Agropedology 2017, 27 (02) 103-116

Characterization and Classification of soils on different Geomorphic Units of North-Eastern Haryana, India

Dinesh, Mohammad Amin Bhat and K.S. Grewal
Department of Soil Science, CCS Haryana Agricultural University, Hisar -125004, India

Abstract: Twelve pedons occurring on different landforms of North-Eastern Haryana were characterized for morphological, physical and chemical characteristics and classified. The soil colour of pedons varied from yellowish brown to reddish dark brown in the hues of 10YR, 5YR and 2.5YR. The soils of Shiwalik hills, upper piedmont plains and flood plains, lower piedmont plains and old alluvial plains were medium to moderately heavy in texture, relatively lighter and light to moderately heavy in texture, respectively. The soils have weak to medium subangular blocky structure. The sub surface horizons in old alluvial plains showed the translocation and accumulation of clay. The soils of the area were moderately alkaline to strongly alkaline (pH 7.5-9.4). The organic carbon was less than 1 per cent except surface horizons of forest areas. The water retention characteristics of soils were strongly associated to texture with the finer soil showing higher retention and *vice-versa*. The particle density, bulk density and total porosity varied from 2.20 to 2.84, 1.16 to 1.45 Mg m^{-3} and 40.43 to 56.78 per cent, respectively and did not show regular pattern down the profile. The cation exchange capacity varied from 5.21 to 17.00 cmol (p+) kg^{-1}.

Keywords : *Pedon, landform unit, parent material, Entisols, Inceptisols*

Introduction

Soils are one of the important natural resources which produces food, fibre and fodder, the basic needs of our existence. The demand for food production has increased enormously with the population upsurge leading to over-exploitation and mismanagement of this valuable natural resource. To overcome this challenge, it is imperative to make efficient utilization of soils in a systematic way through proper planning and management.

Soils are regarded as inherent part of the landscape, the features of which are mostly controlled by the landforms. The variation in soil attributes associated with distinct landforms are mainly assigned to differences in the runoff, erosion and deposition processes that influence soil genesis (Yair 1990; Kharlyngdoh *et al*. 2015). Goyal and Singh (1998) and Sharma *et al*. (2011) studied the morphological, chemical and mineralogical characteristics of soils and their management in western Shiwalik Himalayas. Most of the research studies in Haryana of northwest India have been accomplished in alluvium derived soils of almost level plains. The information regarding the landform-soil relationship units of north-eastern Haryana is meagre. Therefore, the present investigation was attempted to generate comprehensive database about the characteristics, classification and fertility status of the soils developed on various landform units which will help in developing proper soil and water management strategies.

Materials and Methods

The study area is between (76° 31' to 77° 35' E; 30° 03' to 30° 57' N) covering parts of Panchkula, Ambala, Yamuna Nagar and Kurukshetra districts in Haryana, India. Most of the area is covered by quaternary deposits, except, hilly area. The general

* Corresponding author (Email: dineshtomarhau@gmail.com)

topography is undulating in the northern part and flat in the southern part. The area comprises of hilly terrain, piedmont plain and alluvial plain. The general slope of the area is from north to south. Ghaggar and Yamuna rivers flow through this area. The climate is sub-tropical, semi-arid, continental monsoonal having prolonged hot summer with annual precipitation of 578−1486 mm, most of which occurs during monsoon *i.e*., July to September. The soil moisture regime is ustic and udic and soil temperature regime is hyperthermic. For detailed reconnaissance soil survey, the topographic maps of India (1:50,000) and aerial photographs were used for site selection. A total of 12 pedons were exposed and studied for morphology (Soil Survey Division Staff 2006). Horizon-wise soil samples were collected, processed and analysed following standard procedures (Piper 1950; Means and Parcher 1963; Black 1965). Moisture retention capacity of soils at 0.03, 0.08 MPa and 1.5 MPa were determined by using Richard's pressure membrane apparatus (Bruce and Luxmoore 1986). The available water content was computed as the difference between field capacity (0.03 MPa) and permanent wilting point (1.5 MPa). Hydraulic conductivity was determined by the method described by Klute and Dirkson (1986). The pH of the soils was measured with glass electrode using soil suspension of 1:2 (soil:water) and electrical conductivity in supernatant (Jackson 1973). Calcium carbonate was determined by the method described by Richards (1954). Cation exchange capacity and exchangeable cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were determined by neutral normal ammonium acetate extraction (Jackson 1973). Exchangeable sodium percentage (ESP) was determined by alcoholic method and calculated as the ratio of exchangeable sodium and cation exchange capacity. Organic carbon was determined by wet-oxidation method of Walkely and Black (1934). The soils were classified according to USDA Soil Taxonomy (Soil Survey Division Staff 2006).

Results and Discussion

Morphological characteristics

The morphological characteristics of the soils are presented in table 1. The colour of pedons (1, 2, 3, 5, 7, 9, 10 and 12) varied from yellowish brown to dark yellowish brown colour in hue of 10YR with value 3 to 4 and chroma 2 to 4 and the soil colour of pedons 4, 6 and 8 varied from dusky red to reddish brown and dark reddish brown with hue varying from 2.5 to 5YR and value and chroma 2 to 4. The pedon 11 had dark brown to dark yellowish brown with hue of 7.5 to 10 YR with value 3 to 4 and chroma 2 to 4. The variation in soil colour of these areas might be due to variation in parent material, organic matter, landform units and drainage conditions. Walia and Rao (1997) and Leelavathi *et al*. (2009) reported that the soil colour may be the function of chemical and mineralogical composition in addition to textural make-up of soils as conditioned by topographic position and moisture regime. The soils on the plains were very deep and poorly drained, whereas, the soils on Shiwalik hills and valleys are moderately deep to shallow and well drained.

