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Mineralogy of soils of the Kandi area in the Siwalik hills of semi-arid tract of India

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Abstract

Mineralogical analyses of five typifying pedons of sub-mountainous area of the Siwalik range of NW-India was undertaken. Sand and silt fractions are dominated by quartz, feldspars, mica, calcite, chlorite and kaolinite. Semi-quantitative estimates of clay fraction indicated the dominance of mica followed by smectite, mixed layer minerals and chlorite. Kaolinite and vermiculite are present in small amounts. Presence of smectite in fine fraction and calcite in the coarse fraction of these soils of the undulating terrain indicated the inherited nature of most of the soil minerals. The clay mineralogical information may help in evolving appropriate technology in conserving soils of Kandi area.

Additional keywords : Calcite, illite, Kandi area, Siwalik hills, smectite.

Introduction

The sub-mountain tract of Punjab, Haryana, Jammu and Kashmir, and the adjoining piedmont plains in the south of Siwaliks are popularly known as the Kandi zone. This belt constitutes about 9.9 per cent of the geographical area in the state of Punjab. Geologically the area forms the southern part of the Siwaliks. The composition of Siwalik deposits shows alluvial detritus derived from the sub-aerial waste of mountains, swept down by their numerous rivers and streams and deposited at the foot hills. The Siwalik system represents a great thickness of detrital rocks such as coarsely bedded sandstones, sand rocks, clays and conglomerates. The bulk of this formation is similar to the materials constituting the alluvium of the plains. Lithologically the Siwalik deposits are the water borne debris of the granitic core of central Himalayas (Gansser 1965). The erosion of Siwaliks has been proceeding at an extraordinarily rapid rate since their deposition. This has led to the formation of strikingly abrupt topographical features. Because of topographical and lithological constraints, agricultural development of this area is a challenge by itself. An understanding of the mineralogical composition of the soils of Kandi zone may help in evolving appropriate technology to conserve the soils of the Kandi area.

Materials and methods

Location and climate : The study area is located in the eastern parts of the Punjab state at 76°23'42"E longitude and 31°6'24"N latitude. The elevation in the area ranges from 320–450 m (Fig. 1). General slope is from north east to south west. This area receives about 1090 mm rainfall annually (Fig. 2). The rainfall during July, August and September constitute about 75 per cent of the total rainfall. Generally, the dry conditions prevail from October to June. In general, summers are hot and winters are cool. Mean annual air temperature (MAT) is 22.5°C. Estimated mean summer temperature is 28.0°C, and mean winter soil temperature is 16.1°C. For three monsoon months (July, August and September) water supply is more than the water use. The soil moisture regime is ustic. These areas qualify for hyperthermic temperature regime as per Soil Taxonomy (Soil Survey Staff 1975).

