). These soils were classified according to Keys to Soil Taxonomy (Soil Survey Staff 1998).

Results and Discussion

The soils of P_2 were relatively yellower (5Y 6/2) than those of pedons P_1, P_3 and P_4. The slightly redder hue (10YR 5/2) was dominant in P_1. The exclusively rice growing soils (P_1, P_2 and P_3), in general, had chroma of 2 in their surface horizons, which were indicative of localized anaerobic (anthraquic) conditions (Sawhney and Sehgal 1989). The upland rice soils (P_4) had chromas up to 4 suggesting non-aquic conditions in the surface horizons. The redder hue in case of P_1, P_2 and P_3 soils might be attributed to the ferruginous nature of alluminium / prolong redoximorphic conditions. Intense mottlings were observed in all the profiles except P_4 because of water logging owing to their lower physiographical positions in comparison to P_4 (Table 1). Soil structures were dominantly moderately developed, medium to coarse subangular blocky types, most likely as a result of the lower clay contents and the dominance of the bivalent Ca^{2+} and Mg^{2+} cations over the monovalent ions on the exchange complex, which had resulted in the soils being well flocculated. The soils were friable (moist) due to low to medium clay contents and this was attributed to good aggregation of the soil particles. Fe and Mn concretions were present in P_1, P_2 and P_3 soils whereas calcretes were present in significant amount in P_1 and P_3 (Table 2).

The physical properties of these soils showed an uneven distribution of mechanical separates which may be due to different depositional environment of the sediments Bulk density increased with depth for all the soils (Table 3). The lowest density was observed in Ap horizons which may be due to the effect of organic matter.

Table 1. Site characteristics of rice growing soils

Location	P1	P2	P3	P4
Elevation(m) Above msl	76.0	80.5	75.6	88.0
Physiography	Mid-upland	Lowland	Mid-upland	Upland
Geology/parent	Alluvium material	Alluvium	Alluvium	Alluvium
Slope(%)	0-3	0-3	0-3	0-3
Erosion	Slight	Slight	Slight	Moderate
Drainage	Moderately well drained	Imperfectly drained	Moderately well drained	Well drained
Distance from river Ganga	25 km	6 km	15 km	1 km
Land use	Paddy, wheat, mustard	Paddy, wheat, mustard	Paddy, wheat, mustard, pea , lentil	Paddy, wheat, mustard, red gram

Table 2. Morphological characteristics of the soils

Depth (m)	Horizon	Boundary matrix (Moist)	Colour colour	Mottle	Texture	Structure Concretions	Fe-Mn	Calcretes	Roots	Effervescence
Pedon 1: Fine-loamy, mixed, hyperthermic Typic Hapludalfs										
0.0-0.15	Ap	cs	10YR5/2	-	scl	f1 gr	-	-	m m	e
0.15-0.40	2A2	gs	10YR5/2	-	cl	m2 sbk	vf f	-	f f	e
0.40-0.60	3Bt1	gs	10YR5/3	f1f 7.5YR6/8	cl	m3 sbk	f f	m f	vf f	es
0.60-0.85	3Bt2	gs	10YR3/3	c2d 7.5YR6/6	cl	c3 sbk	m m	m f	-	es
0.85-1.05	3Bt3	gs	10YR3/3	c2d 7.5YR6/6	cl	m2 sbk	m m	f f	-	es
1.05-1.50	4C	-	10YR4/3	-	ls	0 sg	-	f f	-	e
Pedon 2: Fine-loamy, mixed, Hyperthermic Dystric Eutrudepts										
0.0-0.20	Ap	cs	5Y 5/2	-	scl	m2 sbk	-	-	c m	-
0.20-0.65	2A2	gs	5Y 6/2	m1f 2.5YR 4/4	scl	m2 sbk	f m	-	f c	-
0.65-0.85	2Bw1	gs	5Y 5/3	f2f 2.5YR 3/4	scl	m2 sbk	f f	-	vf f	-
0.85-1.20	2Bw2	gs	2.5Y 5/4	f1d 2.5YR 3/4	scl	c2 sbk	f f	-	-	-
1.20-1.55	2Bw3	-	2.5Y 5/4	m2d 2.5YR 3/4	scl	c3 sbk	vf f	-	-	-
Pedon 3: Fine-loamy, mixed, Hyperthermic Typic Hapludalfs										
0.0-0.15	Ap	cs	2.5Y 4/2	-	l	f1 gr	-	-	m m	-
0.15-0.45	Bt	gs	2.5Y 5/4	f1d 2.5YR 4/4	scl	f1 sbk	vf f	-	f f	e
0.45-0.80	Bt1	gs	2.5Y 5/4	f1d 2.5YR 3/4	scl	m1 sbk	f f	f f	vf f	e
0.80-1.20	Bt2	gs	2.5Y 5/4	c1d 2.5YR 3/4	l	m2 sbk	m c	f f	-	es
1.20-1.60	2Bt3	-	2.5Y 5/4	c2d 2.5YR 3/4	scl	m2 sbk	c c	m f	-	es
Pedon 4: Coarse-loamy, mixed, Hyperthermic Typic Ustifluvents										
0.0-0.15	Ap	cs	2.5Y 4/4	-	sl	f gr	-	-	m m	es
0.15-0.40	AC1	gs	2.5Y 4/4	-	sl	f gr	-	-	f m	es
0.40-0.75	AC2	ds	2.5Y 5/4	-	sl	f gr	-	-	vf f	es
0.75-1.05	AC3	ds	2.5Y 5/4	-	sl	f gr	-	-	vf f	es
1.05-1.35	AC4	ds	2.5Y 5/4	-	sl	f gr	-	-	vf f	ev
1.35-1.55	AC5	-	2.5Y 6/4	-	S	0 sg	-	-	-	ev

