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Morphological, physical and chemical properties of soils associated in toposequence forestablishing taxonomy classes in Pratapgarh District of Rajasthan, India

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The present study was conducted to study the variability in soil properties in relation to landforms, in the present investigation, two transects that is, Aravalli mountain ranges and Malwa plateau, were selected in the Pratapgarh district having eight landforms namely hill, pediments, valley, and plain in the Aravalli Mountain ranges and Malwa plateau, respectively. Total eight pedons were examined in the field and investigated in the laboratory using standard laboratory procedures. The soils on hill top and pediment were shallow, gravely sandy loam to clay loam single grain in texture with medium coarse weak sub angular blocky structure and exhibited dark yellowish brown to dark reddish brown colour. The soils of valley were deep, sandy loam to loam and silty clay loam to clay loam in texture with medium coarse weak sub angular blocky to medium fine moderate sub angular blocky structure and exhibited dark yellowish brown to dark reddish brown colour. The soils of plain were found deep, silty clay in texture with medium moderate to strong angular structure (angular and sub angular) and exhibited dark brown to very dark grayish brown colour. The available water capacity were recorded higher in the plain soils as compared to soils of other landforms as well as in Aravali mountain ranges and Malwa plateau. The pH was relatively higher in the soils of Aravali mountain ranges than Malwa plateau but EC was relatively lower in the soil of Aravali mountain ranges then Malwa plateau. Distribution of organic carbon was low in soils of all pedons but comparatively higher in soils of Malwa plateau. Base saturation was comparatively lower in the soils of lower topographic position. Cation exchange capacity was found positively correlated with clay and increases as clay increased down the slope as well as with depth. Concentration of exchangeable bases was in order of Ca^{2+}>Mg^{2+}>K^{+}>Na^{+} in all the pedons soils.

Key words: Toposequence associated soil, morphological, physical, chemical properties, taxonomy.

INTRODUCTION

Pratapgarh is newest constituted district of Rajasthan state, which is a tribal dominant with an area of 411736 ha. Pratapgarh is situated in the southern part of Rajasthan. It is situated on the junction of Aravali mountain ranges and the Malwa Plateau; hence characteristics of both are prominent in the area.

Pratapgarh is located at 29.03° North and 74.78° East. It has an average elevation of 491 m (1610 feet).

The western, southern and northern parts of the district are somewhat plains. North and southern part of the district having black cotton soil in abundance. The major irrigation project of the district is the Jakham Dam. The north-west part of this region had dense forests. In the traditional method of soil map compilation, much emphasis is not being given on study of variability in pedogenic factors and quantification of soil properties used for soil classification. As such the information, dealing with variability in genetic related soil properties and their relationship with properties, which have key role in natural resource management, is generally scanty in India and so particularly in context to Rajasthan. Besides, sound and reliable database, dealing with information is needed to prepare base line of indicators to maintain the sustainability of system. So, detailed studies on morphological, physical and chemical properties are required to comprehend the extent of soil variability and to optimizing land use in Pratapgarh district. The present investigation is taken up to study the pathways of soil formation in relation to topography.

MATERIALS AND METHODS

Physical characteristics

Particle size description

International pipet method as described by Black (1980) was followed for estimation of various soil separates. Texture of the soil sample was determined from the composition of separates using triangular chart.

Bulk density

Piper (1950), Keen Reczowasky method was followed.

Particle density

Pycnometer was used to determine volume and weight of soil particle as per method described by Black (1965).

Total density

Percent pore space was calculated by using the following formula:

Percent porosity = 100 (1 - Bulk density /particle density).

Maximum water holding capacity

Piper (1950), Keen Reczowasky method was adopted.

Available water capacity (m^3/m^3)

Gravimetric water content ($m^3/m^{3)}$ at 0.03 Mpa and at 1.5 Mpa (Srivastava et al., 1998).

Phsico-chemcial and chemical determinations

pH

pH was determined in 1:2.5 soil water suspension using glass electrode pH meter as per description of Richard (1954).

Electrical conductivity

Electrical conductivity of 1:2.5 soil water suspensions was determined by using solubridge as described by Richard (1954).

Organic carbon

Walkley and Black rapid titration method was followed as outlined by Jackson (1979).

Calcium carbonate

Acid neutralization method as outlined by Allison and Moddie (1965) was adopted.

Cation exchange capacity

Cation exchange capacity was determined using 1 N neutral ammonium acetate method as described by Richard (1954).

Exchangeable cations: Calcium

In the ammonium acetate leachat, calcium was determined by titrating with versenate solution as per method described by Richard (1954).

Magnesium

The exchangeable Mg was calculated by subtracting the values of Ca from the Ca + Mg as described by Richard (1954).

Sodium

In ammonium acetate extract, sodium was determined flame photo metrically.

Potassium

In ammonium acetate extract, potassium was determined flame photo metrically.

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Table 1. List of standards procedures for laboratory investigations.

S/No.	Soil properties	Methods	References
(A)	**Physical properties**		
1.	Mechanical analysis	International pipette method	Piper (1950)
2.	Bulk density	Core sampler method	Richards (1954)
3.	Particle density	Pycnometer method	Richards (1954)
4.	Water retention characteristics	Using pressure plate apparatus	Richards (1954)
5.	Available water capacity (m^3/m^3)	Gravimetnic water content m^3/m^3 at 0.03 MPa and at 1.5 MPa	Srivastava et al. (1998)
6.	Maximum water holding capacity	Keen Reczowasky method	Piper (1950)
7.	Percent porosity	100 (1-BD/PD)	Richards (1954)
(B)	**Phsico-chemcial and chemical determinations**		
8.	pH	Using 1:2 soil water and 1 N KCl suspension glass electrode pH meter	Richards (1954)
9.	Electrical conductivity (dSm^{-1})	1:2 soil water extract using solubridge	Richards (1954)
10.	Exchangeable cations (Ca^{+2} mg^{+2})	Versenate titration method	Richards (1954)
11.	Exchangeable cations (K^+ Na^+)	By 1 N ammonium acetate extract method	Richards (1954)
12.	Cation exchange capacity of soils	By 1 N ammonium acetate extract method	Richards (1954)
13.	Organic carbon	Walkley and black wet digestion method	Jackson (1979)
14.	Calcium carbonate	Acid neutralization method	Allison and Modi (1965)

RESULTS AND DISCUSSION

Morphologial features

Soil morphology or pedomorphic features has been studied mainly under field conditions. The morphology of a soil can be best evaluated from the *in-situ* examination of the soil profiles. The pedomorphic features of the soil profiles are the mirror image of the processes as responsible for the formation of a particular type of soil. Soil morphology is the stepping stone to the thorough appreciation of the physical, chemical and biochemical properties of the soil (Tables 1 and 2).