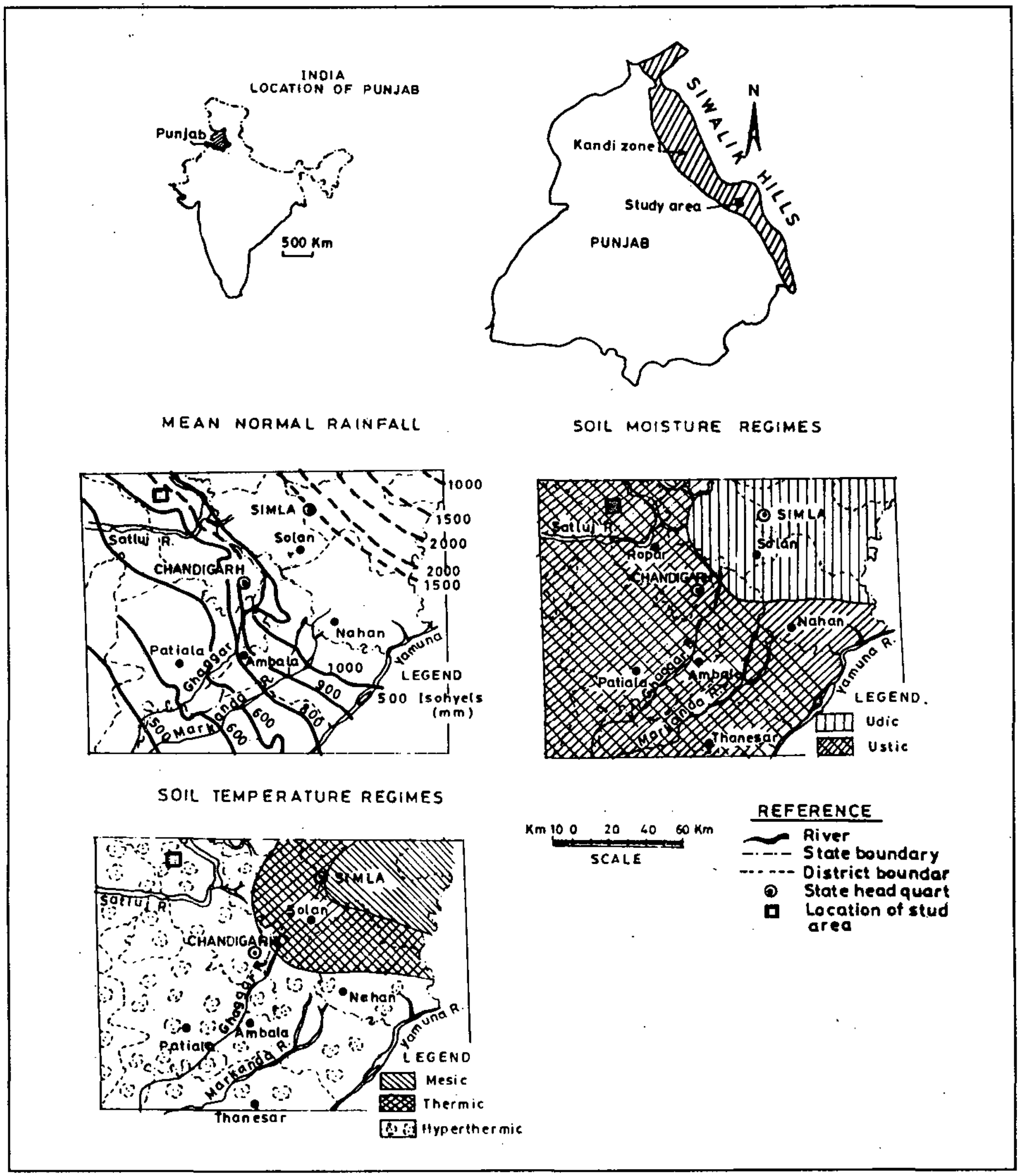


Fig. 1. Geogaphical setting of the study area.