Abbreviations as per Soil Survey Manual (Soil Survey Staff 1951)

Table 3. Mechnical composition of soil (per cent on oven dry basis)

Depth (m)	Coarse sand	Fine sand	Silt	Clay	Texture	Sand/ silt ratio	Sand/ clay ratio	Silt/ clay ratio	Bulk density (Mg m^{-3})
	←	(%)		→					
Pedon 1 : Fine-loamy, mixed, hyperthermic Typic Hapludalfs									
0.0-0.15	0.3	50.5	24.2	25.0	scl	2.09	2.03	0.96	1.40
0.15-0.40	0.1	41.6	30.3	28.0	cl	1.37	1.48	1.08	1.45
0.40-0.60	-	44.2	23.3	32.5	cl	1.89	1.36	0.71	1.47
0.60-0.85	-	45.6	21.8	32.6	cl	2.09	1.39	0.66	1.53
0.85-1.05	-	45.5	21.3	33.2	cl	2.13	1.37	0.64	1.57
1.05-1.50	1.5	72.5	18.5	7.5	ls	4.00	9.86	2.46	1.61
Pedon 2 : Fine-loamy, mixed, hyperthermic Dystric Eutrudepts									
0.0-0.20	1.3	52.0	23.0	23.7	scl	2.31	2.24	0.97	1.38
0.20-0.65	0.8	48.0	25.3	25.9	scl	1.92	1.88	0.97	1.42
0.65-0.85	-	45.4	27.3	27.3	scl	1.66	1.66	1.00	1.49
0.85-1.20	-	46.5	27.5	26.0	scl	1.69	1.78	1.05	1.52
1.20-1.55	-	47.2	27.6	25.2	scl	1.71	1.87	1.09	1.55
Pedon 3 : Fine-loamy, mixed, hyperthermic Typic Hapludalfs									
0.0-0.15	0.0	49.1	30.6	20.3	l	1.60	2.41	1.50	1.35
0.15-0.45	0.0	46.0	27.4	26.6	scl	1.68	1.72	1.03	1.36
0.45-0.80	0.0	47.1	25.7	27.2	scl	1.83	1.73	0.94	1.41
0.80-1.20	0.0	44.5	30.5	25.0	l	1.45	1.78	1.22	1.45
1.20-1.60	0.0	47.4	25.1	27.5	scl	1.88	1.72	0.91	1.47
Pedon 4 : Coarse-loamy, mixed, hyperthermic Typic Ustifluvents									
0.0-0.15	3.5	54.5	30.0	12.0	sl	1.93	4.83	2.50	1.48
0.15-0.40	1.8	57.2	27.9	13.1	sl	2.11	4.50	2.12	1.55
0.40-0.75	1.6	57.3	30.0	11.1	sl	1.96	5.25	2.70	1.57
0.75-1.05	1.5	56.4	31.8	10.1	sl	1.82	5.75	3.14	1.58
1.05-1.35	2.5	59.7	30.7	7.1	sl	2.02	8.76	4.32	1.63
1.35-1.55	5.0	81.1	8.9	5.0	s	9.67	17.22	1.78	1.65

