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Characterization and classification of soils under different land uses in Binwa watershed of Himachal Pradesh

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ABSTRACT

The knowledge of soils with respect to their characteristics, properties, classification, distribution and potential uses is always needed for sustainable land use planning. Binwa watershed represents high-, mid- and low hill soil zones and agro-situations of Himachal Pradesh and lies between 76°34′08″ to 76°45′53″E longitudes and 31°53′15″ to 32°11′58″N latitudes. The area under built-up, cropland, tea plantation, forest, scrubland and grasslands, rock outcrops and water bodies is 4.7, 24.9, 1.3, 33.4, 23.4, 8.4 and 3.9% of the total watershed area (340.1 km^2), respectively. A reconnaissance soil survey of Binwa watershed was conducted to describe and classify the soils and predict soil potentials for sustainable land uses. Based on 478 augerbore/minipit observations, sixteen pedons were identified to represent soils under different land uses. The soils are characterized by the presence of A-C, A-Bw-C and A-Bt1…. horizon sequences. Soils of high and mid-hill soil zones are loamy skeletal to fine silty, very shallow to very deep and acidic (base saturation <60%), while those of low hill zone are loamy skeletal to coarse loamy, very shallow to deep and non-acidic (base saturation >60%). Taxonomically, the soils of Binwa watershed are member of loamy skeletal to fine silty, shallow to very deep, nil to very gravelly, acid to non-acid, mixed, thermic families of *Typic / Lithic Udorthents / Dystrudepts / Eutrudepts / Hapludalfs / Paleudalfs* and are put into ten tentative soil series, each with unique characteristics, properties and productivity potentials. Use and management of soils had no effect on the natural identity of the soils. Soils were found deficient in available N, P, Mg, S, Cu and Zn. Agricultural lands have more nutrient contents and better nutrient status as compared to non-agricultural lands.

1. INTRODUCTION

Hill agro-ecosystems of Himachal Pradesh are characterized by unique problems of low productivity, high male outmigration, a high reliance on women in agriculture, the pressure to expand cultivated land at the cost of forest land, difficult terrains, small and scattered holdings, poor transport facilities, limited irrigation facilities, large number of animals to compete with human beings for the same resources, severe soil erosion due to natural and anthropogenic activities etc. Sehgal and Abrol (1994) reported that about 57% of the total geographical area of India was suffering from one or another land degradation problem. A total of more than 5000 Mt of top soil is being eroded every year (Dhruvanarayana and Rambabu, 1983). The north-western Himalayan region has been found to be eroding at the rate of 20 Mg $ha^{-1}yr^{-1}$ (Singh *et al.,* 1992). Land degradation problems are further escalating because of the over-exploitation of land resources to feed the ever-increasing population. Reddy (2011) predicted that India needs 350 Mt of food grains to feed the projected population of 1.48 billion by 2030. Land degradation problems are of serious concern in hilly states like Himachal Pradesh. According to Sidhu *et al.* (1997); 53.8, 23.1 and 0.3% of total geographical area (TGA) of Himachal Pradesh is suffering from water erosion, stoniness and flooding, respectively. Notwithstanding endowment with rich soil and water resources in the state, low land productivity tells adversely upon the socio-economic status of the people.

According to FAO (1989), sustainable land management (SLM) approach is crucial for minimizing land degradation; rehabilitate degraded areas and ensure the optimal use of land resources for the benefit of present and future generations. It requires collaboration and partnership at all levels (land users, land use planners and policy makers) to ensure that land use systems and practices are suitably identified and properly implemented. Soil, terrain and socio-econmic databases form the basis for sustainable land use planning. Soil and climate are the pivotal factors which determine the soil-site suitability of a land use. Since climate does not change much, the detailed knowledge about soils with respect to their extent, distribution, characteristics and potential use is always needed for effective planning.

Soil surveys help to describe and classify the soils and predict their potentials for sustainable land uses. Taxonomic classification of soils allows determining the best possible use and management of soils and exchange soil information world-wide. A reconnaissance soil survey helps to characterize and evaluate soil resources of a large area. Availability of soil and terrain databases at a watershed level is quite limited in hilly states like Himachal Pradesh because of their climatic, topographical and financial constraints. However, an appreciable effort on soil mapping at a state level has been made by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur to prepare the soil map on 1:50,000 scale but data on larger scale is rarely available. Systematic soil fertility characterization is always needed for evolving soil nutrient management strategies. For that purpose, soil fertility maps using soil taxon as a mapping unit are more suitable than those using an administrative boundary (villages, blocks, tehsils, etc.) as mapping unit (Sekhon *et al*., 1985).