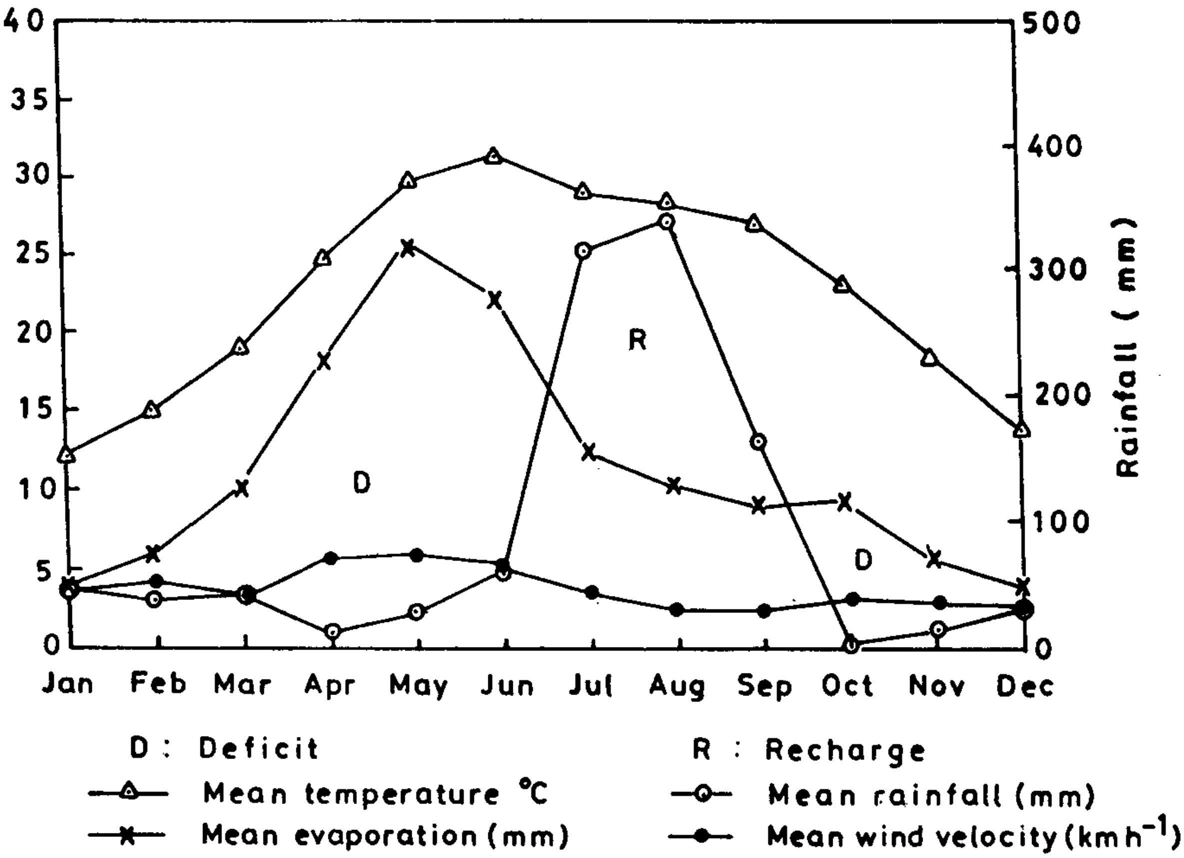


Fig. 2 : Climatic data and water balance diagram.

Methods : Morphological, physical and chemical characteristics of seventeen pedons were investigated. Detailed morphology and soil characteristics have been reported elsewhere (Rajkumar *et al.*, 1995). The mineralogical investigation was limited to five typifying pedons occurring at different physiographic positions. Profiles P-1, P-2 and P-3 represent shoulder slopes of undulating hills, undulating piedmont, and moderately sloping piedmont plains, respectively. The profiles P-4 and P-5 represent two different parent materials occurring in the nearby Siwalik hills. The soils are classified as Typic Ustifluvents (P-1), Typic Ustipsamments (P-2 and P-5) and Fluventic Haplusteps (P-3 and P-4). Important physical and chemical characteristics of the pedons are presented in table 1.

Table 1. Physical and chemical characteristics of the soils

Horizon	Depth (cm)	Sand (%) (50–200 m)	Silt (%) (2–50m)	Clay (%) (<2m)	pH_2 (1:2)	EC (dS m^{-1})	Org. C (%)	$CaCO_3$ Equivalent (%)	CEC cmol (p+) kg^{-1}
				P-1 (Typic Ustifluvents)					
Ap	0–21	69.2	26.0	4.8	8.4	0.15	0.21	6.4	2.7
C1	21–47	85.2	10.8	4.0	8.5	0.11	0.23	10.0	2.7