The texture of pedons 1 and 2 of Shiwalik hills varied from silt to clay and loam to clay loam, respectively and that of pedon 9 varied from loam to sandy clay loam in texture except pedon 3 that had sand to loamy sand texture. The soils of upper piedmont plains (P5 and P6) were sand to sandy loam in texture compared to lower piedmont plains (P7) having loamy sand to sandy clay loam texture. The soils of pedon 8 were sand to sandy loam in texture except surface horizon having sandy clay loam texture. The soils of old alluvial plains were sandy loam to clay loam in texture. The variation in texture may be due to variation in parent material and differential degree of weathering. Irregular distribution of clay content with depth was observed in few pedons of Shiwalik hills and valleys, piedmont plains, active flood plains and low lying alluvial plains showing the process of stratification and lithological discontinuity. (Sawhney *et al.* 2000; Rao *et al.* 2008 and Nasre *et al*. 2013). Pedons 6, 8 and 12 were found to be stratified due to periodic deposition of new sediments much faster than soil development. Rao *et al*. (2008) reported that wide variation in soil texture is caused by topographic position, nature of parent material, *in-situ* weathering, and translocation of clay and age of soils.

The soils of Shiwalik hills, piedmont plains and old alluvial plains were weak to medium, fine to coarse, subangular blocky structure throughout the solum which may be due to coarser texture having low content of silt, clay and organic matter. Moreover, the variation in soil structure is reflection of physiographic position of the pedons (Singh and Aggarwal 2005; Rao *et al.* 2008). Sharma *et al*. (1996) reported that the soil structure was relatively better developed in genetically

Table 1. Morphological characteristics of the soil

Pedon / Horizon	Depth (cm)	Boundary	Colour (moist)	Structure	Consistence	Roots	Coarse fragment	Reaction
			(Shiwalik hills (Top)					
Pedon 1	Loamy - skeletal Typic Udorthents							
A1	0-37	a w	10YR4/3	2md sbk	sp	-	Boulders (>35%)	1
C1	37-152	g s	5YR4/2	2fn sbk	vs vp	-	Pebbles (>35%)	1
2C2	152-242	-	10YR4/2	2fn sbk	vs vp	-	Pebbles (>35%)	-
			Shiwalik hills (Slope)					
Pedon 2	Fine-loamy, Typic Udorthents							
A1	0-41	a s	10YR3/4	2co sbk	sp	-	f fn > 7.5%	1
AC	41-70	g w	10YR4/3	2md sbk	vs vp	-	vf fn <7.5%	2
C1	70-90	g w	10YR4/4	2md sbk	vs vp	-	md co > 7.5%	2
C2	90-127	-	10YR4/4	2md sbk	vs vp	-	vf fn <7.5%	2
			(Shiwalik hills (Valley)					
Pedon 3	Coarse-loamy, Typic Udipsamments							
A1	0-23	d w	10YR3/3	0 sbk	sssp	-	-	1
AC	23-53	g w	10YR3/3	1 sbk	sssp	-	f fn > 7.5%	2
C	53-106	d s	10YR4/3	1 sbk	sp	-	vf fn <7.5%	2
2C	106-190	-	10YR4/2	-	sp	-	-	2
Pedon 4	Loamy-skeletal, Fluventic Udorthents							
A1	0-10	c w	2.5 YR 3/2	1 md gr	sssp	-	Stones (10-20%)	-
AC	10-31	c w	2.5 YR 2/2	1 md gr	sp	-	Pebbles (10-20%)	-
C1	31-66	c w	2.5 YR 2/2	2 co gr	ssnp	-	Pebbles (10-20%)	-
C2	66-88	a w	2.5 YR 2/2	2 co gr	ssnp	-	Pebbles (10-20%)	-
R	88+				Hard rock			
			Piedmont plains (Upper)					
Pedon 5	Coarse-loamy, Typic Eutrudepts							
Ap	0-35	d w	10YR3/3	3 md sbk	nsnp	-	Stones (8.5%)	-
Bw	35-110	g w	10YR3/3	1md sbk	nsnp	-	Boulders (3%)	-
BC	110-241	-	2.5YR3/3	1 md sbk	sssp	-	-	-
Pedon 6	Loamy-skeletal Lithic Udorthents							
Ap	0-15	c w	5YR3/4	1 fn sbk	sssp	f md	-	-
AC	15-38	d s	5YR3/3	2 fn sbk	sp	f md	Pebbles (2%)	-
C	38-63	-	5YR3/3	2 md sbk	sp	f md	Stone layer	-
R	63+				Stone layer			
			Piedmont plains (Lower)					
Pedon 7	Coarse-loamy Udic Haplustepts							
Ap	0-16	g-w	10YR4/4	1 sbk	Massive	c fn md	-	-
Bw1	16-29	g-w	10YR4/4	1 sbk	vs sp	md fn	-	-
Bw2	29-40	g-w	10YR4/4	2 sbk	vs sp	f fn	-	-
Bw3	40-110	g-w	10YR4/4	3 sbk	vs sp	-	-	-
Bw4	110-155	g-w	10YR4/4	3 sbk	vs sp	-	-	-