Binwa watershed of Himachal Pradesh (340.1 km^2 in area) represents high, mid and low hill soil zones and agro-situations of wet temperate zone of north-west Himalayas. It sustains agriculture on terraces and hill slopes besides a considerable area under forests and scrubland / grasslands. The scientific land management practices in the watershed are almost non-existent. Arable lands are scattered in most parts of the watershed except in mid-hill soil zone. Scrubland / grasslands are closely associated and difficult to map separately at a smaller scale. Keeping in view the above-mentioned facts and figures, present investigation was carried out with the objectives to characterize and classify the soils under different land uses in Binwa watershed.

2. MATERIAL AND METHODS

Geographically, the study area lies between 76°34′08″ to 76°45′53″E longitudes and 31°53′15″ to 32°11′58″N latitudes, comprising of a part of lesser Himalayas and Shivalik hills. The watershed extends over an area of about 340.1 km^2 with an altitude ranging from 600 to 4286 m above mean sea level. The soils of Binwa watershed are developed on parent materials derived from the rocks of lesser Himalayas, lower Shivaliks and upper Shivaliks and also on fluvio-glacial / fluvial deposits. The important rocks of lesser Himalayas are gneiss, granite, phyllite, shale, slate, sandstone, quartzite etc. (Wadia, 1960). Upper Shivaliks compose mainly of conglomeratic beds. Lower Shivaliks are dominated with shales and sandstones (Dey 1968). Geological formations of lesser Himalayas are older than those of Shivaliks and therefore, affect soil development. Fluvio-glacial terraces are developed from the glacial action on lesser Himalayas. The occurrence of huge boulders along the Binwa watershed tract and on steep slopes of terraces is an indication of glacial movements in the past. Fluvial terraces are developed due to the water movements along the side of the streams in the low hill zone.

The drainage is mainly characterized by dendritic drainage system in the study area (Fig. 1). The watershed is represented by wet temperate climate with an annual rainfall ranging from 1757 to 2798 mm. The mean maximum and minimum temperature ranges were from 24.2˚C to 27.7˚C and 13.7˚C to 14.6˚C, respectively and is characterized by the presence of udic soil moisture regime and thermic temperature regime (Sidhu *et al.,* 1997).

The natural vegetation comprises of *Quercus incana* (Oak), *Bambusa arundinacea* (Magar), *Grewia optiva* (Biul), *Celtis australis* (Khirak), *Albizia chinensis* (Ohi), *Bambusa nutans* (Nal), *Bauhinia vahlii* (Taur), *Bauhinia variegata* (Kachnar), *Bombax ceiba* (Simbal), *Ficus religiosa* (Pipal),

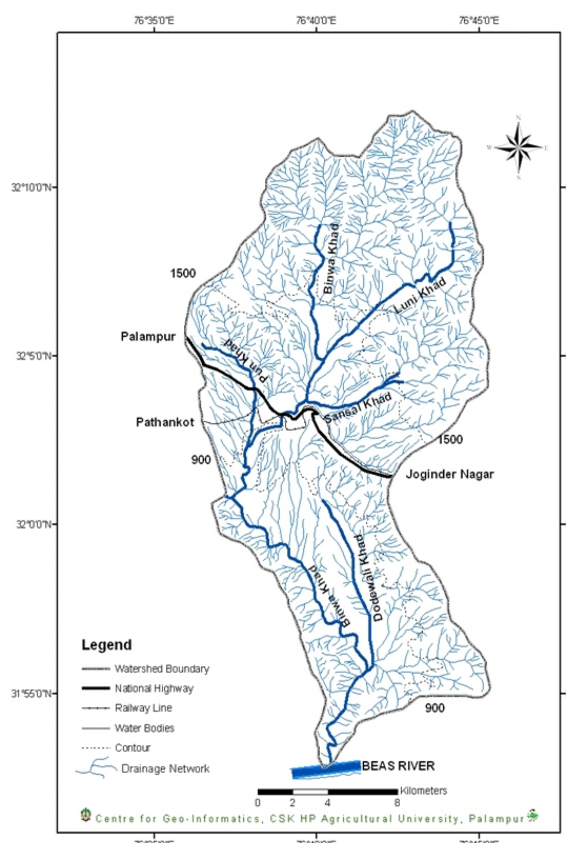

Fig. 1. Drainage map of Binwa watershed

Ficus roxburgii (Trembal), *Mangifera indica* (Mango), *Morus alba* (Tut), *Pinus roxburghii* (Chir), *Prunus padum* (Pajah), *Pyrus pashia* (Kainth), *Rhododendron arboreum* (Bras), *Syzigium cumini* (Jamun), *Terminalia belerica* (Bahera), *Toona ciliata* (Tuni), *Acacia catechu* (Khair) etc. Major crops grown are paddy-wheat in irrigated areas where as maize-wheat under rainfed conditions.