C2	47-59	90.0	6.0	4.0	8.4	0.10	0.11	21.0	2.6
C3	59-74	90.4	6.2	3.4	8.7	0.12	0.05	3.5	2.0
C4	74-134	42.4	48.8	8.8	8.4	0.14	0.15	8.5	5.0
				P-2 (Typic Ustipsamments)					
Ap	0-18	88.8	5.3	5.9	8.4	0.11	0.26	5.5	3.4
C1	18-59	92.1	2.3	5.6	8.7	0.08	0.03	3.5	3.4
C2	59-79	91.6	2.5	5.9	8.7	0.09	0.02	2.1	4.3
C3	79-100	93.9	0.7	5.4	8.8	0.08	0.02	1.6	3.8
C4	100-140	94.1	0.3	5.6	8.7	0.09	0.02	2.5	3.8
				P-3 (Fluventic Hapustepts)					
Ap	0-21	30.5	47.1	22.4	8.3	0.26	0.27	2.7	8.6
B1	21-41	29.3	46.1	24.6	8.4	0.22	0.21	2.5	8.1
B21	41-60	20.4	57.0	22.6	8.5	0.22	0.12	2.8	8.4
B22	60-81	15.6	57.2	27.2	8.6	0.22	0.18	1.7	9.2
B23	81-106	17.1	52.3	30.6	8.5	0.22	0.21	5.0	9.3
				P-4 (Unconsolidated material - Clay)					
A1	0-19	18.9	61.3	19.8	8.0	0.14	0.51	7.1	9.9
C1	19-46	13.7	65.5	20.8	8.2	0.12	0.44	14.0	9.1
C2	46-82	9.5	67.0	23.5	8.2	0.14	0.37	20.5	8.6
C3	82-114	16.4	58.6	25.0	8.3	0.14	0.34	13.0	7.6
C4	114-144	29.2	51.6	19.2	8.3	0.13	0.25	8.8	7.0
				P-5 (Unconsolidated material - Sand stone)					
A1	0-14	92.8	3.0	4.2	8.2	0.06	0.13	6.0	2.7
C1	14-31	95.2	0.5	4.3	8.4	0.05	0.12	2.0	2.3
C2	31-60	94.8	1.2	4.0	8.5	0.05	0.05	1.8	3.0
C3	60-93	94.4	1.9	3.7	8.5	0.05	0.12	2.1	2.4
C4	93-150	94.2	1.4	4.4	8.5	0.05	0.13	1.4	2.9

Soil samples from selected horizons of five pedons were fractionated into sand (50-2000 m), silt (2-50 m) and clay (<2 m) following the procedure outlined by Jackson (1979). The sand and silt were separately ground in agate mortar and pestle and random powder X-ray diffractograms were obtained. X-ray diffraction patterns of clay fraction were obtained from basally oriented specimens after Mg saturation, glycerol solvation, K saturation and heating at 400°C using a Philips diffractometer with Ni filtered CuK_a radiation. Semi-quantitative estimates were obtained on the basis of relative peak area ratio after necessary background correction following the procedures of Gjems (1967) and Ghosh and Datta (1974).

Table 2. Semi-quantitative estimates of sand size minerals

Depth (cm)	Chlorite	Mica	Kaolinite	Quartz	Microcline	Feldspars	Calcite
			P-1 (Typic Ustifluvents)				
0-21	++	++	++	+++++	++++	+++	++
47-59	–	++	++	+++++	+++	+++	++
73-134	++	+++	++	+++++	+++	+++	+
			P-2 (Typic Ustipsamments)				
0-18	–	++	+	+++++	+++	++++	++
54-79	+	+++	++	+++++	+++	+++	+++
100-140	+	++	++	+++++	+++	++++	++
			P-3 (Fluventic Haplustepts)				
0-21	++	+++	++	++++	++++	++	++
41-60	++	+++	++	+++++	+++	++++	+++
81-106	++	++++	++	+++++	+++	+++	+
			P-4 (Unconsolidated material - Clay)				
0-19	++	+++	+++	++++	++	+++	+++
46-82	++	++	++	+++++	++	++	+++
82-144	++	++	++	+++	++	+	+++
			P-5 (Unconsolidated material - Sand stone)				
0-14	++	++	++	+++++	++	+++	++
14-31	++	++++	++	+++++	++	++++	++
31-60	+	++++	++	+++++	+++	++++	+++
60-93	++	++++	++	+++++	++	++++	++

Table 3. Semi-quantitative estimates of silt size minerals

Depth (cm)	Chlorite	Mica	Kaolinite	Quartz	Microcline	Feldspars	Calcite
			P-1 (Typic Ustifluvents)				
0-21	++	+++	++	+++++	++	+++	++
47-59	++	+++	++	++++	++	++++	+
73-134	++	++++	++	+++++	++	++++	–
			P-2 (Typic Ustipsamments)				
0-18	++	+++	+	++++	+++	++++	+
54-79	–	++++	++	++++	+++	+++	++
100-140	–	+++	++	++++	++	++	++
			P-3 (Fluventic Haplustepts)				
0-21	+++	++++	++	++++	–	+++	+
41-60	++	++++	+++	++++	–	++++	+