Pedon / Horizon	Depth (cm)	Boundary	Colour (moist)	Structure	Consistence	Roots	Coarse fragment	Reaction
			Flood plains					
Pedon 8	Coarse -loamy Typic Ustorthents							
Ap	0-26	g-w	7.5YR3/2	2 md sbk	fi sp	c fn md	-	3
C1	26-54	d-w	5YR3/3	2 md sbk	fi sp	f fn	-	3
C2	54-86	d-s	5YR3/3	2 md sbk	fi sp	f fn	-	3
2C1	86-112	d-s	7.5YR4/4	1 md sbk	fi sp	vf fn	-	3
2C2	112-190	d-s	5YR4/4	1 md sbk	fi sp	vf fn	-	3
3C	19-240	-	5YR4/4	1 md sbk	ns sp	-	-	3
			Old alluvial plains					
Pedon 9	Fine -loamy Fluventic Haplustepts							
Ap	0-17	g-w	10YR4/4	2 md sbk	sp fi	f md	-	2
AB	17-28	g-w	10YR4/3	2 md sbk	sp fi	vf md	-	2
Bw1	28-50	c-s	7.5YR4/4	2 md sbk	svp fi	-	-	3
Bw2	50-82	g-w	7.5YR4/4	2 md sbk	sp	-	-	3
Bw3	82-121	g-w	5YR3/4	2 md sbk	vs vp	-	-	3
BC	121-134	a-s	5YR4/4	2 md sbk	sp	-	-	2
C	134-165	-	10YR4/3	1 fn sbk	ss np	-	-	2
2C	165-210	-	5YR3/4	1 md sbk	sp	-	-	3
Pedon 10	Fine-loamy Aquic Haplustepts							
Ap	0-21	g-w	10YR4/3	2 md sbk	ss sp	f md	-	-
AB	21-41	d-s	10YR4/3	2 md sbk	sp	f md	-	-
Bw1	41-72	c-w	10YR3/3	2 co sbk	vs vp	vf vn	-	-
Bw2	72-164	-	10YR3/3	2 co sbk	vs vp	-	Fe, Mn	-
			Lowlying old alluvial plains					
Pedon 11	Fine-loamy Aquic Ustorthents							
Ap1	0-12	a-w	7.5YR3/2	massive	vs vp	m fn	-	2
Ap2	12-20	c-w	7.5YR3/2	3 sbk	vs vp	c fn	-	2
C1	20-35	g-w	7.5YR3/3	3 sbk	vs vp	-	Vf fn Fe, Mg	2
C2	35-51	g-w	7.5YR4/4	3 sbk	vs vp	-	vf fn Fe, Mg	3
2C1	51-124	g-w	10YR4/4	3 sbk	sp	-	-	3
2C2	124-150	-	10YR4/4	3 sbk	sp	-	-	3
Pedon 12	Fine- loamy Aquic Ustorthents							
Ap	0-18	c-w	10YR3/2	2 md co sbk	vs vp fi	c md	-	1
AC	18-33	g-w	10YR3/2.5	3 v co sbk	vs vp fi	c md	-	1
2C	33-53	c-w	10YR3/2.5	3 v co sbk	vs vp fi	f md	-	1
3C1	53-80	c-w	10YR3/3	3 co sbk	vs vp fi	f fn	Fe, Mn vfn	1
3C2	80-102	c-w	10YR4/4	3 co sbk	vs vp fi	f fn	Fe, Mn c fn md	0
3C3	102-180	-	10YR4/4	3 md co sbk	vs vp fi	f fn	Fe, Mn c fn md	1
4C	180-250	-	10YR4/4	1 fn sbk	vs vp fi	f fn	-	1

well developed soils of alluvial plains, moderately developed in piedmont plains and flood plains, whereas, the soil structure was weakly developed in coarse strata. Massive structure with A-C horizons in pedon 11 indicated lack of profile development.

Presence of ped coatings in sub-surface horizons of pedon 6, 9, 10 and 12 are patchy to broken and thin which may be the result of frequent seasonal floods, intensive irrigation and accumulation of finer sediments on the matrix of lower horizons.

Physical Characteristics

The physical characteristics of the soils are presented in table 2. The results on distribution of soil particles indicated that sub-surface horizons of pedons 9, 10 and 11 were having more clay content than other pedons which may be due to translocation and accumulation of clay. Pedons 6, 8 and 12 exhibited irregular distribution of clay content showing the lithological discontinuity due to stratification of fluvial sediments. Tripathi *et al*. (2006) ascertained that sub-surface horizons exhibited higher clay content compared to surface horizons which may be due to illuviation process occurring during soil development. Similarly, the illuviation process also affected the vertical distribution of silt and sand contents. Sand fraction was higher in pedon 3 as compared to other pedons of Shiwalik hills and old alluvial plains indicating the nature of sediments of the rivers. Sand constitutes the bulk of the mechanical fraction which may be assigned to dominance of physical weathering and siliceous nature of parent material.

Water retention characteristics of horizons were strongly associated to texture with the finer soil showing higher retention and *vice versa* (Table 2). Water retention at field capacity and permanent wilting point varied from 13.98 to 30.22 and 4.18 to 14.82 per cent, respectively. Significant correlations between moisture retained at suctions 0.03 and 1.5 MPa with silt + clay, clay and organic carbon were obtained (Table 4). Clay and silt content had greater correlation than sand on retention behaviour of different pedons. This might be explained by the drainage that occurs when suction pressure is increased from 0.03 to 1.5 MPa. Since, macropores are emptied in lower suction range and micropores in higher suction range, the effect of clay content gets expressed in the form of higher permanent wilting point because of greater number of micropores (Nikam *et al*. 2006). The values of coefficient of correlation between moisture retention and silt + clay ($r = 0.74$ to 0.86; $p \leq 0.01$) and clay fraction (0.77 to 0.87; $p \leq 0.01$) were higher than the correlation of organic carbon ($r = 0.23$ to 0.27) indicating that increase in clay increased water retention. As the contribution of clay towards moisture retention is highly significant, the effect of organic carbon was masked by clay as OC decreased with depth but clay, in general, increased with depth. Moreover, a positive and significant relationship was observed between water retention and cation exchange capacity (Table 4) which implies that clay mineralogy influences the water retention characteristics of soil as CEC is directly related to clay mineralogy. Since, in the soil water is held by capillary and adsorptive forces which are mainly a function of clay content and clay mineralogy. The hydraulic conductivity of soils of pedons 1, 2, 6, 9, 10, 11 and 12 was low (0.22 to 1.28 cm hr^{-1}) due to presence of higher clay content and pedons 5 and 7 was medium (0.91 to 1.40 cm hr^{-1}), whereas, higher hydraulic conductivity was observed in pedon 3 (1.31 to 2.60 cm hr^{-1}) which may be ascribed to the sandy texture of these pedons having higher number of macropores as the flow rate in the soil pores is proportional to the fourth power of the radius. The hydraulic conductivity decreased with depth in pedons 1, 7 and 10 which may be due to increase in silt and clay contents with depth. A positive and significant correlation between sand and hydraulic conductivity ($r = 0.81$; $p \leq 0.01$) and negative and significant correlation with clay ($r = -0.83$; $p \leq 0.01$). The coefficient of correlation of hydraulic conductivity with silt + clay ($r = -0.81$; $p \leq 0.01$) was higher as compared to organic carbon ($r = 0.21$) indicating that there is no linear relationship between hydraulic conductivity and organic carbon on account of low organic carbon. Nath and Krishna (2014) also reported negative correlation between hydraulic conductivity and clay and positive relationship between hydraulic conductivity and sand and organic carbon.