Soil colour

The colour of the soils ranged between very dark gray brown (10YR 3/1) to dark reddish brown (5YR 2.5/2) In Aravali mountain ranges, the colour variation was observed from brown (10YR 4/3) to dark brown (7.5YR 3/2). In case of soils of Malwa plateau colour was found varies from very dark grayish brown (10YR 3/1) to dark reddish brown (5YR 2.5/2). The colour of Aravali mountain range soils was brown to dark brown in almost all samples. And in case of soils of Malwa plateau the colour of soils of higher topographic positions (hill top, pediment and valley) varied from dark reddish brown (5YR 2.5/2) to yellowish brown (7.5YR 4/4), while plain soils were ranged in colour from very dark gray (10YR 3/1) to very dark grayish brown (10YR 3/2).

After thorough examination of data (Table 2) it was observed that the soils of hill top in Aravali mountain ranges showed a shade of dark yellowish brown and as topography gets gentler the colour of soil becomes brown (10YR 4/3) or dark brown (7.5YR 3/2) in plain. It was also found that the colour of surface horizon was brighter then lower horizons. While in case of soils of Malwa plateau it was observed that hill top soil and valley soils showed dark reddish brown in all upper horizon and radish brown in lower most horizon of both transect and in pediments it found dark brown (7.5YR/3/2) while in plain it found very dark gray (10YR 3/1) in upper and (10YR 3/2) very dark grayish brown in lower horizons. Maximum samples in both transect were found under the category of dark yellowish brown followed by dark brown colour. Similar pattern of soil colour variation were also reported by Rajkumar et al. (2005) and Sarkar et al. (2001).

Depth of soil solum

Solum thickness is a combined expression of pedogenetic horizons and varied from 50 to 75 cm and

Table 2. Salient morphological features.

Profile	Depth (cm)	Horizon designation	Colour (moist)	Texture	Gravel volume (%)	Structure	Reaction with HCl 0.01 N
			I Aravali Mountain Ranges				
			Hills (Dipora)				
P_1	0-30	Al	10 YR 4/4	Gsl	40-50	sg	-
			Pediments (Lodiya)				
P_2	0-20	A1	10 YR 4/3	L	10	mc_1sbk	-
	20-50	C	10 YR 4/3	Gcl	>80	mc_1sbk	-
			Valley (Bhagadera)				
P_3	0-15	Ap	10YR 4/4	Sl	-	mc_1sbk	-
	15-31	A2	10YR 4/3	Sil	-	mc_1sbk	-
	31-48	Bw1	10YR 4/3	Cl	-	m_2sbk	-
	48-75	C	10YR 4/3	L	-	mf_2sbk	-
			Plain - (Charpotiya)				
P_4	0-12	AP	7.5YR 4/3	Sic	-	m_2sbk	E
	12-20	Bw1	7.5YR 4/3	Sic	-	m_2abk	Es
	20-32	Bw2	7.5YR 4/3	Sic	-	m_2abk	Es
	32-40	Bw3	7.5YR 3/2	Sic	10	m_2abk	Es
	40-55	Bw4	7.5YR 3/2	Gsic	20	m_2abk	Es
	55-70	Ck	7.5YR 3/2	Weathered material of schist			Es
			II Malwa Plateau				
			Hills (Chiklad)				
P_5	0-15	A1	5YR 3/4	Sl	15	sg	-
	15-40	C	5YR 4/4	Gsl	>80	sg	-
			Pediments (Shah ji ka pathar)				
P_6	0-18	A1	7.5YR 3/2	L	10	f_2sbk	-
	18-30	Bw	7.5YR 3/4	Cl	10	f_2sbk	-
	30-50	C	7.5YR 4/4	Cl		f_1sbk	-
			Valley (Ghotarsi)				
P_7	0-12	Ap	5YR 2.5/2	Sicl	-	mf_1sbk	Es
	12-30	Bw1	5YR 4/3	Sil	-	mf_1sbk	Es
	30-45	Bw2	5YR 4/3	Cl		mf_2sbk	Es
	45-80	Bw3	5YR 4/4	Cl		mf_2sbk	E
			Plain - (kuni)				
P_8	0-10	Ap	10YR 3/1	Sic		m_1abk	Es
	10-25	Bss1	10YR 3/1	Sic		m_2abk	Es
	25-45	Bss2	10YR 3/2	Sic		m_3abk	Es
	45-60	Bss3	10YR 3/2	Sic		m_3abk	Es
	60-80	C	10YR 3/2	Sic		m_3abk	Es

40 to 80 cm in Aravali mountain ranges (P_1-P_4) and Malwa plateau (P_5-P_8), respectively (Table 2). Soils of Aravali mountain ranges were very shallow on pediments (P_2) and shallow on hill top (P_1) while remaining soils of Aravali mountain ranges on valley (P_3), plain (P_4) were deep. Whereas soils of Malwa plateau were very shallow on hill top (P_5), shallow on pediments (P_6), while the remaining soils of Malwa plateau on valley (P_7), plain (P_8)

were moderately deep. Gentle to moderate slope, rapid runoff and severe erosion account for very shallow to shallow soils on the elevated segment of transect. These altogether cast rapid removal of weathering product from the site of formation, resulting in shallower depth of soils. Sidhu et al. (2000), Rathore (2003) and Singh (2004) also reported shallow soils at higher elevation. However, shallow depth in very gently sloping alluvial plain must be due to resistance of parent material to weathering, which prevents soil development and its accumulation. Therefore, the depth of soils was found to be a function of the topography, type of basement rock and configuration of the landscape.