The land use/cover (LU/LC) map was prepared by using Survey of India (SoI) toposheets and IRS IC Geocoded False Colour Composites (FCCs) on 1:50,000 pertaining to two seasons *viz., kharif* (May and August, 2009 and *rabi* (October, 2008 and February, 2009) on 1:50,000 scale and by adopting visual interpretation techniques (NRSA, 1995) in conjunction with collateral data and through ground checks. Dark bluish green, bright red to red, dark red to red, light red to dark brown and light red to light / dark brown tones on FCCs represented built-up, cropland, tea garden, forest and scrubland / grassland areas, respectively.

Percent of total area under built-up, cropland, tea plantation, forest, scrubland / grassland, rock outcrops and water bodies in Binwa watershed was 4.7, 24.9, 1.3, 33.4, 23.4, 8.4 and 3.9, respectively (Table 1 and Fig. 2). Maximum area in high hill, mid-hill and low hill zone is under forest (54.7%), cropland (35.3%), and cropland (45.9%) land use, respectively. Area under built-up is lowest in high hill soil zone.

A reconnaissance soil survey of Binwa watershed was carried out by adopting the standard methodology (AIS& LUS, 1970). Four hundred seventy-eight auger-bore / mini-pit observations were taken at a distance interval of ¼ to 1 km depending upon the soil heterogeneity, land use and terrain form. Soil characteristics like soil colour, texture, depth, gravelliness, calcareousness, etc. upto a depth of 1.2 m and external land features like slope, existing land use, natural vegetation, erosion hazards, etc. were recorded during the field traverses.

There was a considerable spatial variation in profile characteristics. On the basis of auger-bore / mini-pit observations, sixteen pedons *viz*., Sansal, Sokru, Galua and Mandehr (four in high hill soil zone); Harer, Chuhair, Bag, Mahalpat, Kunsal, Phatahar, Keori (seven in mid-hill soil zone) and Dagog, Bhirdi, Chakol, Karsal and Bandian (five in low hill soil zone) were exposed and studied for morphological characteristics as per Soil Survey Manual (Soil Survey Division Staff, 1993). The horizon-wise soil samples were collected, air dried and passed through 2 mm sieve and analysed for mechanical separates following International pipette method (Piper, 1966), soil pH and electrical conductivity (EC) in 1:2.5 soil water suspension (Jackson, 1973). Organic carbon (OC) was estimated by Walkley and Black (1934) by Rapid titration method. The cation exchange capacity (CEC), exchangeable cations, available macro and micro-nutrients were determined by adopting standard procedures. The soils were classified as per key to soil taxonomy (Soil Survey Staff, 1998).

Eight pedons (Galua, Mandehr, Mahalpat, Kunsal, Phatahar Keori, Karsal, Bandian), three pedons (Sansal,