The increase in bulk density with depth was attributed to lower organic matter, more compaction and less aggregation. The silt contents of the soils were relatively high, ranging from 20-34 per cent. The clay content (5.0 to 33.2%) varied widely and in general, increased with depth. This may be due to abrupt change in sand/silt ratio between the horizons. Abrupt increase in clay content in B horizon of P_1 without any sign of argillic horizon was indicative of lessivage. Lower silt/clay ratio, especially in B horizons of P_1 and P_3 suggests that most of the primary minerals had been transformed to clay-sized secondary minerals since silt/clay ratio reflects the ratio of primary to secondary minerals. The abrupt change in the sand/silt and sand/clay in lower most horizons of P_4 indicated lithologic discontinuity (Sidhu *et al.* 1976). These soils were low in organic carbon content due to high rate of decomposition of organic matter under the subtropical conditions.Organic carbon content decreased down the depth in all the pedons except P_4 where its distribution was irregular. The organic carbon varied from 3.30 g kg^{-1} to 7.65 g kg^{-1} in the surface layers. Generally surface soils were rich in organic carbon (Ponnamperuma 1972). These soils were neutral to moderately alkaline in reaction (pH 7.1 to 8.3), low in CEC [8.2 to 20.2 cmol (p+) kg^{-1}] but high in base status (80.0 to 99.0%). The higher pH of P_4 might be ascribed to the high content of free calcium carbonate (Table 4). The electrical conductivity of all soils were very low. Irregular distribution of $CaCO_3$ with depth may be attributed to differential dissolution by CO_2 rich water which is moderated by physiography, rising and receding water table and drainage conditions. Ca was the most dominant exchangeable cations followed by Mg, Na and K (Table 4). Exchangeable Ca and Mg in all the soils showed higher accumulation in the subsurface horizons. Relatively high exchangeable Ca^{+2} and Mg^{+2} in the lower layers might be due to the deposition of calcitic or dolomitic parent materials carried by the river during fluvial cycle in the past (Walia and Chamuah 1994).

The morphological, physical and chemical properties of pedons (Table 1 and 2) indicated marked differences in soil genesis. However, all the pedons developed over similar parent material and climatic condition but dissimilar topography. Pedon P4 did not show distinct horizonation

Table 4. Chemical characteristics of the soils

Depth (m)	pH	EC (dS m^{-1})	OC (g kg^{-1})	Exchangeable Bases: Ca	Mg	Na	K	CEC	Base Saturation (%)
				← cmol (p+) kg^{-1}				→	
Pedon 1 : Fine-loamy, mixed, hyperthermic Typic Hapludalfs									
0.0-0.15	7.4	0.09	3.85	6.3	6.3	0.3	0.9	15.5	87.7
0.15-0.40	7.5	0.36	3.00	7.3	5.9	0.4	0.5	15.6	90.4
0.40-0.60	7.4	0.37	1.98	7.4	6.4	0.5	0.5	16.3	90.8
0.60-0.85	7.7	0.42	1.89	8.0	5.6	0.4	0.4	15.5	93.0
0.85-1.05	7.6	0.45	1.80	8.1	5.6	0.6	0.6	17.0	87.6
1.05-1.50	7.7	0.43	1.80	8.1	3.1	0.7	0.5	14.0	88.5
Pedon 2 : Fine-loamy, mixed, hyperthermic Dystric Eutrudepts									
0.0-0.20	7.1	0.30	5.56	8.6	4.1	0.1	1.2	17.5	80.0
0.20-0.65	7.1	0.41	5.00	9.7	6.0	0.2	0.8	19.7	84.8
0.65-0.85	7.2	0.44	3.21	10.7	5.8	0.5	0.4	20.2	86.1
0.85-1.20	7.4	0.35	2.85	11.3	3.9	0.6	0.5	18.5	88.1
1.20-1.55	7.5	0.38	2.60	11.4	4.0	0.6	0.5	18.5	89.2
Pedon 3 : Fine-loamy, mixed, hyperthermic Typic Hapludalfs									
0.0-0.15	7.3	0.14	7.65	9.1	5.5	0.4	0.3	16.8	91.0
0.15-0.45	7.6	0.15	5.40	10.5	6.3	0.3	0.3	18.6	93.5
0.45-0.80	7.6	0.16	3.19	10.8	4.1	0.2	0.4	16.6	93.4
0.80-1.20	7.7	0.15	3.15	11.3	4.1	0.1	0.4	17.9	94.4
1.20-1.60	7.8	0.17	2.05	12.1	5.0	0.1	0.4	18.4	95.6
Pedon 4 : Coarse-loamy, mixed, hyperthermic Typic Ustifluvents									
0.0-0.15	8.0	0.15	3.30	5.8	2.0	0.5	0.2	10.1	84.1
0.15-0.40	8.2	0.16	3.26	5.6	3.5	0.3	0.5	10.0	99.0
0.40-0.75	8.2	0.15	2.42	5.7	3.6	0.7	0.3	11.3	91.1
0.75-1.05	8.1	0.18	2.56	5.7	4.1	0.8	0.3	11.3	96.4
1.05-1.35	8.1	0.20	2.00	6.2	3.6	0.8	0.3	11.2	97.3
1.35-1.55	8.3	0.22	2.25	4.1	2.1	0.7	0.2	8.2	86.5