81-106	-	+++++	+++	+++++	-	+++	+
			P-4 (Unconsolidated material - Clay)				
0-19	++	++++	+++	+++++	-	++++	+
46-82	+++	++++	++++	+++++	-	+++	+
114-144	+++	+++	+++	+++++	-	+++	+

Results and discussion

The soils varied widely in their characteristics (Table 1). The sand, silt and clay content ranged from 9.5 to 95.2, 0.3 to 67.0 and 3.7 to 30.6 per cent, respectively. Soils are alkaline (pH 8.0-8.8) and calcareous ($CaCO_3$: 1.4-21.0 per cent). Cation exchange capacity of the soils is low (2.3-9.3 cmol (p+) kg^{-1}).

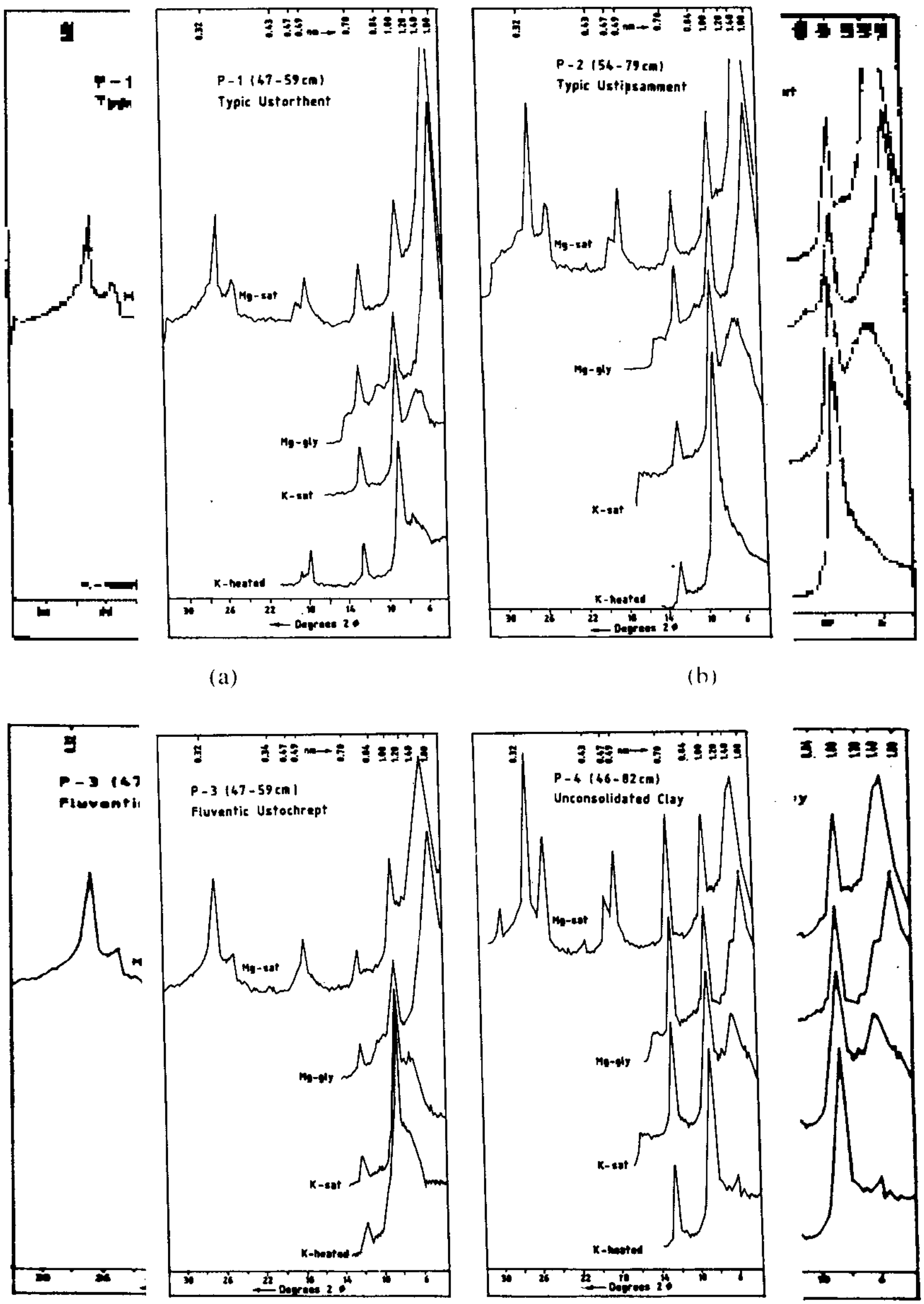
Mineralogy of sand and silt : The random powder diffractograms of the sand and silt fractions of these soils showed strong and sharp reflections for most of the primary minerals. Quartz (0.426 nm) was the dominant mineral followed by plagioclase feldspar (0.312 to 0.323 nm), mica (1.0 nm), microcline (0.321 to 0.328 nm), chlorite (1.4 nm), kaolinite (0.7 nm) and calcite (0.303 nm). Different horizons did not show much variation in mineralogical make up with depth thereby indicating little alterations associated with pedogenesis.