Texture

The variation in soil texture of different landforms is shown in Table 2. The soils of Aravali mountain ranges were gravel sandy loam on hill top (P_1), Loam at the surface and gravel clay loam in sub surface of pediment (P_2), all horizons having different texture (sandy loam to loam) in valley (P_3) while clayey in charpotiya (P_4). Malwa plateau had sandy loam to gravel sandy loam on hill top soil (P_5), and loam to clay loam in pediment (P_6), silty clay loam at the upper surface and clay loam in sub surface of valley (P_7) had sandy clay loam texture. In case of pedon of plain (P_8) the texture was found silty clay. The variation in the intensity of erosion and deposition explains the variation in soil texture topographically. Thus the variation in type of parent rock, the portions on the landscape and the some from where the matter is carried by flowing water determine the texture as a function of topography. As a result of rapid downward movement of rain water, the finer particles were readily carried away toward the lower areas while coarse particles remain. This could be attributed as a main reason for the behavior of texture with change of slope. Similar results were also observed by Gupta et al. (1999), Sarkar et al. (2001) and Maji et al. (2005).

Soil structure

Single grain structure was the feature of soils associated with the hill top of Aravali mountain ranges. The structure become medium coarse weak sub angular blocky in the soils of pediment and upper horizon of pedon P_3 while the soils of pedon P_4 had medium moderate sub angular blocky in upper horizon and in subsequent horizons the structure become medium moderate angular blocky. The structure of lower horizons of pedon P_3 exhibit medium moderate fine sub angular blocky arrangement.

The soils of Malwa plateau associated with the hill top had single grain structure. The structure become moderately fine sub angular blocky in the soils of pediment. It was found medium weak fine sub angular blocky in upper layers and in subsequent layers it become medium moderate fine sub angular blocky in soils of valley. The soils of plain (P_8) had medium moderate to strong angular blocky structure.

Lime concretions and effervescence

The extent of distribution of calcareousness (reaction to dilute HCl) over different physiographic units is shown in Table 2. The data reveal that calcareousness was uniform and throughout in soils of plain pedon (P_4) in Aravali mountain ranges and valley and plain pedons (P_7, P_8) in Malwa plateau soils evident by the reaction with dilute HCl being slight to violent effervescence in all these pedons. While in pedon P_1 it was seen non-effervescent in the surface layer that is, A1. In rest of the pedons which occurring on elevated topographic position, no reaction was observed with dilute HCl, indicating that these soils were either free of calcareousness or the content was too low to be detected by dilute HCl.

Horizon designation

Absence of cultivation over the surface was designated as Al (P_1, P2, P_7 and P_8). A2 was allocated to the horizon, having slight improvement in soil structure in term of grade and angularity (P_3). Those soils which were under cultivation and leaves of stubble at the surface which are ploughed before sowing of every crop. As such, surface horizons were therefore designated as Ap horizon that is, plough layer. Bw is given to layer which show some evidence of development either due to increase in clay content , formation of well defined peds or some reddening of hue (P_3, P_4, P_6 and $P_{7,}$). Bss horizons are the mark of slickenside presence (P_4, and P_8). Slickensides are formed as a result of the swelling of clay minerals and shear failure, commonly at angle of 20 to 60 degree above horizontal. C horizon is marked for weathered material in pedons P_2-P_8 except P_4 and P_7 where it was designated as Ck due to accumulation of carbonates.

PHYSICAL PROPERTIES

Results pertaining to mechanical composition, bulk density, porosity and water retention characteristics of soils associated in both transect namely Aravali mountain ranges and Malwa plateau, are described in this section while data on these features are elucidated in Tables 3 to 5.

Mechanical composition

Relative proportions of sand, silt and clay in soils of both

Table 3. Physical properties – Mechanical composition in soils of various land forms.

Pedons	Horizon designation	Mechanical composition (%) Sand (Size in mm) Very coarse 2.0-1.0	Coarse 1.0-0.5	Medium 0.5-0.25	Fine 0.25-0.1	Very fine 0.1-0.05	Total Sand 0.05-2.0	Silt 0.05-0.002	Clay <0.002
				I Aravali Mountain Ranges					
				Hill (Dipora)					
P1	Al	4.63	5.32	8.51	14.68	18.53	51.67	32.26	16.07
				Pediments (Lodiya)					
P2	Wt. mean	3.43	6.41	7.36	9.92	11.06	38.19	35.41	26.38
				Valley (Bhagadera)					
P3	Wt. mean	0.08	0.59	2.77	19.79	20.92	44.09	32.83	22.94
				Plain (Charpotiya)					
P4	Wt. mean	0.18	0.32	0.63	2.58	6.27	9.85	42.51	47.51
				II Malwa Plateau					
				Hill (Chiklad)					
P5	Wt. mean	0.17	0.78	13.51	38.72	5.92	59.15	20.14	20.77
				Pediments (Shah ji ka pathar)					
P6	Wt. mean	0.37	1.30	3.36	28.10	11.80	44.93	24.28	30.79
				Valley (Ghotarsi)					
P7	Wt. mean	0.33	2.12	1.95	3.23	14.54	22.17	48.31	29.52
				Plain (Kuni)					
P8	Wt. mean	0.41	1.08	2.42	4.36	6.28	14.56	40.35	42.50

transect are presented in Table 3.

Sand

Total sand content of all pedons in Aravali mountain ranges ranged from 8.09 to 51.67% with a weighted mean value of 35.95%. The content was highest in the soils associated with hill (P_1) followed by valley (P_3), pediments (P_2), while it was lowest in the soils of plain (P_4). However, in general, fine sand fraction dominates over the different sand fractions of all the profiles. Generally, soil texture was coarser on the higher landforms or sloping landforms, because the fine materials like silt and clay are removed from the relatively higher location to those portion where slopes become gentler attain heavily level relief. In soils of Malwa plateau transect, total sand content ranges from 12.09 to 62.51% with a weighted mean value of 35.75%. The sand content was higher in the soils on hill top (P_5) and pediments (P_6), while it was lower in the soils of plain (P_8). However, valley (P_7) and had intermediate amount of sand. By and large fine sand fraction on higher elevation, dominates over other fraction while on lower elevation, very fine sand fractions were dominant over fine sand. Similar results were also reported by Singh (2004).