Bulk density of soils varied from 1.16 to 1.45 Mg m^{-3} and did not show any regular pattern with depth except pedons 4 and 8 showing the increasing pattern with depth which may be ascribed to progressive compaction due to filling of pores by eluvial materials, lower organic matter and less aggregation. Singh and Aggarwal (2005) and Kharlyngdoh *et al*. (2015)

Table 2. Soil physical properties

Pedon / and Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density	Particle density (Mgm^{-3})	Pore space (%)	Per cent moisture retention (Mpa) 0.03	0.08	1.5	Available water (%)	Hydraulic conductivity ($cm\ hr^{-1}$)
								Shiwalik hills (Top)				
Pedon 1		Loamy - skeletal Typic Udorthents (Shiwalik hills (Top)										
A1	0-37	59.21	19.57	21.22	1.25	2.61	52.1	18.77	16.10	8.61	10.16	0.73
C1	37-152	54.51	21.60	23.87	1.31	2.58	49.22	21.88	18.20	9.94	11.94	0.42
2C2	152-242	52.10	21.20	27.70	1.35	2.60	48.07	22.92	17.90	9.10	12.82	0.38
								Shiwalik hills (Slope)				
Pedon 2		Fine-loamy, Typic Udorthents										
A1	0-41	43.61	30.00	26.39	1.27	2.51	49.40	25.75	23.10	11.21	14.54	0.23
AC	41-70	42.27	31.73	24.00	1.30	2.54	48.81	23.83	20.90	10.37	13.46	0.22
C1	70-90	56.04	20.96	23.00	1.28	2.62	51.14	22.20	19.17	9.60	11.60	0.27
C2	90-127	61.10	18.75	20.15	1.24	2.63	52.85	22.85	17.90	8.95	13.90	0.29
								Shiwalik hills (Valley)				
Pedon 3		Coarse-loamy, Typic Udipsamments (Shiwalik hills (Valley)										
A1	0-23	90.49	5.91	3.60	1.40	2.61	46.36	14.7	11.10	4.21	10.49	2.42
AC	23-53	92.59	5.00	2.41	1.45	2.68	45.89	13.98	10.05	4.18	9.80	2.60
C	53-106	88.44	6.82	4.74	1.41	2.46	42.68	15.42	12.10	4.94	11.48	2.40
2C	106-190	78.58	8.16	13.26	1.35	2.48	45.56	20.12	18.75	9.22	13.90	1.31
Pedon 4		Loamy-skeletal, Fluventic Udorthents										
A1	0-10	50.00	21.65	28.35	1.21	2.40	49.58	25.28	20.10	11.75	13.53	0.70
AC	10-31	51.2	27.08	21.90	1.21	2.42	50.00	25.08	19.69	10.76	12.88	0.65
C1	31-66	70.33	16.66	12.51	1.27	2.28	44.29	18.26	16.90	8.22	10.04	1.18
C2	66-88	79.43	10.00	10.57	1.30	2.42	46.28	16.78	14.10	7.44	9.34	1.15
R	88+	Hard rock										
								Piedmont plains (Upper)				
Pedon 5		Coarse-loamy, Typic Eutrudepts										
Ap	0-35	80.80	11.20	8.00	1.17	2.65	55.84	18.91	16.30	8.92	9.99	1.37
Bw	35-110	77.10	11.67	11.23	1.33	2.63	49.42	17.23	14.70	7.85	9.38	1.15
BC	110-241	68.10	16.76	15.14	1.35	2.64	49.24	20.26	16.76	9.54	10.72	1.25
Pedon 6		Loamy-skeletal Lithic Udorthents										
Ap	0-15	77.22	9.97	12.81	1.38	2.73	49.45	17.78	14.59	7.23	10.55	0.96
AC	15-38	82.28	6.55	10.17	1.30	2.57	49.41	17.50	13.80	6.93	10.57	1.28
C	38-63	80.61	8.00	12.33	1.29	2.64	51.13	16.23	13.94	6.42	9.81	0.98
R	63+	Stone layer										