due to alternate washing and deposition of newer alluvium. On the other hand, pedons 1, 2 and 3 reflected more or less well developed characters *viz*., illuviation of clay. Chemical composition of the soils of P_1, P_2 and P_3 (except P_4) showed fairly high SiO_2 and SiO_2/Al_2O_3 and SiO_2/R_2O_3 molar ratios in surface soils (Table 5). This indicates less siliceous substratum and thereby advanced stage of pedogenic development (Singh and Mishra 1994). Sudden change in sand/silt and sand/clay ratios of two lower most horizons of pedon 1 and 4 was indicative of lithological discontinuities due to stratified nature of parent materials in the profile. The alumina content was negatively correlated with SiO_2 and sand content and the finding was similar to Choudhari (1988). The depth function of CaO and MgO were not clear. It was noticed that in majority of the soils, their contents decreased in horizons next to the Ap and A2 horizons but increased in the lower most horizons. Maximum content of K_2O was observed in Bt horizons of P_1 and P_3 which may be due to higher amount of clay-sized mica. The silica content tended to decrease in Bw and Bt horizons because of illuviation (Walia and Rao 1996). This was also reflected in the decrease of molar ratios of SiO_2 / Al_2O_3 and SiO_2 / R_2O_3 down the profile for P_1, P_2 and P_3.

Table 5. Chemical composition of the soils (per cent on oven dry basis)

Depth (m)	SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	CaO	MgO	K_2O	SiO_2/R_2O_3	SiO_2/Al_2O_3
Pedon 1 : Fine-loamy, mixed, hyperthermic Typic Hapludalfs									
0.0-0.15	78.2	5.0	2.6	7.6	1.0	0.4	0.9	19.96	26.59
0.15-0.40	71.3	7.1	2.7	9.8	0.9	0.6	1.1	13.73	17.07
0.40-0.60	72.4	9.8	2.5	12.3	1.3	0.5	1.6	10.80	12.56
0.60-0.85	74.5	10.1	2.8	12.9	3.4	0.6	2.3	10.65	12.54
0.85-1.05	74.2	10.9	3.1	14.0	4.6	0.6	2.4	9.79	11.57
1.05-1.50	80.0	4.5	1.3	5.8	6.5	0.6	0.5	25.51	30.22
Pedon 2 : Fine-loamy, mixed, hyperthermic Dystric Eutrudepts									
0.0-0.20	75.0	12.5	2.6	15.1	2.1	2.3	0.8	9.00	10.20
0.20-0.65	73.5	12.2	3.0	15.2	2.2	2.4	1.0	8.85	10.24
0.65-0.85	72.3	11.8	3.1	14.9	2.1	1.2	1.1	8.92	10.42
0.85-1.20	70.1	14.2	3.0	17.2	2.6	1.1	1.1	7.39	8.39
1.20-1.55	54.4	19.0	3.0	22.0	2.9	1.2	1.1	4.42	4.87
Pedon 3 : Fine-loamy, mixed, hyperthermic Typic Hapludalfs									
0.0-0.15	84.0	9.8	4.5	14.3	1.8	0.5	1.7	11.27	14.57
0.15-0.45	82.6	11.0	2.6	13.6	1.6	0.8	1.6	11.09	12.77
0.45-0.80	75.6	15.4	4.6	20.0	2.6	0.7	2.3	7.01	8.35
0.80-1.20	73.2	16.5	4.8	21.3	1.5	0.8	2.2	6.36	7.54
1.20-1.60	66.5	16.8	5.2	22.0	2.5	0.8	2.3	5.62	6.73
Pedon 4 : Coarse-loamy, mixed, hyperthermic Typic Ustifluvents									
0.0-0.15	84.2	8.8	0.6	9.4	2.4	0.2	0.5	15.59	16.27
0.15-0.40	81.5	9.8	0.7	10.5	2.4	0.3	0.5	13.54	14.16
0.40-0.75	75.0	7.5	1.2	8.7	2.5	0.6	0.3	15.42	17.00
0.75-1.05	70.2	7.4	1.2	8.6	2.6	0.1	0.3	14.62	16.13
1.05-1.35	78.3	5.6	1.3	6.9	3.9	0.4	0.3	20.71	23.78
1.35-1.55	80.2	4.6	1.3	5.9	3.8	0.4	0.3	25.11	29.65