Silt

The content of the silt in the soils of Aravali mountain ranges varied between 31.47 to 43.87% with a weighted mean value of 35.75%. Highest average silt observed in soils of plain (P_4). While lowest average found in soils of hill top (P_1) followed by valley (P_3). While the soils of pediment (P_2) exhibited intermediated trend of percent silt contribution toward the mechanical composition of these soils. In the soils of Malwa plateau transect, it was observed that the silt content varied between 19.21 to 60.00% with a mean value of 33.27% with highest

Table 4. Physical properties: Bulk density, particle density and porosity in soils of various land forms.

Pedons	Horizon designation	BD	PD	Porosity (%)
		Mg m^{-3}		
	I Aravali Mountain Ranges			
	Hill (Dipora)			
P1	Al	1.45	2.56	43.35
	Pediments (Lodiya)			
P2	Wt. mean	1.52	2.57	40.95
	Valley (Bhagadera)			
P3	Wt. mean	1.61	2.61	37.93
	Plain (Charpotiya)			
P4	Wt. mean	1.57	2.54	38.29
	II Malwa Plateau			
	Hill (Chiklad)			
P5	Wt. mean	1.40	2.63	46.59
	Pediments (Shah ji ka pathar)			
P6	Wt. mean	1.36	2.60	47.84
	Valley (Ghotarsi)			
P7	Wt. mean	1.51	2.61	42.29
	Plain (Kuni)			
P8	Wt. mean	1.51	2.60	41.93

average value in valley (P_7) followed by plain (P_8) and lowest average value in hill top (P_5) followed by pediment (P_6) soils. An increasing trend of higher silt content from elevated topographic position to lower topographic position as well as along with down the depth of pedons was observed which could be because of movement of silt particles along with downward movement of water as well as due to erosion agents.

Clay

The clay content varied from 16.07 to 49.75% in soils of Aravali mountain ranges with a mean value 28.22%. The highest average value of clay content was observed in the soils of plain (P_4). Whereas lowest value of clay content was in the soils of hill top (P1). The soils of pediment (P_2) and valley (P_3) were found intermediate in clay content. While in case of soils of Malwa plateau, clay content varied from 18.46 to 44.95% with mean value 30.89%. The highest average value of clay content was observed in the soils of plain (P_8) followed by pediment (P_6), and valley (P_7) whereas lowest value of clay content was in the soils of hill top (P_5). The higher clay content down the slope was also reported by Sarkar et al. (2001).

Physical properties

Bulk density

Bulk density is a reliable index for determining the presence of compact layers particularly in the subsoil. An examination of data, presented in Table 4 indicates that values of bulk density increase with the depth of the soil. Bulk density of soils in Aravali mountain ranges between 1.45 to 1.65 mg m^{-3} with a weighted mean value of 1.53 mg m^{-3}. The highest value of bulk density (1.65 mg m^{-3}) was observed in Bw_1 horizon of valley (P_3). Whereas the lowest value of bulk density (1.45 mg m^{-3}) was observed in the soils of hill top (P_1). In case of soils of Malwa plateau, bulk density varied from 1.33 to 1.62 mg m^{-3} with a weighted mean value 1.44 mg m^{-3}. The highest value of bulk density (1.62 mg m^{-3}) was observed in C horizon of plain (P_8) whereas the lowest value (1.33 mg m^{-3}) in soils of pediment (P_6). In generally an increase in bulk density in the subsurface horizons was observed in all the pedons examined along both transect. Chaudhary et al. (2005) while studying the soils of Himalayas also found similar results of increasing trend of B.D. with depth.

Particle density

It is evident from the data presented in Table 4 that the particle density of the soils of Aravali mountain ranges was found to range between 2.52 to 2.65 mg m^{-3}. While in case of soils of Malwa plateau, particle density varied from 2.55 to 2.64 mg m^{-3}. It was found to increase with depth but such an increase was only up to a certain depth of various landforms followed by decrease. Particle density was found higher in the soils of Malwa plateau as compared to the soils of Aravali mountain ranges which suggest heterogeneity in profile development in Malwa plateau. Similar trend was also recorded by Veerpal (1976), Datta et al*.* (1990) and Singh et al. (1999).

Porosity

The packing pattern of soil fragment determines the porosity of the soils. The porosity of various pedon ranged between 35.79 to 43.35% with a weighted mean value of 40.13 in soils of Aravali mountain ranges. While in soils of Malwa plateau, it was ranged between 37.93 to 48.85%. The maximum value of porosity was recorded in A1 layer of hill top (P_1) while minimum value was recorded in ck horizon of plain soils in Aravali mountain ranges. In case of Malwa plateau soils the maximum value was observed in the Ap horizon of hill top soils while minimum value was recorded in C layer of plain (P_8). This difference was mainly due to variation in silt and sand fractions and their arrangement or shape of orientation at different locations of the transect. Generally the porosity was high in surface horizons and decreases with depth (Table 4) which may be due to higher value of bulk density in subsurface soils. Similar observations were also reported by Wick and Whiteside (1959); Rathore (1993) and Sharma (1994). Further, the bulk density and porosity were inversely related which is also supported by the findings of Kolarkar et al. (1974), Rathore (1993) and Sharma (1994).

Moisture retention characteristics

The data on the effect of different landform on water retentions characteristics are presented in Table 5. It was seen from the data that the amount of the water retained at 0.03 MPa ranged from 0.25 to 0.49 m^3/m^3 with a weighted mean value of 0.35 m^3/m^3 in soils of Aravali mountain ranges. Water retention was recorded highest, ranging from 0.43 to 0.49 m^3/m^3 with a weighted mean value 0.46 m^3/m^3 in the soils of plain (P_4) followed by valley (P_3). Lowest water retention was recorded in soils of hill top (P_1) followed by pediments (P_2). Whereas in case of soils of Malwa plateau, water retention at 0.03 MPa ranged from 0.19 to 0.52 m^3/m^3 with a weighted mean value of 0.30 m^3/m^3. Water retention was highest, ranging from 0.41 to 0.52 m^3/m^3 (mean value 0.45 m^3/m^3) in soils of plain (P_8) followed by valley (P_7). The water retention in remaining pedon was in pediment>hill top soil sequence.