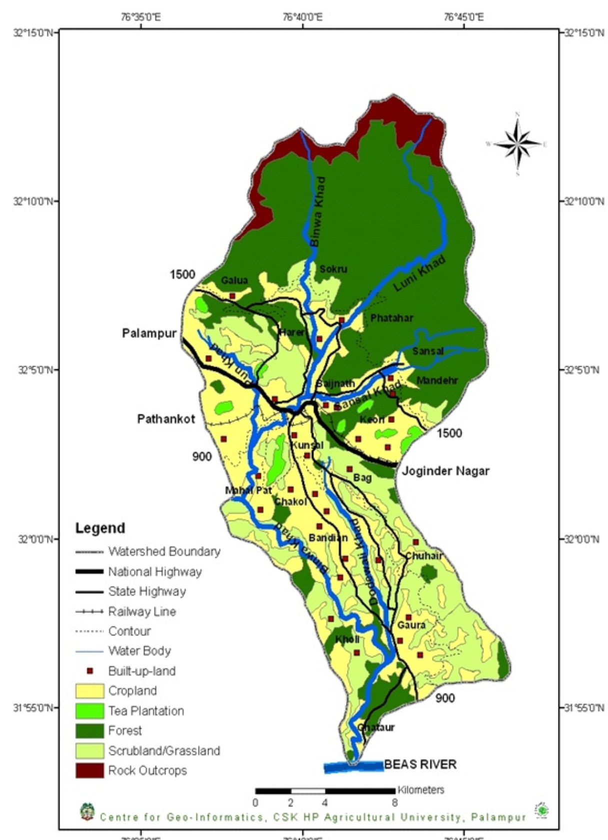

Fig. 2. Land use map of Binwa watershed

Table: 1
Percent distribution of major land uses in Binwa watershed

Soil zone	Area (km^2)	Percent of total area of zone / watershed under							
		Built-up	Crop land	Tea plantation	Forest	Scrubland / Grassland	Rock outcrops	Water bodies	Total
High hill	137.9	0.7	2.7	-	54.7	18.9	20.7	2.3	100
Mid-hill	114.7	8.2	35.3	3.9	27.1	21.9	-	3.6	100
Low hill	87.5	6.6	45.9	-	9.3	31.2	-	7.0	100
Binwa watershed	340.1	4.7	24.9	1.3	33.4	23.4	8.4	3.9	100

Harer, Dagog) and five pedons (Sokru, Chuhair, Bag, Bhirdi and Chakol) were identified to represent the cultivated soils, forest soils and scrubland / grasslands, respectively in Binwa watershed based on their morphological characteristics and physico-chemical properties.

3. RESULTS AND DISCUSSION

Morphological characteristics and physico-chemical properties of soils under different land uses in Binwa watershed is presented in Table's 2 and 3, respectively.

Soil Morphological Characteristics

Cultivated soils of Binwa watershed (high, mid and low hill soil zone) were shallow to very deep, very gently sloping to extremely steep, slightly to very gravelly, acid to non-acid, dark brown (10 YR 3/3) to yellowish brown (10

Table: 2
Morphological characteristics of soils under different land uses in Binwa watershed

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence			Roots distribution	Coarse fragments (%)
					D	M	W		
Cultivated soils									
Pedon 1 (Galua): Coarse loamy, mixed, thermic family of *Typic Dystrudepts*									
Ap	0-16	10YR 4/3	sl	sbk	sh	fr	sp ss	mf	8
BA	16-29	10 YR 4/4	sl	sbk	s	fr	sp ss	mf	10
Bw1	29-55	10 YR 4/4	sl	sbk	h	fi	p s	mf	10
Cr	55+	Weathered sandstone							
Pedon 2 (Mandehr): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
Ap	0-11	10 YR 4/4	csl	sbk	sh	fr	sp ss	mf	15
AC	11-23	10YR 4/3	csl	sbk	s	fr	sp ss	mf	35
CA	23-45	10YR 5/3	csl	sbk	s	fr	sp ss	ff	45
Cr	45+	Weathered sandstone							
Pedon 3 (Mahalpat): Fine silty, mixed, thermic family of *Typic Paleudalfs*									
Ap	0-17	10 YR 3/3	l	sbk	h	vfi	vp vs	mf	-
AB	17-33	7.5YR 3/3	l	sbk	vh	vfi	vp vs	cf	-
Bt1	33-59	7.5 YR 3/3	sicl	sbk	vh	vfi	vp vs	ff	-
Bt2	59-106	7.5 YR 3/4	sicl	sbk	eh	efi	vp vs	ff	-
Bt3	106-152	7.5 YR 3/4	sicl	sbk	eh	efi	vp vs	ff	-
Pedon 4 (Kunsal): Fine loamy, mixed, thermic family of *Typic Hapludalfs*									
Ap	0-16	10YR 4/3	l	sbk	h	fi	p s	mf	-
AB	16-35	10 YR 4/4	l	sbk	h	fi	p s	cf	-
Bt1	35-67	10YR 5/4	cl	sbk	vh	vfi	vp vs	ff	-
Bt2	67-115	10 YR 4/5	cl	sbk	eh	vfi	vp vs	ff	-
BC	115-160	10 YR 5/4	l	sbk	h	fi	p s	ff	-
Pedon 5 (Phatahar): Fine loamy, mixed, thermic family of *Typic Dystrudepts*									
Ap	0-14	10 YR 4/3	l	sbk	h	fi	p s	mf	-
BA	14-41	10 YR 4/4	l	sbk	h	fi	p s	cf	10
Bw1	41-63	10 YR 4/3	l	sbk	vh	vfi	vp vs	ff	10
Bw2	63-105	10 YR 5/5	l	sbk	eh	vfi	vp vs	ff	24
Cr		Weathered sandstone							
Pedon 6 (Keori): Fine loamy, mixed, thermic family of *Typic Dystrudepts*									
Ap	0-19	10 YR 5/3	l	gr	sh	fr	np ns	mf	10
Bw1	19-43	10YR 5/4	l	sbk	sh	fr	sp ss	cf	12
Bw2	43-80	10YR 4/4	l	sbk	l	fr	np ns	ff	18
Cr	80+	Weathered sandstone							
Pedon 7 (Karsal): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
Ap	0-16	10 YR 5/4	csl	sbk	s	fr	sp ss	mf	12
AC	16-41	10 YR 5/4	csl	sbk	s	fr	sp ss	mf	48
Cr	41+	Conglomeratic substratum							
Pedon 8 (Bandian): Coarse loamy, mixed, thermic family of *Typic Eutrudepts*									
Ap	0-17	10YR 5/3	fsl	sbk	sh	fi	p s	mf	9
Bw1	17-46	10 YR 4/4	fsl	sbk	h	fi	p s	cf	11
Bw2	46- 62	10YR 5/4	fsl	sbk	h	fi	p s	cf	16
Cr	62+	Conglomeratic substratum							