Pedon / and Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density	Particle density (Mgm^{-3})	Pore space (%)	Per cent moisture retention (Mpa) 0.03	0.08	1.5	Available water (%)	Hydraulic conductivity (cm hr^{-1})
Piedmont plains (Lower)												
Pedon 7	Coarse-loamy Udic Haplustepts											
Ap	0-16	84.25	6.91	8.84	1.30	2.77	53.00	20.50	15.90	9.50	11.00	1.40
Bw1	16-29	76.43	11.97	11.60	1.33	2.77	51.98	17.00	15.20	6.40	10.60	1.06
Bw2	29-40	70.39	14.01	15.60	1.33	2.77	51.98	16.80	14.30	6.40	10.40	1.15
Bw3	40-110	51.41	28.05	20.54	1.27	2.84	55.28	22.10	18.30	9.00	13.10	0.92
Bw4	110-155	50.48	28.88	20.64	1.27	2.84	53.28	22.50	18.80	9.00	13.50	0.91
Flood plains												
Pedon 8	Coarse -loamy Typic Ustorthents											
Ap	0-26	50.15	23.50	26.35	1.18	2.20	46.63	26.88	19.55	11.95	14.93	0.32
C1	26-54	67.00	16.15	16.85	1.30	2.54	48.8	22.64	16.85	9.10	11.54	0.95
C2	54-86	76.68	12.02	11.30	1.31	2.57	49.02	19.22	15.75	8.10	11.22	1.05
2C1	86-112	74.60	12.85	12.55	1.29	2.41	46.47	20.03	14.20	7.10	12.93	1.12
2C2	112-190	80.00	8.44	11.56	1.32	2.29	42.35	18.23	12.70	6.27	11.96	1.10
3C	19-240	86.62	5.88	7.50	1.37	2.30	40.43	16.35	10.10	6.10	10.25	1.24
Old alluvial plains												
Pedon 9	Fine -loamy Fluventic Haplustepts											
Ap	0-17	61.70	18.48	19.82	1.36	2.61	47.89	24.44	19.86	12.62	11.88	1.19
AB	17-28	58.00	20.10	21.90	1.27	2.75	53.81	25.69	22.25	13.30	12.39	0.81
Bw1	28-50	49.78	23.60	26.57	1.22	2.66	54.13	28.52	24.23	14.82	13.70	0.65
Bw2	50-82	52.60	22.45	24.95	1.16	2.50	53.60	27.54	22.46	14.29	13.31	0.72
Bw3	82-121	46.00	24.62	29.38	1.23	2.59	52.50	30.22	26.10	14.68	15.54	0.85
BC	121-134	75.02	12.67	12.31	1.36	2.52	46.03	22.24	18.36	10.90	11.34	0.92
C	134-165	76.00	13.08	10.92	1.44	2.61	44.82	19.25	15.70	9.83	9.42	0.88
2C	165-210	53.30	22.47	25.23	1.30	2.33	44.20	25.30	23.03	14.22	13.17	0.68
Pedon 10	Fine-loamy Aquic Haplustepts											
Ap	0-21	72.60	11.60	15.80	1.30	2.40	45.83	21.47	17.50	9.86	11.61	1.11
AB	21-41	73.80	13.40	12.80	1.31	2.25	41.77	19.46	16.10	9.28	10.18	0.98
Bw1	41-72	58.68	19.80	21.52	1.25	2.28	45.17	25.42	22.2	12.57	12.85	0.61
Bw2	72-164	38.84	27.16	34.00	1.21	2.36	48.72	28.33	24.7	14.79	13.54	0.23
Low lying old alluvial plains												
Pedon 11	Fine-loamy Aquic Ustorthents											
Ap1	0-12	40.84	27.58	31.58	1.17	2.68	56.34	26.34	22.67	11.50	14.84	0.26
Ap2	12-20	42.13	27.00	30.87	1.26	2.75	54.18	25.90	21.90	10.87	15.03	0.23
C1	20-35	51.55	24.00	24.40	1.21	2.80	56.78	22.81	19.65	9.68	13.13	0.85
C2	35-51	65.70	15.00	20.30	1.21	2.37	48.94	20.70	18.10	9.15	11.55	0.80
2C1	51-124	57.60	20.27	22.13	1.25	2.38	47.47	22.05	19.34	9.80	11.25	0.86
2C2	124-150	67.00	15.62	18.38	1.20	2.38	49.57	19.23	16.90	8.75	10.48	1.10
Pedon 12	Fine-loamy, Aquic Ustorthents											
Ap	0-18	59.53	19.52	20.95	1.22	2.39	48.95	26.17	24.79	13.02	13.15	0.82
AC	18-33	61.73	17.27	22.00	1.25	2.44	48.77	23.92	20.52	12.25	11.67	0.85
2C	33-53	64.26	17.38	18.36	1.23	2.39	48.53	24.75	21.20	12.32	12.43	1.15
3C1	53-80	55.04	20.96	24.00	1.22	2.41	49.37	27.57	23.78	13.87	13.70	0.81
3C2	80-102	59.85	18.85	21.40	1.25	2.47	49.39	24.92	21.04	12.78	12.14	0.75
3C3	102-180	62.53	16.47	21.00	1.29	2.39	46.00	24.10	20.73	12.72	11.38	0.81
4C	180-250	68.20	14.30	18.50	1.27	2.45	48.16	21.48	19.34	11.12	10.36	1.18

reported the increase in bulk density down the profile as a result of low organic matter and compaction of soil aggregates. Similar findings were reported by Singh *et al.* (1993) while studying the pedogenesis and taxonomy of soils in a toposequence of central Himalayas. The particle density and total porosity varied from 2.20 to 2.84 Mg m^{-3} and 40.40 to 56.78 per cent, respectively and did not show any trend with depth. A significant and positive correlation was observed between pore space and moisture retention (Table 4) showing that higher the porosity higher is the water retention as higher porosity is mainly related to fine soil texture. Higher porosity was observed in heavy textured soils because of relatively large number of micropores associated with silt and clay content. The available water content varied from 9.34 to 15.54 per cent and the differences were due to variation in depth, clay and organic carbon of the pedons. A significant positive relationship was observed between clay and available water content ($r = 0.76; p \leq 0.01$) and silt+clay and available water content ($r = 0.77; p \leq 0.01$); however, a significant negative correlation was observed between sand and available water content ($r = -0.77; p \leq 0.01$). Consequently, silt and clay were found to be the dominant factors in regulating soil water content in all pedons.

Chemical characteristics

The chemical properties of the soil are presented in table 3. According to pH classes, the soils of pedon 4, 5 and 6 were slightly acidic to neutral (6.45-7.35) in reaction which may be due to high rainfall and more vegetation in the area. The soils of pedons 2, 3, 7 and 10 were moderately alkaline (7.5 to 8.3), whereas, pedons 1, 8, 9, 11 and 12 were strongly alkaline (8.3 to 9.4) in reaction. There was an increase in pH with depth in all pedons except pedon 4 and 7 which might be attributed to the loss of bases from the surface. Moreover, the increasing trend may be due to increase in accumulation of exchangeable sodium and calcium carbonate (Rajeshwar *et al*. 2009; Singh *et al*. 2016). Kaistha and Gupta (1993) also reported increase in pH in deeper horizons in the soils of the north-west Himalayan region.