The water retention at 1.5 MPa also followed the similar trend, ranging from 0.10 to 0.26 m^3/m^3 with a weighted mean value of 0.16 m^3/m^3 in soils of Aravali mountain ranges whereas corresponding value are slightly higher 0.05 to 0.29 m^3/m^3 with a weighted mean value of 0.14 m^3/m^3 in soils of Malwa plateau. indicated that an increase in clay and silt content had contributed marginally towards the available water capacity due to corresponding increase in water retention at both levels that is, 0.03 and 1.5 MPa suction pressures. The amount of water retained was found to be higher in subsurface layer in comparison to surface layer in both transects. Similar observations were made by Nagar et al. (1995) and Balpande et al. (2007).

Available water capacity (AWC) volume basis

Available water capacity is an important indicator for sowing seed/or crop planning, irrigation scheduling and crop selection under rainfed conditions/areas like Pratapgarh district. Available water capacity is the difference of water content at 0.03 and 1.5 MPa suction pressures. Available water capacity was varying from 0.14 to 0.24 m^3/m^3 with a weighted mean value of 0.19 m^3/m^3 in the Aravali mountain ranges. Maximum available water capacity observed in plain (P_4) followed by valley (P_3) and hill top (P_1), whereas lowest value comes under pediments (P_2). While in case of Malwa plateau, available water capacity was ranged from 0.13 to 0.24 m^3/m^3 with weighted mean value 0.16 m^3/m^3. Maximum available water capacity in this transect was observed in plain (P_8) followed by valley (P_7) and whereas lowest value comes under pediments and hill top (P_1 and P_2). It was observed that soils of Malwa plateau had more available water content compare to soils of Aravali mountain ranges which could be attributed to the relatively higher finer fraction in these soils.

Water holding capacity (WHC)

The water holding capacity ranges from 23.56 to 40.11% where maximum water holding capacity found in plain (P_4) and minimum in pediments (P_2) in Aravali mountain ranges. In case of Malwa plateau maximum water holding

Table 5. Physical properties : Moisture characteristics of soils.

Pedons	Horizon designation	Moisture retention (m^3/m^3) on suction		AWC (m^3/m^3)	WHC (%)
		0.03 MPa	1.5 MPa		
		I Aravali Mountain Ranges			
		Hill (Dipora)			
P_1	Al	0.32	0.10	0.22	37.55
		Pediments (Lodiya)			
P2	Wt. mean	0.28	0.15	0.13	24.28
		Valley(Bhgadera)			
P3	Wt. mean	0.36	0.16	0.21	31.59
		Plain (Charpotiya)			
P4	Wt. mean	0.46	0.24	0.22	34.64
		II Malwa Plateau			
		Hill (Chiklad)			
P5	Wt. mean	0.20	0.08	0.13	33.28
		Pediments (Shah ji ka pathar)			
P6	Wt. mean	0.23	0.09	0.13	34.61
		Valley (Ghotarsi)			
P7	Wt. mean	0.34	0.15	0.18	27.52
		Plain (kuni)			
P8	Wt. mean	0.45	0.24	0.22	32.09

capacity found 41.11% in pediments (P_6) and minimum in valley (P_7).

CHEMICAL PROPERTIES

In order to understand the specificity of relationship between the soils and physiography it is imperative to analyze the results of various chemical properties in light of micro-topographical variations imposed by variations in landforms.

Soil reaction (pH)

Soil reaction (pH) is one of the important parameter controlling availability of plant nutrients in the soils. In the present investigation the pH of the soils in Aravali mountain ranges was between 6.92 to 7.72 with a mean value of 7.43 indicating that the soils are near neutral to slightly alkaline (Table 6). In soils of Malwa plateau, the pH ranged between 6.03 to 7.75 with a mean value 6.92. It was near neutral in the soils of hill top pedon P_1 (6.03) and moderately alkaline in the soils of plain pedon P_8 (6.92 to 7.59). A critical examination of data indicates that soil pH in most cases was found to increase with depth in both transects. This increase level of pH down the depth of pedons was mainly due to movement of soluble salts and increased content of calcium carbonate. The higher pH values in soils of lower slopes and its increased value with soil depth could be attributed to the deposition of illuviated bases from surrounding upper slopes. Similar results were also observed by Dutta et al. (1990), Deshmukh and Bapat (1993), Rathore (1993), Sharma (1994) and Chamuah et al. (1996).

Electrical conductivity (EC)

EC is a measure of concentration of soluble salts in the soil at any temperature and it was determined in soil: water, 1:2 suspension and data presented in Table 6. The electrical conductivity was found range between 0.32 to 1.26 dSm^{-1} with a mean value of 0.56 dSm^{-1} in soils of

Table 6. Chemical properties: pH, EC, organic carbon and $CaCO_3$.

Pedons	Horizon designation	pH (1:2)	EC (dSm^{-1})	OC ($g\ kg^{-1}$)	$CaCO_3$ ($g\ kg^{-1}$)
		I Aravali Mountain Ranges			
		Hill (Dipora)			
P_1	Al	7.33	0.56	7.85	0.00
		Pediments (Lodiya)			
P2	Wt. mean	7.41	0.40	4.29	0.00
		Valley (Bhagadera)			
P3	Wt. mean	7.46	0.61	2.70	0.00
		Plain (Charpotiya)			
P4	Wt. mean	7.55	0.70	2.42	86.14
		II Malwa plateau			
		Hill (Chiklad)			
P5	Wt. mean	6.04	0.44	5.19	0.00
		Pediments (Shah ji ka pathar)			
P6	Wt. mean	7.13	0.98	5.01	0.00
		Valley (Ghotarsi)			
P7	Wt. mean	7.14	1.25	5.54	126.21
		Plain (Kuni)			
P8	Wt. mean	7.38	0.97	4.32	92.04

Aravali mountain ranges. Maximum average electrical conductivity was recorded in plain (P_4). While in case of Malwa plateau, electrical conductivity was found to range between 0.32 to 1.97 $dSm^{-1}$with a mean value 0.91 dSm^{-1}. The general trend of soluble salt distribution was found increasing from upper rolling topographic position to lower elevation, indicates that the appreciable amount of salts moved down the slope along with flowing water. The findings are in line with the results of Gaikawad et al. (1974), Dutta et al. (1990) and Sharma (1994).