Table: 2
Continued...

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence			Roots distribution	Coarse fragments (%)
					D	M	W		
Forest soils									
Pedon 9 (Sansal): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-13	10 YR 3/3	csl	gr	s	fr	sp ss	mf	20
AC	13-23	10 YR 4/3	csl	sbk	s	fr	sp ss	cc	42
Cr	23+	Weathered shale							
Pedon 10 (Harer): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-14	10 YR 3/3	fsl	gr	s	fr	sp ss	mf	18
AC	14-29	10 YR 4/3	fsl	gr	s	fr	sp ss	mf	35
CA	29-49	10 YR 5/4	fsl	gr	s	fr	sp ss	mf	60
Cr	49+	Weathered sandstone							
Pedon 11 (Dagog): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-13	10 YR 4/4	csl	gr	s	fr	sp ss	mf	32
AC	13-43	10 YR 3/3	csl	gr	s	fr	sp ss	mf	64
Cr	43+	Conglomeratic substratum							
Scrubland / grassland soils									
Pedon 12 (Sokru): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-9	10 YR 4/6	csl	sbk	s	fr	sp ss	mf	28
AC	9-20	10 YR 5/3	csl	sbk	s	fr	sp ss	cf	54
Cr	20+	Weathered sandstone							
Pedon 13 (Chuhair): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-10	10YR 3/3	csl	gr	s	fr	sp ss	mf	20
AC	10-24	10YR 4/5	csl	gr	s	fr	sp ss	cf	48
CA	24-38	10YR 5/4	csl	gr	s	fr	sp ss	cf	65
Cr	38+	Weathered sandstone							
Pedon 14 (Bag): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-12	10YR 4/4	csl	gr	s	fr	sp ss	mf	15
AC	12-28	10 YR 4/3	csl	gr	s	fr	sp ss	mf	35
CA	28-46	10 YR 5/4	csl	gr	s	fr	sp ss	mf	58
Cr	46+	Weathered sandstone							
Pedon 15 (Bhirdi): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-8	10 YR 4/4	csl	gr	s	fr	sp ss	cf	45
AC	8-35	10 YR 4/3	csl	gr	s	fr	sp ss	mf	74
Cr	35+	Conglomeratic substratum							
Pedon 16 (Chakol): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*									
A	0-16	10YR 4/3	csl	gr	s	fr	sp ss	mf	25
AC	16-41	10YR 5/4	csl	gr	s	fr	sp ss	mf	45
Cr	41+	Conglomeratic substratum							

YR 5/5) in all the pedons whereas dark brown (7.5YR 3/3 to 7.5YR 3/4) in sub surface soils of Pedon 3 (Mahalpat), loam to sandy loam in texture, granular to sub-angular blocky structure, moderately well drained to somewhat excessively drained with slightly to moderately eroded and taxonomically classified as the member of loamy skeletal to fine loamy, mixed, thermic families of *Typic / Lithic / Dystrudepts / Paleudalfs / Hapludalfs / Udorthents / Eutrudepts.*