The organic carbon (OC) was found to be higher in surface horizon of pedon 11, medium in pedons 8, 9 and 12. The higher OC in the pedon 11 might be attributed to the abundance of slow decomposition compounds like lignin of organic matter as these pedons are under forest cover. It was low in pedons 1, 2, 3, 5, 6, and 7. The low OC content in these pedons may be attributed to high rate of organic matter decomposition under hyperthermic temperature regime which leads to extremely high oxidising conditions (Singh *et al*. 2014). The OC decreased with depth in all the pedons except pedons 4 and 9 in which irregular distribution with depth showed the stratification in these areas.

Calcium carbonate ($CaCO_3$) was absent in pedons 4, 5, 6, 7 and 10 (Table 5). Irregular distribution of $CaCO_3$ was observed which indicated the fluvial nature of these soils. Higher amount of $CaCO_3$ was observed in soils developed on old alluvial and flood plains (0.62 to 2.42%) as compared to Shiwalik hills (0.10 to 0.25%). Absence or low amount of $CaCO_3$ in piedmont and Shiwalik hills was due to high rainfall in the study area. Sawhney *et al.* (1996) also reported the highest amount of $CaCO_3$ in the soils developed on the toe slopes which may be due to finer texture of soils that slow down the infiltration rate of water and/ or accretion of carbonates due to lateral subsurface water flow. Calcium carbonate concretions were absent in all the pedons of study area. It was further observed that the process of nodulation was absent and might be due to poor enrichment of $CaCO_3$ in the sediment. Due to absence of concretions in the study area, their composition could not be reported.

The cation exchange capacity (CEC) was found to be less (5.21 to 12.71 cmol (p^+) kg^{-1}) in pedons 5, 6 and 7 compared to pedons 1, 2, 3, 8, 9, 10, 11 and 12 (9.61 to 17 cmol (p^+) kg^{-1}). The low CEC of these soils is due to dominance of illite and other low charge minerals and low organic matter content (Sharma *et al*. 2011). The higher CEC in pedons 2, 8, 9 and 11 was due to more clay content in these pedons. Sireesha and Naidu (2015) reported that the variation in content and nature of organic carbon and inorganic colloids may be responsible for higher CEC. A significant positive correlation was observed between CEC and clay ($r = 0.65; p \leq 0.01$) and silt ($r = 0.48; p \leq 0.01$) suggesting that clay and silt were the principal factors that influenced CEC. Moreover, positive and significant correlation was observed between OC and CEC. Karmakar (2014) established positive and significant

Table 3. Chemical properties of soils

Pedon / Horizon	Depth (cm)	pH (1:2)	EC_e (dSm^{-1})	OC (%)	$CaCO_3$ (%)	CEC cmol(p^+) kg^{-1}	Ca^{2+}	Mg^{2+}	Na^+	K^+	ESP	BSP
Shiwalik hills (Top)												
Pedon 1	Loamy - skeletal Typic Udorthents (Shiwalik hills (Top)											
A1	0-37	8.51	0.53	0.25	0.17	11.10	7.30	2.50	0.92	0.11	8.28	93.06
C1	37-152	9.05	0.77	0.18	1.47	15.24	7.10	4.80	2.02	0.24	13.40	92.91
2C2	152-242	9.05	1.12	0.11	-	13.96	4.00	7.10	1.88	0.33	14.12	95.34
Shiwalik hills (Slope)												
Pedon 2	Fine-loamy Typic Udorthents											
A1	0-41	8.45	0.37	0.14	0.10	14.49	8.00	5.60	0.19	0.13	1.31	96.06
AC	41-70	8.25	0.44	0.13	-	9.61	7.70	1.60	0.12	0.09	1.25	98.90
C1	70-90	8.55	0.35	0.27	0.25	14.71	8.10	5.70	0.24	0.12	1.63	96.26
C2	90-127	8.50	0.34	0.05	0.10	13.43	10.60	2.84	0.51	0.07	3.80	98.88
Shiwalik hills (Valley)												
Pedon 3	Coarse-loamy Typic Udipsamments (Shiwalik hills (Valley)											
A1	0-23	8.40	0.39	0.19	0.20	7.83	4.10	3.20	0.12	0.08	1.53	95.83
AC	23-53	8.65	0.31	0.11	0.25	6.70	4.20	2.10	0.12	0.09	1.79	97.25
C	53-106	8.65	0.29	0.06	0.15	6.70	4.00	2.40	0.11	0.07	1.64	96.10
2C	106-190	8.70	0.28	0.06	-	9.20	5.80	3.00	0.14	0.11	1.54	95.20
Pedon 4	Loamy-skeletal Fluventic Udorthents											
A1	0-10	6.85	0.67	1.59	-	14.83	5.10	9.20	0.15	0.38	0.98	97.56
AC	10-31	6.50	0.21	0.34	-	8.29	3.95	4.10	0.12	0.12	1.42	98.45
C1	31-66	6.45	0.28	0.75	-	11.15	4.81	6.10	0.12	0.12	1.46	98.58
C2	66-88	6.45	0.22	0.63	-	6.64	3.05	3.35	0.13	0.11	1.95	96.65
R	88+	Hard rock										
Piedmont plains (Upper)												
Pedon 5	Coarse-loamy Typic Eutrudepts											
Ap	0-35	7.35	0.25	0.60	-	9.05	2.80	4.80	1.02	0.31	11.27	98.67
Bw	35-110	6.80	0.21	0.15	-	8.92	4.00	3.50	1.20	0.13	13.45	98.99
BC	110-241	7.00	0.21	0.07	-	12.71	6.10	4.70	1.18	0.11	9.28	94.33
Pedon 6	Loamy-skeletal Lithic Udorthents											
Ap	0-15	7.00	0.21	0.20	-	5.21	3.00	1.80	0.12	0.08	2.30	96.04
AC	15-38	7.00	0.22	0.18	-	7.92	4.02	3.20	0.10	0.10	1.26	93.63
C	38-63	7.05	0.24	0.15	-	7.84	5.00	2.00	0.10	0.08	1.27	91.63
R	63+	Stone layer										