X-ray diffraction analysis indicated the presence of illite as the dominant clay mineral followed by kaolin (Fig. 1 & 2). Singh *et al.* (1991) also found illite as the dominant clay mineral in the alluvial soils of the Varanasi district of eastern Uttar Pradesh. They also reported that some of the soils had small amounts of kaolin. Sand mineralogy also indicated the dominance of mica and quartz. Thin sections of P_3 showed moderately developed subangular blocky structure with channels and vughs micro-structure. Plasma separation was weak to undiffemtiated (Fig. 6). 1-2% of mottles and Fe/ Mn concretions were observed under thin section of P_1 (Fig.5). Moderate plasma separation along voids and grains was recorded under thin section of soils of P_1 (Fig. 4). Their distribution pattern was porphyric and pedogenic carbonate (Fig. 5) were in the range of 2-3 per cent which occurred as discrete nodules. The clay oriented around the skeleton grains probably created congenial conditions for the retention of moisture in the pedon (Venugopal *et al.* 1989). The presence of suppressed argillans (Fig. 3) in P_3 was an indication of submergence of field for longer time.

Soil genesis

The contents of Al_2O_3, Fe_2O_3 and K_2O were very low in the recently deposited river sands of P_3. Generally soil forming processes lead to addition, losses, translocation and transformation of various elements. Although all pedons developed over similar parent material and under similar climatic conditions, nevertheless their rate and state of weathering was quite different. Total chemical analysis (Table 5) indicated that CaO, MgO and K_2O contents constituted less than 5 per cent of the soil mass which reflected in moderate weathering conditions (Gupta and Tripathi 1993). The P_4 soils did not show much horizonation which was due to its youthful nature. The soils of P_1, P_2 and P_3 were more

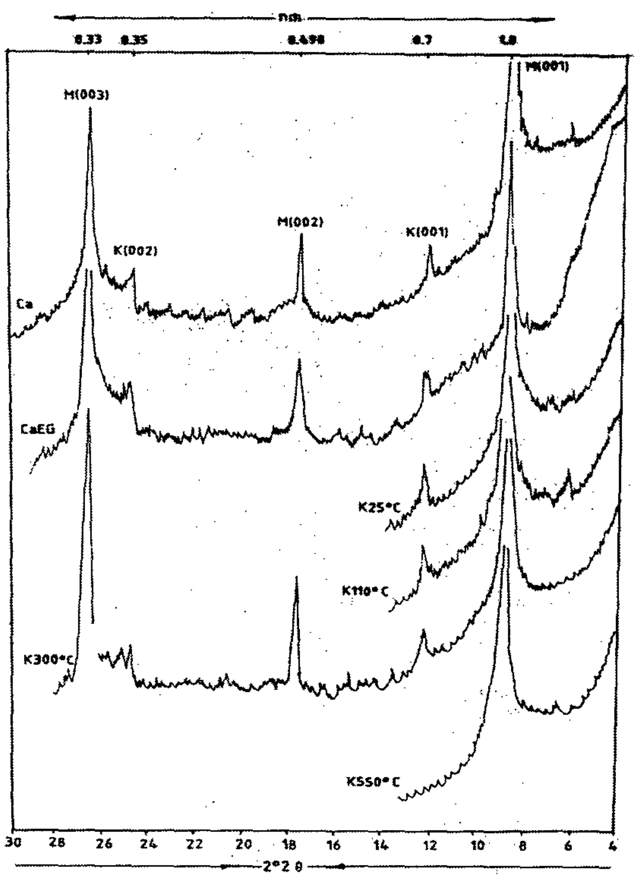

Fig. 1. Representative X-ray diffractograms of the total clay fractions (<2 m) of the soils. M = Mica, K = Kaolinite of Pedon 1.