Mineralogy of silt fraction was similar to sand fraction. However, in some of the horizons chlorite and microcline were absent. With increase in fineness, the content of micaceous minerals increased and that of calcite decreased. The general order of mineral preponderance was quartz, mica, feldspars, chlorite, kaolinite and calcite.

Mineralogy of clay : X-ray diffractograms of basally oriented clays from various horizons of these pedons indicated a very strong and well defined peaks for illite (1.0, 0.498, 0.333 nm) accompanied by a strong 1.4nm peak along with its higher orders at 0.472 nm and 0.354 nm in Mg-saturated samples (Fig. 3a-d).

On glycerol solvation a portion of 1.4 nm peak resolved to 1.69 nm maxima indicating the presence of smectite. A part of the remaining 1.4 nm reflection collapsed to 1.0 nm on K-saturation and heating of the sample, thereby confirming the prsence of vermiculite. The 1.4 nm peak that persisted even after heating was attributed to chlorite. Mixed layer minerals registered peaks around 1.26 nm. In general, 1.0 nm and 1.4 nm reflections were strong and peaks were identical. Persistence of 0.7 nm peak after HCl treatment of clay confirmed the presence of small amounts of kaolinite.

In addition to the above minerals, X-ray diffractograms also showed sharp but low intensity peaks at 0.426 and 0.323 nm due to quartz and feldspars, respectively. These primary minerals have been reported under other minerals in table 4. Semi-quantitative estimates indicate the dominance of illite (43-67%) followed by smectite (11-34%), mixed layer minerals (3-17%) and chlorite (2-8%). Vermiculite, kaolinite and certain primary minerals were present in small amounts only.



(a) (b)

(c) (d)

Fig. 3. Representative XRD diagrams of the clay fractions.

Table 4. Semi-quantitative estimates of clay minerals

Depth (cm)	Smectite	Vermiculite	Chlorite	Mixed layer minerals	Mica	Kaolinite	Others
			P-1 (Typic Ustifluvents)				
0-21	23	2	4	4	65	1	2
47-59	28	1	3	3	63	2	1
73-134	19	2	2	12	60	2	2
			P-2 (Typic Ustipsamments)				
0-18	22	2	3	13	56	1	1
54-79	29	4	5	15	46	0	1
100-140	34	2	2	17	43	2	1
			P-3 (Fluventic Haplusteps)				
0-21	20	2	8	10	58	0	2
41-60	16	2	5	11	59	0	2
81-106	14	2	4	12	65	1	1
			P-4 (Unconsolidated material - Clay)				
0-19	13	2	8	7	65	2	3
46-82	16	2	4	6	67	-	3
114-144	11	2	6	11	65	3	2