Organic carbon

The organic carbon content of the soils is an indication of nitrogen status. In the soils of the Aravali mountain ranges, organic carbon content was found to range between 1.35 and 7.85 g kg^1 with a weighted mean value of 4.31 g kg^{-1}. It was minimum in soils of plain P_4 followed by valley P_3 and pediments P_2 (weighted mean value 2.42, 2.70, and 4.29 g kg^{-1}) respectively, and maximum in soils of hill top (7.85 g kg^{-1}). In the soils of Malwa plateau, the organic carbon content was found to range between 2.35 to 9.50 g kg^{-1} with a weighted mean value of 5.01 g kg^{-1}. No specific trend of distribution has emerged out with respect to the topography in the soils selected for the study. In general the content of organic carbon is higher at the surface, decreasing down the depth in soil profile. This was mainly due to accumulation of plant residues on the soil surface and very less opportunity to move it down the depth due to rapid decomposition at higher temperature and inadequate pedoturbation. Almost all soils were low in organic carbon (<5 g kg^{-1}) content except soils of pedon P_1 in Aravali mountain ranges and pedon (P_5-P_7) in Malwa pateau, and it was mainly due to rapid rate of mineralization at higher temperature and adequate soil moisture level. The organic carbon distribution is mainly associated with physiography and land use. Similar results were also observed by Sharma et al. (1999), in soils of Haldi-Ghati region of Rajasthan (Walia and Rao, 1996).

Calcium carbonate

In present investigation, the content of calcium carbonate of both transect is shown in Table 6. It can be seen that the content of calcium carbonate in Aravali mountain ranges ranged between 0.00 to 175.40 g $kg^{-1}$with a weighted mean value 86.14 g kg^{-1}. While in Malwa plateau, its content ranged between 0.00 to 146.40 g $kg^{-1}$with a weighted mean value 109.12 g kg^{-1}. It was observed that calcium carbonate content in higher topographic positions that is, hill and pediment (P_1, P_2 and P_5, P_6) in both transects was found absent throughout whole profile which could be ascribed to the completely leached out of the profile as well removal of calcium carbonate and its subsequent deposition in lower topographic positions. The increasing trend for calcium carbonate content was found to be associated with decreasing topographic positions. A specific regular trend of distribution of calcium carbonate has emerged out with respect to the topography (hill top to plain) in the soils of Aravali mountain ranges and Malwa plateau.

In cases of both transect, the surface layer contained lower/ nil values of calcium carbonate which gradually increased down the depth of profile. This was due to downward movement of calcium ions and precipitated in subsurface layers at higher pH level. An increasing trend of calcium carbonate with depth was registered in some soils of Udaipur and Chittaurgarh districts of Rajasthan by Singh et al. (1999). Similar observations were also recorded by Maji et al. (2005) and Kumar and Prasad (2010).

Exchangeable cations

A critical examination of data from Table 7 revealed that exchangeable calcium was the dominant cation followed by magnesium, potassium and sodium in soils of both transect. Exchangeable calcium, magnesium, potassium and sodium ranged between 5.86 to 22.05, 4.08 to 12.60, 0.18 to 0.89 and 0.44 to 0.95 C mol (p^+) kg^{-1} with a weighted mean value of 12.65, 7.09, 0.60 and 0.72 C mol (p^+) kg^{-1}, respectively in soils of Aravali mountain ranges. The soils of plain (P_4) had maximum average exchangeable calcium, magnesium, sodium and potassium. The soils of pediments (P_2), valley (P_3) hill top (P_1) come next with respect to these cations. In case of Malwa plateau, exchangeable calcium, magnesium, sodium potassium and ranged between 7.04 to 23.35, 6.07 to 12.05, 0.35 to 1.55 and 0.42 to 1.32 C mol (p^+) kg^{-1} with a weighted mean value of 15.98, 8.62, 0.8 and 0.84 C mol (p^+) kg^{-1} respectively. Exchangeable calcium was higher (23.35 C mol p^+ kg^{-1}) in soils of plain (P_8) followed by pediments pedon P_6 [20.60 C mol (p^+) kg^{-1}]. The exchangeable magnesium was followed the same trend of distribution. No specific trend of distribution has emerged out with respect to the exchangeable potassium and sodium. Calcium was dominant cation followed by magnesium, potassium and sodium also reported by Maji et al. (2005). The higher content of exchangeable calcium in soils of lower plains of Aravali mountain ranges had been attributed to the presence of dolomitic parent materials which contributes most of the calcium ions in runoff water which carry them to deposit in the soils of lower landforms and to the movement of bases from the upper part of transect to lower one, which are carried with the moving finer fractions of soils under influence of erosion, Walia and Chamuah (1994) also recorded higher base saturation at the lower topographical position.

Cation exchange capacity

Data pertaining to cation exchange capacity of soils are presented in Table 7 Cation exchange capacity in different pedons found to vary between 12.20 to 40.07 C mol (p^+) $kg^{-1}$with a weighted mean value of 22.44 C mol (p^+) kg^{-1} in soils of Aravali mountain ranges. The maximum value of CEC, observed in soils of plain P_4 [40.07 C mol (p^+) kg^{-1}] and lowest value [12.20 C mol (p^+) kg^{-1}] in valley pedon P_3 followed by hill top pedon P_1 [12.90 C mol (p^+) kg^{-1}]. While in soils of Malwa plateau, cation exchange capacity was found to vary from 15.08 to 39.23 C mol (p^+) $kg^{1}$with weighted mean value of 26.06 C mol (p^+) kg^{-1}. The soils of plain (P_8) have maximum value of cation exchange capacity followed by the soils of Pedimant (P_6). While the soils of hill top (P_5) have the lowest value of CEC. A critical examination of data indicated that the cation exchange capacity of soils was found to be closely related to the clay content. The drifting of clay along with the bases down the slope might be the factor for the increased level of cation exchange capacity in subsurface layer of soils (Bhatia et al., 2005; Maji et al., 2005). It can be inferred that increase in clay content provide more exchange sites to get the cations adsorbed on it.