Pedon / Horizon	Depth (cm)	pH (1:2)	EC_e (dSm^{-1})	OC (%)	$CaCO_3$ (%)	CEC cmol(p^+) kg^{-1}	Ca^{2+}	Mg^{2+}	Na^+	K^+	ESP	BSP
Piedmont plains (Lower)												
Pedon 7	Coarse loamy Udic Haplustepts											
Ap	0-16	8.20	0.89	0.06	-	11.00	4.50	4.45	0.81	1.02	7.36	98.00
Bw1	16-29	7.60	0.75	0.05	-	11.02	4.50	4.65	0.70	1.02	7.35	98.63
Bw2	29-40	7.40	0.50	0.03	-	5.90	2.90	1.85	0.49	0.36	8.30	94.91
Bw3	40-110	7.40	0.50	0.03	-	5.91	2.90	1.80	0.45	0.25	7.61	91.37
Bw4	110-155	7.50	0.30	0.03	-	5.95	2.90	1.80	0.45	0.25	7.56	90.75
Flood plains												
Pedon 8	Coarse -loamy Typic Ustorthents											
Ap	0-26	8.05	0.94	0.51	1.87	15.00	12.10	2.00	0.26	0.29	1.72	97.66
C1	26-54	8.90	0.59	0.21	1.92	12.00	9.10	2.00	0.22	0.13	1.82	95.41
C2	54-86	8.85	0.52	0.13	2.42	10.90	7.00	1.50	0.12	0.12	2.58	98.20
2C1	86-112	8.90	0.47	0.10	1.50	10.20	8.00	1.00	0.18	0.12	1.76	91.17
2C2	112-190	8.10	0.46	0.09	0.87	13.10	5.00	7.00	0.40	0.15	3.04	95.80
3C	19-240	8.80	0.44	0.07	1.45	9.30	5.70	2.50	0.84	0.12	9.23	98.60
Old alluvial plains												
Pedon 9	Fine -loamy Fluventic Haplustepts											
Ap	0-17	8.30	0.71	0.64	1.60	12.27	8.50	2.50	0.24	0.25	1.94	93.64
AB	17-28	8.60	0.44	0.21	0.60	11.20	7.00	3.50	0.20	0.29	1.78	98.12
Bw1	28-50	8.80	0.39	0.33	1.15	15.30	11.10	3.00	0.38	0.22	2.48	96.07
Bw2	50-82	9.20	0.40	0.28	2.25	16.40	10.00	5.00	1.02	0.13	6.20	98.47
Bw3	82-121	9.20	0.55	0.13	1.90	13.00	6.90	4.00	1.76	0.18	13.44	98.76
BC	121-134	9.30	0.29	0.10	0.75	12.75	8.00	3.50	0.72	0.14	5.64	96.94
C	134-165	9.40	0.31	0.02	0.87	12.30	6.00	4.50	0.82	0.12	4.22	90.56
2C	165-210	9.15	0.38	0.09	1.50	16.23	10.50	4.00	1.16	0.18	7.14	97.59
Pedon 10	Fine-loamy Aquic Haplustepts											
Ap		7.10	0.38	0.43	-	9.82	7.10	1.50	0.16	0.17	1.62	90.93
AB	21-41	8.00	0.29	0.13	-	8.85	6.10	2.00	0.20	0.09	2.26	94.80
Bw1	41-72	8.30	0.24	0.12	-	13.10	11.00	1.00	0.34	0.07	2.58	94.77
Bw2	72-164	8.30	0.26	0.12	-	17.00	11.00	4.00	0.48	0.06	2.66	91.77
Low lying old alluvial plains												
Pedon 11	Fine-loamy Aquic Ustorthents											
Ap1	0-12	8.20	0.75	1.23	1.27	14.00	7.50	3.50	1.46	0.69	11.10	93.92
Ap2	12-20	8.30	0.61	1.00	1.85	16.40	8.00	5.10	2.42	0.60	16.00	98.82
C1	20-35	8.65	0.53	0.23	0.65	11.42	6.30	2.07	2.36	0.39	21.75	97.37
C2	35-51	8.90	0.44	0.13	1.62	9.92	5.00	2.15	2.34	0.30	23.39	98.68
2C1	51-124	8.80	0.49	0.07	0.60	11.50	4.60	3.80	2.82	0.20	24.69	98.44
2C2	124-150	9.10	0.55	0.09	0.57	11.40	4.00	3.65	3.31	0.07	30.00	96.75
Pedon 12	Fine-lLoamy Aquic Ustorthents											
Ap	0-18	8.50	0.76	0.49	0.30	11.62	6.50	3.50	1.40	0.14	12.14	92.85
AC	18-33	8.60	0.60	0.41	0.40	10.50	6.50	2.50	1.24	0.14	11.98	93.78
2C	33-53	8.45	0.58	0.34	0.27	9.72	5.50	3.00	1.28	0.10	12.95	87.06
3C1	53-80	8.75	0.51	0.20	0.37	10.10	5.10	2.90	1.52	0.08	15.83	82.21
3C2	80-102	9.10	0.33	0.17	0.17	9.80	4.00	3.50	1.96	0.08	20.54	81.06
3C3	102-180	9.20	0.23	0.15	0.27	9.80	4.10	2.80	2.75	0.06	28.32	93.77
4C	180-250	9.10	0.31	0.11	0.25	9.30	4.50	2.00	2.70	0.04	29.23	97.22