The forest soils occurring on high and mid-hill soil zone are very shallow to shallow, extremely steep, gravelly to very gravelly, acid to non-acid, dark brown (10 YR 3/3) to yellowish brown (10 YR 5/4), fine sandy loam to coarse sandy loam in texture, granular to sub-angular blocky structure, excessively drained with severely eroded and taxonomically classified as the member of loamy skeletal, mixed, thermic families of *Lithic Udorthents.*

The soils of scrubland / grassland occurring on high and mid-hill soil zone are very shallow to shallow, extremely steep, slightly gravelly to very gravelly, acid to non-acid, dark brown (10 YR 3/3) to yellowish brown (10 YR 5/4), coarse sandy loam, granular to sub-angular blocky in structure, excessively drained with severely to very severely eroded and taxonomically classified as the member of loamy skeletal, mixed, thermic families of *Lithic Udorthents.*

Table: 3
Physico-chemical properties of soils under different land uses in Binwa watershed

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2.5)	EC (dS m^{-1})	OC (%)	CEC [cmol (P^+)kg^{-1}]	Exchangeable cations cmol (P+) kg^{-1} Ca	Mg	Na	K	Base saturation (%)	Ca^{+2}/ Mg^{+2}	CEC/ clay	Bulk density Mg m^{-3}	Water retention (%) 0	33 kPa	1500 kPa
Cultivated soils																			
Pedon 1 (Galua): Coarse loamy, mixed, thermic family of *Typic Dystrudepts*																			
Ap	0-16	65.3	20.4	14.3	5.3	0.16	0.86	7.1	2.4	0.7	0.3	0.2	51	3.2	0.49	1.48	24.7	11.2	7.2
BA	16-29	64.9	21.3	13.8	5.5	0.18	0.58	5.8	1.9	0.8	0.3	0.2	55	2.4	0.42	1.52	22.2	10.3	6.3
Bw1	29-55	65.0	19.6	15.4	5.5	0.20	0.22	6.4	2.2	0.9	0.3	0.2	56	2.4	0.41	1.55	26.5	11.7	6.7
Cr	55+								Weathered sandstone										
Pedon 2 (Mandehr): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
Ap	0-11	71.1	17.8	11.1	5.4	0.12	0.76	6.8	2.6	0.8	0.2	0.1	54	3.3	0.61	1.44	24.2	10.7	6.8
AC	11-23	72.3	16.9	10.8	5.4	0.11	0.48	5.2	1.8	0.7	0.2	0.1	53	2.6	0.48	-	18.5	9.5	6.3
CA	23-45	75.7	13.8	10.5	5.5	0.07	0.20	4.9	1.7	0.8	0.2	0.1	57	2.1	0.47	-	14.6	7.4	4.8
Cr	45+								Weathered sandstone										
Pedon 3 (Mahalpat): Fine silty, mixed, thermic family of *Typic Paleudalfs*																			
Ap	0-17	29.4	45.4	25.2	5.2	0.26	1.28	11.2	3.8	1.0	0.4	0.3	49	3.8	0.44	1.31	51.2	20.4	9.3
AB	17-33	24.5	49.5	26.0	5.4	0.27	0.77	12.3	4.3	1.3	0.5	0.3	52	3.3	0.47	1.34	48.1	21.7	13.5
Bt1	33-59	16.5	51.4	32.1	5.5	0.32	0.65	14.9	5.6	1.7	0.5	0.4	55	3.3	0.46	1.38	58.3	25.3	15.9
Bt2	59-106	16.1	50.7	33.2	5.5	0.34	0.38	13.4	5.0	1.5	0.5	0.4	55	3.3	0.40	1.38	62.5	26.4	14.8
Bt3	106-152	18.4	50.0	31.6	5.5	0.34	0.28	12.8	4.6	1.5	0.5	0.4	54	3.1	0.40	1.39	56.1	24.2	13.7
Pedon 4 (Kunsal): Fine loamy, mixed, thermic family of *Typic Hapludalfs*																			
Ap	0-16	43.4	35.4	21.2	5.5	0.28	0.85	10.2	3.8	1.1	0.2	0.2	52	3.5	0.44	1.32	48.9	20.6	8.1
AB	16-35	41.5	36.3	22.2	5.6	0.28	0.67	9.3	3.4	1.2	0.2	0.2	54	2.8	0.42	1.34	54.4	22.6	8.3
Bt1	35-67	31.1	38.6	30.3	5.7	0.32	0.35	13.9	5.7.	1.8	0.3	0.3	58	3.2	0.46	1.36	62.8	23.5	12.1
Bt2	67-115	27.7	39.7	32.6	5.8	0.32	0.24	13.4	5.8	1.7	0.4	0.3	58	3.4	0.41	1.36	60.4	25.8	13.5
BC	115-160	38.2	38.2	23.6	5.9	0.26	0.24	11.3	4.7	1.4	0.4	0.3	60	3.4	0.48	1.38	42.6	18.4	12.6
Pedon 5 (Phatahar): Fine loamy, mixed, thermic family of *Typic Dystrudepts*																			
Ap	0-14	46.3	32.3	21.4	5.4	0.24	0.78	10.2	3.6	1.3	0.3	0.2	53	2.8	0.48	1.39	38.8	16.9	8.5
BA	14-41	45.4	32.8	21.8	5.5	0.24	0.44	9.8	3.5	1.3	0.3	0.2	54	2.7	0.45	1.42	36.3	16.4	9.5
Bw1	41-63	42.6	33.1	24.3	5.6	0.26	0.28	10.6	3.9	1.6	0.4	0.3	58	2.4	0.42	1.46	44.7	18.8	10.5
Bw2	63-105	43.4	32.8	23.8	5.9	0.18	0.12	9.8	3.7	1.6	0.2	0.2	58	2.2	0.41	-	30.5	12.5	6.2
Cr									Weathered sandstone										
Pedon 6 (Keori): Fine loamy, mixed, thermic family of *Typic Dystrudepts*																			
Ap	0-19	47.5	33.2	19.3	5.7	0.22	0.79	9.0	3.3	1.1	0.3	0.2	54	3.0	0.47	1.44	34.5	12.5	7.8
Bw1	19-43	48.3	30.5	21.2	5.8	0.25	0.45	9.6	3.3	1.4	0.3	0.3	56	2.4	0.45	1.48	38.3	16.3	8.3
Bw2	43-80	46.4	30.7	22.9	5.9	0.27	0.29	10.0	3.5	1.5	0.3	0.3	56	2.3	0.44	1.50	41.6	15.4	8.1
Cr	80+								Weathered sandstone										
Pedon 7 (Karsal): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
Ap	0-16	73.7	13.6	12.7	6.7	0.23	0.68	7.0	3.4	1.2	0.2	0.1	70	2.8	0.55	1.56	24.4	11.4	6.9
AC	16-41	74.5	14.9	10.6	6.8	0.20	0.24	5.2	2.4	1.1	0.2	0.1	73	2.2	0.49	-	19.4	10.2	6.4
Cr	41+								Conglomeratic substratum										