Base saturation

The data on per cent base saturation are presented in Table 7 Base saturation is by and large uniform in the soils of transect under study. It was found to range from 84.40 to 97.95% with a weighted mean value of 93.58% in soils of Aravali mountain ranges. While in soils of Malwa plateau it was found to range from 89.94 to 97.40% with a weighted mean value 93.92%. The higher base saturation in the soils of the study area could be attributed to the basic nature of the parent materials and also to the semi arid climatic conditions which allows bases to accumulate in soil matrix. It was uniform in all the soils of the area irrespective of the landforms.

Exchangeable sodium percentage (ESP)

Sodium saturation in the soils is expressed as ESP in the soil solution, because of its significance in deteriorating physico-chemical properties of soil and adversely

Table 7. Chemical properties: Exchangeable cations, base saturation, ESP and CEC.

Pedons	Horizon designation	Exchangeable cations (C mol (p^+) kg^{-1})				Base saturation (%)	ESP (%)	CEC C mol (p^+) kg^{-1}
		Ca^{++}	Mg^{++}	Na^+	K^+			
		I Aravali Mountain Ranges						
		Hill (Dipora)						
P1	Al	5.86	4.08	0.55	0.84	93.60	4.26	12.90
		Pediments (Lodiya)						
P2	Wt. mean	12.22	7.17	0.49	0.73	95.01	2.39	21.02
		Valley (Bhagadera)						
P3	Wt. mean	11.66	5.85	0.62	0.51	94.00	3.10	19.24
		Plain (Charpotiya)						
P4	Wt. mean	20.87	11.27	0.77	0.80	91.73	2.08	36.60
		II Malwa plateau						
		Hill (Chiklad)						
P5	Wt. mean	8.93	7.06	0.82	0.96	93.30	4.58	18.22
		Pediments (Shah ji ka pathar)						
P6	Wt. mean	19.38	8.68	1.29	1.06	96.84	4.31	26.59
		Valley (Ghotarsi)						
P7	Wt. mean	13.14	7.28	0.46	0.65	94.21	2.05	22.65
		Plain (Kuni)						
P8	Wt. mean	22.47	11.49	0.63	0.70	91.36	1.69	36.81

affecting the growth of plant. The values of exchangeable sodium percentage ranges between 1.47 to 4.30% with a weighted mean value of 2.95% in soils of Aravali mountain ranges. The highest value of exchangeable sodium percentage was found in the soils of hill top P_1 (4.26%) followed by valley soils (3.10%) while the lowest value of exchangeable sodium percentage was recorded in plain P_4 (2.08%) and in pediments (2.39%) exhibit intermediate pattern with respect to exchangeable sodium percentage. In case of soils of Malwa plateau, exchangeable sodium percentage ranges between 0.88 to 5.65% with a weighted mean value 3.1%. The soils of Malwa plateau followed the similar pattern of distribution of exchangeable sodium in all topographic positions as in the soils of Aravali mountain ranges. Highest value of exchangeable sodium percentage is observed in soils of hill top pedon P_5 (4.58%) followed by pediment soils P_6 (4.31%). While lowest value of exchangeable sodium percentage observed in soils of plain P_8 (1.69%). The variation in exchangeable sodium percentage in surface soil with respect to slope was similar to exchangeable sodium. Generally, its content was less than 5.17 percent in all the pedons. Similar results were also reported by Saxena and Singh (1982).

SOIL CLASSIFICATION

The key diagnostic properties used for the classification of soils of both transects are listed in the Tables 8 and 9 at the different categorical levels and briefly described prior the taxonomic description of the soils. The classification of the soils up to the family level is elucidated in the Table 9. The brief description about the classification is given in diagnostic characteristics

Diagnostic characteristics

The following diagnostic characteristic are used in the classification of soil in both transects under investigation.

Cambic horizons

The improvement in soil structure in terms of angularity

Table 8. Diagnostic criteria for soil classifications.

Pedons	Order	Suborder	Great group	Subgroup	Family*
P_1	No horizon development	Other entisols	Ustic moisture regime	Lithic contact depth < 50 cm	Coarse loamy skeletal mixed hyper thermic
P_2	No horizon development	Other entisols	Ustic moisture regime	Lithic contact depth < 50 cm	Loamy skeletal mixed hyper thermic
P_3	Cambic horizon	Other ustepts	Ustic moisture regime	Meets the central concept of great group	Fine loamy mixed hyper thermic
P_4	Cambic horizon	Other ustepts	Ustic moisture regime	Meet the central concept of great group	Fine calcareous hyper thermic
P_5	No horizon development	Other entisols	Ustic moisture regime	Lithic contact depth < 50 cm	Loamy mixed hyper thermic
P_6	No horizon development	Other entisols	Ustic moisture regime	Lithic contact depth < 50 cm	Fine loamy calcareous mixed hyper thermic
P_7	Cambic horizon	Other ustepts	Ustic moisture regime	Meet the central concept of great group	Fine loamy calcareous mixed hyper thermic
P_8	Intersecting slikensides cracks >40 cm deep	Other usterts	Ustic moisture regime	Meets the central concept of great group	Fine calcareous mixed hyper thermic

*Mixed mineralogy and hyper thermic temperature regime considered for all soils to classify at family level.

Table 9. Soil classification.

Pedons	Order	Suborder	Great group	Subgroup	Family*
P_1	Entisols	Orthents	Ustorthents	Lithic ustorthents	Coarse loamy skeletal mixed hyper thermic
P_2	Entisols	Orthents	Ustorthents	Lithic ustorthents	Loamy skeletal mixed hyper thermic
P_3	Inceptisols	Ustepts	Haplustepts	Typic haplustepts	Fine loamy mixed hyper thermic
P_4	Inceptisols	Ustepts	Haplustepts	Typic haplustepts	Fine calcareous hyper thermic
P_5	Entisols	Orthents	Ustorthents	Lithic ustothents	Loamy mixed hyper thermic
P_6	Entisols	Orthents	Ustorthents	Lithic ustothents	Fine loamy calcareous mixed hyper thermic
P_7	Inceptisols	Ustepts	Haplustepts	Typic haplustepts	Fine loamy calcareous mixed hyper thermic
P_8	Vertisols	Usterts	Haplusterts	Typic haplusterts	Fine mixed calcareous hyper thermic

*Content in the last column is prefixed to the name of subgroup for complete name of soil.

and grade in the subsurface horizon and/or richer in organic carbon and clay and darker in chroma and value as compared to the overlying or underlying horizons characterized the presence of cambic horizon in soils of valley (P_3) and plain (P_4) in case of Aravali mountain ranges soils while in case of Malwa plateau it was found in the soils of valley (P_7) pedons. The presence of cambic horizon is used as a diagnostic characteristic to separate the soils of inceptisols from Entisols after giving the due weight age to other features essentially needed for the other orders.