Table 4. Correlation matrix among physic properties

	Sand	Silt	Clay	Silt + Clay	Bulk density	Particle density	Pore space	Moisture retention 0.03	Moisture retention 1.5	Available water	Hydraulic conductivity	OC	CEC
Sand	1.00												
Silt	-0.97**	1.00											
Clay	-0.97**	0.88**	1										
Silt + Clay	-0.99**	0.97**	0.97**	1									
Bulk density	0.63**	-0.58**	-0.65**	-0.64**	1								
Particle density	-0.02	0.08	-0.05	0.01	0.19	1							
Pore space	-0.45**	0.46**	0.42**	0.45**	-0.53**	0.72**	1						
Moisture retention 0.03	-0.85**	0.79**	0.87**	0.86**	-0.65**	-0.14	0.34*	1					
Moisture retention 1.5	-0.74**	0.66**	0.77**	0.74**	-0.59**	-0.21	0.24	0.94**	1				
Available water	-0.77**	0.73**	0.76**	0.77**	-0.51**	-0.02	0.32*	0.81**	0.61**	1			
Hydraulic conductivity	0.81**	-0.75**	-0.83**	-0.81**	0.56**	0.07	-0.33*	-0.69**	-0.61**	-0.56**	1		
OC	-0.30*	0.24	0.33*	0.29*	-0.39**	-0.08	0.21	0.27*	0.23	0.25	-0.21	1	
CEC	-0.58**	0.48**	0.65**	0.58**	-0.37**	-0.21	0.11	0.63**	0.60**	0.52**	-0.61**	0.28*	1

** Correlation is significant at the 0.01 level of significance
* Correlation is significant at the 0.05 level of significance

Table 5. Correlation matrix among chemical properties

	pH	EC	OC	$CaCO_3$	CEC	Ca^{2+}	Mg^{2+}	Na^+	K^+	ESP	BSP	Sand	Silt	Clay
pH	1													
EC	0.26*	1												
OC	-0.34**	0.25	1											
$CaCO_3$	0.51**	0.34*	0.11	1										
CEC	0.39**	0.37**	0.28*	0.47**	1									
Ca^{2+}	0.38**	0.15	0.08	0.50**	0.76**	1								
Mg^{2+}	-0.10	0.23	0.40**	-0.07	0.51**	-0.07	1							
Na^+	0.45**	0.24	-0.04	0.18	0.21	-0.15	0.10	1						
K^+	-0.10	0.58**	0.27*	0.07	0.17	-0.07	0.26	0.11	1					
ESP	0.38**	0.16	-0.10	0.07	0.01	-0.29*	-0.01	0.97**	0.07	1				
BSP	-0.10	0.02	0.09	0.19	0.15	0.11	0.19	-0.05	0.24	-0.10	1			
Sand	-0.16	-0.30*	-0.30*	-0.19	-0.58**	-0.46**	-0.19	-0.27*	-0.09	-0.18	0.08	1		
Silt	0.10	0.23	0.24	0.15	0.48**	0.41**	0.14	0.20	0.07	0.12	-0.06	-0.97**	1	
Clay	0.22	0.35**	0.33*	0.24	0.65**	0.49**	0.23	0.35**	0.11	0.25	-0.09	-0.96**	0.88**	1

** Correlation is significant at the 0.01 level of significance
* Correlation is significant at the 0.05 level of significance

correlation between CEC and clay and silt which established that silt fraction also carries adequate negative charge which may be due to weathering and or finer silt fraction nearer to 0.002 mm size.

The exchangeable bases exhibited regular and irregular trends as a result of variations in soil depth and topographic position (Table 3). Among exchangeable cations, calcium was dominant (2.80 to 12.10 cmol (p^+) kg^{-1}) in all the geomorphic units followed by magnesium (1.00 to 9.20 cmol (p^+) kg^{-1}), sodium (0.10 to 2.85 cmol (p^+) kg^{-1}) and potassium (0.07 to 1.02 cmol (p^+) kg^{-1}). Similar results were ascertained by Sharma *et al.* (2011) in western Shiwalik Himalayas. The soils of all the geomorphic units under study were non-sodic in nature (ESP <15%) except sub-surface horizons of pedon 11 and 12 which were sodic in nature (ESP; 15.83 to 30.00%). The exchangeable complex was dominated by bases with base saturation percentage (BSP) ranging from 81.06 to 98.82. The base saturation of exchangeable complex is high on account of the occurrence of cations where exchangeable Ca^{2+} is sufficiently high. Sharma *et al*. (2011) reported that the difference of cation exchange capacity, base saturation and water retention percentages between soils may be ascribed largely to the varied type/ content of the soil colloids and soil pH values.

The electrical conductivity (EC_e) of saturation extract revealed that soils of all geomorphic units were non-saline in nature (0.21 to1.12 dSm^{-1}). Sharma *et al.* (2011) also reported low electrical conductivity while studying the soils of western Shiwalik Himalayas in Punjab.

Soil classification

The soils of the Shiwalik hills (top and slope), Shiwalik hills (valleys), and piedmont plains, active and recent flood plains, lacked pedogenic development and horizon differentiation and placed under the order Entisols except pedon 7 of piedmont plains. The soils of pedon 9, 10 and 12 of old alluvial plains and pedon 7 of piedmont plain showed stratification because of irregular distribution of organic carbon within the profile were Fluventic in nature. The soils were placed under Inceptisols due to presence of cambic subsurface horizons.

The soils of the Shiwalik hills (top and slope), valleys, piedmont plains (except pedon 5 and 7) and active and recent flood plains were placed under great groups of Udorthents, Udipsamments and Psammaquents. The soils of old alluvial plains (pedon 9 and 10) and low lying alluvial plains (pedon 12) were classified as Haplustepts and Eutrudepts. However, pedon 11 of low lying plain was placed under Ustorthents. Because of variation in particle size distribution, these soils were classified as coarse, loamy/fine loamy family. The soils of Shiwalik hills (pedons 1and 2) were placed under loamy-skeletal due to presence of more than 35 per cent coarse gravels. The soils of pedon 4 of the valley were classified to Fluventic Udorthents.

Conclusions

The results revealed considerable variations in the morphological, physical and chemical characteristics of the soils depending on their geomorphic position in the study area. The texture of the study area varied from sand to clay loam. The soils are slightly acidic to strongly alkaline in nature. The soils were non-sodic except the subsurface horizons of low lying alluvial plains. Among exchangeable cations, calcium was dominant followed by magnesium, sodium and potassium. The factors responsible for the evolution of landforms are also responsible for the formation of soils. The soils of the study area were classified into Entisols and Inceptisols.

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Received : April, 2017 Accepted : October, 2017