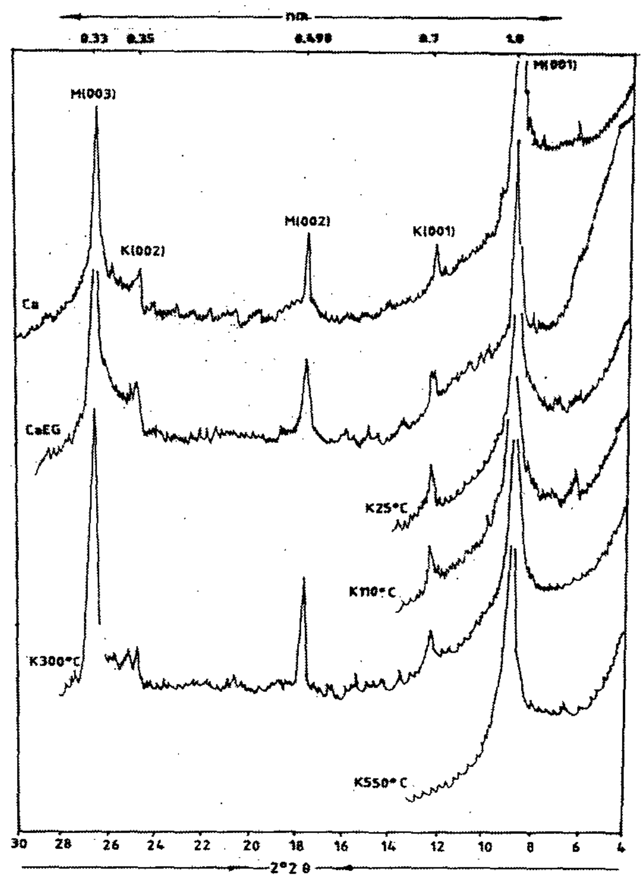

Fig. 2. Representative X-ray diffractograms of the total clay fractions (<2 m) of the soils. M = Mica, K = Kaolinite of Pedon 3.

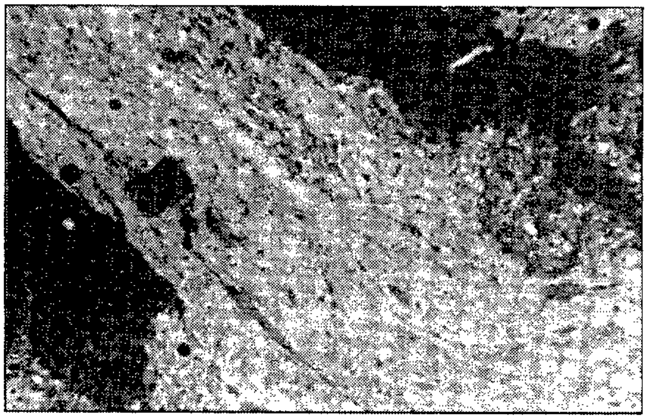

Fig: 3 Showing presence of suppressed argilans (X40)

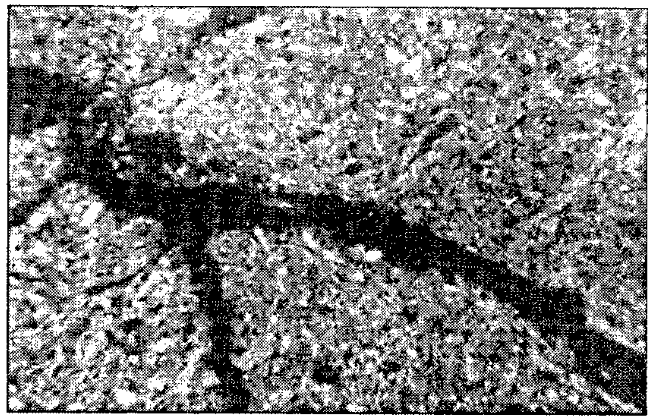

Fig: 4 Showing voids with thin coating of pedogenic $CaCO_3$ on the border (X40)