The 1.0 nm reflection in the clay fraction is much broader and asymmetrical towards low angle as compared with the 1.0 nm reflections in the sand and silt fractions. This effect can be due to both replacement of interlayer K by hydrated cation and small particle size. Earlier Sehgal (1974) has suggested illite in Punjab soils as dominantly trioctahedral being simply formed by mechanical disintegration and loss of interlayer K from biotite in the coarser fraction. The ratios of the 0.498 nm to 1.0 nm intensities ranged between 0.04 and 0.29 for sand, 0.14 and 0.32 for silt and 0.22 and 0.56 for clay (Table 5). These ratios were relatively lower than the one reported by Sidhu and Gilkes (1977) and Jassal and Sidhu (1991) for the alluvial soils of central Punjab. X-ray intensity ratio of peak heights of 002/001 reflection of mica for the alluvial soils of Assam (north-east India) and West Bengal were also relatively higher (Pal *et al.* 1987). This trend does not correspond to one documented for dioctahedral mica (Brown, 1955; White, 1962) where intensity of the (001) reflection increases more rapidly than that of 002 when interlayer K is depleted during weathering. Entirely different explanation to such a situation has been suggested by Kapoor (1972). When muscovite and biotite co-exist in soil, the contribution of the later to second order mica reflection is almost negligible. During weathering, as the concentration of biotite, which is unstable under natural weathering conditions, diminishes, it would result in a greater decrease in the intensity of 1.0 nm reflection than 0.5 nm. Relatively, higher peak intensity ratio (002/001) in the sand, silt or clay separates of soils than for the pure mineral sample has been reported due to very low content of biotite in these fractions.

Table 5. The ratios of the intensities (peak area) of 0.5 nm to 1.0 nm reflections

Pedon	Depth (cm)	Sand	Silt	Clay
P–1	0–21	0.29	0.14	0.48
47–59	0.04	0.14	0.22	
73–134	0.18	0.20	0.34	
P–2	0–18	0.15	0.21	0.41
54–79	0.17	0.17	0.46	
100–140	0.26	0.21	0.56	
P–3	0–21	0.16	0.14	0.29
41–60	0.16	0.32	0.26	
81–106	0.20	0.22	0.27	
P–4	0–19	0.21	0.30	0.48
46–82	0.29	0.27	0.35	
114–144	0.21	0.26	0.52	
P–5	0–14	0.14	–	–
14–31	0.15	–	–	
31–60	0.07	–	–	
60–93	0.16	–	–	

A comparison of the semi-quantitative estimates of clay minerals of individual pedons indicate that P-1 and P-2 pedons having lower amounts of clay (3.4–8.8%) in the soil have relatively higher amounts of smectite minerals (19-34%), as compared to fine textured (19.2-30.6% clay) soils (P-3, P-4) having only 11 to 20 per cent smectite. Presence of higher amounts of smectite in these coarse textured soils, though imparts relatively higher cation exchange capacity and nutrient availability, might also be responsible for the soil crusting problem.

Presence of smectite in clay fraction and calcite mineral in the sand and silt fraction of these soils occurring in the undulating hilly terrain with high rainfall (~1100 mm), do not support the formation of these as well as other minerals by pedogenesis. Occurrence of smectite rich geological formations in the Siwalik hills have been earlier reported by Rajkumar *et al.* (1993). Most of the minerals in the fine as well as coarse fractions of these soils seem to be inherited from the Middle Siwalik formations in the Siwalik hills.

Conclusions

The Siwalik hills represents a great thickness of detrital rocks from the adjoining Himalayas. Bulk of this formation forms the parent material of the alluvial deposits of the great Indo-Gangetic plains. Soils of the Kandi area are calcareous and alkaline in reaction. Quartz, feldspar, mica, calcite, chlorite and kaolinite constitute the coarse fraction minerals. These soils have mixed mineralogy with illite and smectite dominating the fine fraction minerals. Coarse textured soils have relatively higher concentration of smectite. Most of the minerals in the coarse and fine fraction of these soils are inherited from the Siwaliks. Soil management strategy suggests to establish sufficient vegetative cover with minimum tillage operations. Keeping in view the natural constraints and soil quality, agricultural crops should be discouraged. Integrated management should aim at soil conservation by growing grasses and trees of economic importance.

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