Slickensides

A layer of 25 cm or more thick with an upper boundary within 100 cm of the mineral soil surface that has either slickensides close to intersect or wedge shaped aggregates, which have their long axis tilted 10 to 60° from horizontal. This is one of the chief diagnostic characteristic required to mark a soil in Vertisols. In the present investigation, soils of pedon P_8 (plain) have more than 25 cm thick horizon within 100 cm of the surface, which have the above mentioned characteristics.

Soil moisture regime

The soils of both transects throughout the moisture control section remain dry for more than 90 days during the year and therefore quality for ustic soil moisture regime. The criterion was used as differential

Strip I		Strip II	
Aravali mountain ranges	SRM Unit	Malwa plateau	SRM Unit
P1 Dipora	172	P5 Chiklad	318
P2 Lodiya	193	P6 Shah ji ka pathar	330
P3 Bhagadera	239	P7 Ghotarsi	324
P4 Charpotiya	229	P8 Kuni	337

Figure 1. Site for profile examination and sampling in aravali mountain ranges and malwa plateau.

characteristics for classifying the soils at the suborder level within soil great group level (Table 8).

Lithic contacts

The presence of rock within 50 cm from the surface in the soil profile is characterized as lithic contacts in the soils of hill (P_1), pediments (P_2) of Aravali mountain ranges and in soils of hill (P_5) and pediment (P_6) of the Malwa plateau (Figure 1). The criteria is used to classify the soils of both transects at subgroup level for separating the soil bearing this trait from their typic counter part.

Soil temperature regime

The soil temperature was more than 20°C within the control section and therefore qualifies for hyper thermic soil temperature regime. The difference between MWST and MSST is greater than 5°C and therefore does not qualify for isohyperthermic soil temperature regime. The criteria are used to classify the soils at the family level.

Particle size class

Coarse loamy skeletal, loamy skeletal, fine loamy, fine loamy mixed calcareous, calcareous, particle size (Table 9) characterized the soils of both transects. These together with soil temperature regime are used to classify the soils of both transect at the family level.

Depth, texture and coarse fragments

The characteristics of the soils are not directly visible in the classification. However, these together constitute the particle size class of the soils.

Taxonomic descriptions

The taxonomic classification of the soils of Pratapgarh district has been worked out based on morphological, physical and physico-chemical properties and climatic data according to Soil Taxonomy (Soil Survey Staff, 2000) into the order Entisols (Pedons P_1 and P_2 of Aravali mountain ranges and pedon P_5 and P_6 of Malwa plateau), Inceptisols (Pedons P_3 and P_4 of Aravali mountain ranges and Pedons P_7 of Malwa plateau) and Vertisols (Pedon P_8 of Malwa plateau).

No diagnostic horizon and decrease in organic carbon was observed in the soils of hill (P_1) and pediment (P_2) of the Aravali mountain ranges and in the soils of hill (P_5) and (P_6) of the Malwa plateau. While cambic horizon is a key characteristics to mark as alteration in the original parent material in soils of valley (P_3), plain (P_4) of the Aravali mountain ranges and in the soils of valley (P_7) of the Malwa plateau. Slickenside was the important feature in the soil of plain (P_8) of the Malwa plateau. Based on these diagnostic features, soils of pedon P_1, P_2, and P_5 were classified in Entisols soil order, while the soils of pedon $P_{3,}$ P_4, and P_7, were put under Inceptisols soil order. The soils of pedon P_8 was classified in Vertisol soil order.

The soil orders are further taken down to the suborder level, using the other differential characteristics. Since the soils of P_1, P_2 and $P_{5,}$ P_6 could not qualify for psamments and fluents suborder, consequently placed in orthents. Based on the soil moisture regime, the soils of inceptisols and vertisol soil order are classified as a member of ustepts and usterts suborder, respectively. The Ustic moisture regime is considered for bringing down the soil of orthents to the Ustorthents at great group level. Since ustepts and usterts do not qualify for any other great group within suborder, consequently, these have been placed in Haplustepts and Typic Haplusterts great group of their respective suborder.

Presence of rock within 50 cm of the soil profile was the criteria to separate the soils of pedon P_1, P_2, P_5 and P_6 from other Ustorthents to Lithic Ustorthents and Ustepts to Lithic Ustepts at the subgroup level, respectively. The soils of pedon $P_{3,}$ P_4, P_7, P_8, and P_9, represent the central concept of Haplustepts subgroup. As a result, these have been classified in Typic Haplustepts subgroup. The soils of pedon P_8 belonging to the Haplusterts great group also represent the central concept, consequently qualify for Typic Haplusterts subgroup of vertisols soil order.

Based on the particle size class, hyperthermic soil temperature regime, mixed mineralogy class, soils of both transects are further taken down to the lowest taxa of soil taxonomy, soil family. According these features, soils of pedon P_1 and P_2 have been classified as a member of loamy skeletal mixed hyper thermic family of Lithic Ustorthents subgroup under Entisols soil order. While soils of P_5 has been classified as a member of fine loamy mixed hyperthermic family of Typic Ustorthents subgroup. The soils of pedons P_6 in Lithic Haplustepts subgroup are classified as a member of fine loamy calcareous mixed hyper thermic soil family of Entisols soil order. In case of Pedon P_3 and P_9 soils have been classified as a member of fine loamy hyper thermic family of Typic Haplustepts in Inceptisols order. While the soils of Pedon P_4, have been classified as a member of fine loamy calcareous hyper thermic family of Typic Haplustepts in Inceptisols order. Soils of Pedon P_8 have classified as a fine mixed calcareous hyperthermic family of Typic Haplusterts subgroup of Vertisols soil order.

Conflict of Interest

The authors have not declared any conflict of interest.

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