Fig: 5 Showing presence of pedogenic $CaCO_3$ in the aggregated ferriargilans (X40)

Fig: 6 Showing presence of pedogenic $CaCO_3$ (X40)

weathered than P_4 because of their location in mid-upland and lowland topographical situation where water works for a longer duration, accelerating the leaching of clay and translocation of Al_2O_3 and Fe_2O_3. It was also observed that stratification was maximum nearby the river but pedogenesis was maximum away from the river. Fine sand mineralogy showed the dominance of quartz followed by biotite, muscovite and feldspars. Relatively high quartz content in these soils could be due to granite gneiss of the Himalayan origin (Pettijohn 1957). Primary minerals were almost common in these soils suggesting similarity in parent material. As these soils were derived from alluvium of the Indo-Gangetic plains, originating from the Himalayas, quartzite, sandstone, slate, limestone, schists and conglomerate were the chief rock types observed (Bhargava and Sharma 1982). Some of the transparent heavy minerals identified were anatase, zircon and tourmaline. These soils appeared to have developed from pre-existing sediments (Pettijohn 1969). Majority of these quartz grains appeared as rounded one indicating that these have formed on transported materials. Direct conversion of mica (Dekimpe and Tardy 1969) to kaolinite may be one of the causes of substantial quantity of kaolinite in these soils, although condition did not support kaolinite genesis. P_3 soils exhibited lithologic discontinuity between Bt2 and Bt3 horizons because of the abrupt change in sand/silt ratio. These soils were mainly derived from sedimentary rocks such as shale. This is evident from dominant proportions of mica in these soils and neutral rock weathering and soil forming processes may have favoured the concentration of mica in clay fraction of these soils (Reichenback *et al.* 1975). Little or no pedogenic processes were evident in the P_4 soils as there was no plasma separation or movement of clay. Sand was present in the highest amount in this pedon. Pedogenic carbonates in the form of nodules (1%) but mainly as micrite crystals in the groundmass appeared in the thin section of P_1 and P_3 soils. Moreover, the occurrence of carbonate concretion in the subsurface of the soils was indicative of translocation. The other observed features indicated that the soils of P_1 and P_3 experienced lessivage, illuviation and calcification which were the dominant soil forming processes active in these soils.

Soil Classification

The diagnostic criteria for classification of P_1, P_2 and P_3 according to the USDA Soil Taxonomy (Soil Survey Staff 1998) include an udic soil moisture regime and an hyperthermic soil temperature regime chracteristic of semi arid to subhumid subtropical monsoonic climate. Absence of diagnostic sub-surface horizons in P_4, qualified it to be placed under the order Entisols. In essence, its properties of a ustic soil moisture regime and irregular distribution of organic carbon, the value of which is more than 0.2 per cent at a depth of 125cm, qualified it for the great group Ustifluvents. Since the soils did not have chracteristic of any of the subgroup recognized, it keyed out to the suborder Typic Ustifluvents and at family level as coarse-loamy, mixed, hyperthermic. Typic Ustifluvents. P_1 and P_3 were characterized by ochric epipedons and argillic B horizons, whereas, P_2 had a cambic B horizon and ochric epipedon. Base saturation was high, generally above 80%. The clay mineralogy of the soils was dominated by illite followed by kaolinite. Such base saturated soils of P_1 and P_3 were therefore, classified at the family level of as fine-loamy, mixed, hyperthermic Typic Hapludalfs; whereas, P_2 qualified as fine-loamy, mixed, hyperthermic, Dystric Eutrudepts as the particular pedon did not have free carbonates throughout the horizon beginning from 85 cm depth which is within 100 cm of the mineral surface. Moreover, P_2 soils did not have any sulfuric horizon, duripan or fragipan but had more than 60% base saturation in all the horizons.

Conclusions

Based on morphological, physical, chemical and mineralogical data these soils were placed under three orders, Alfisols, Inceptisols and Entisols. Thin sections of Bt horizons of P_1 and P_3 showed argillans and argiferrans along with irregular voids. Illuviation, lessivage and calcification were the dominant soil forming processes in P_1 and P_3 soils. The farmers may be advised to follow intermittent rice cultivation practices to reduce the rising concentration of Fe- Mn in the solum of the soils. The data generated from this study may be helpful for the decision-makers in framing the standard cultivation measures for enhancing the productivity of rice soils of this region.

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