Table: 3
Continued...

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2.5)	EC (dS m^{-1})	OC (%)	CEC [cmol (P$^+$)kg^{-1}]	Exchangeable cations				Base saturation (%)	Ca^{+2}/ Mg^{+2}	CEC/ clay	Bulk density Mg m^{-3}	Water retention (%)		
									Ca	Mg	Na	K					0	33 kPa	1500 kPa
									cmol (P+) kg^{-1}										
Pedon 8 (Bandian): Coarse loamy, mixed, thermic family of *Typic Eutrudepts*																			
Ap	0-17	70.7	17.9	11.4	6.5	0.22	0.68	5.9	2.4	1.1	0.3	0.2	68	2.2	0.51	1.48	20.8	10.5	5.8
Bw1	17-46	70.3	17.0	12.7	6.6	0.24	0.36	5.7	2.4	1.1	0.3	0.2	70	2.2	0.45	1.52	22.3	9.7	5.4
Bw2	46- 62	69.9	16.2	13.9	6.7	0.24	0.18	6.0	2.6	1.2	0.3	0.2	72	2.2	0.43	1.54	25.3	10.8	6.7
Cr	62+	Conglomeratic substratum																	
Forest soils																			
Pedon 9 (Sansal): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-13	72.7	14.8	12.5	5.3	0.14	1.26	7.1	2.3	0.9	0.2	0.1	49	2.6	0.57	1.46	19.8	7.4	3.6
AC	13-23	75.6	12.7	11.7	5.4	0.11	0.74	5.5	1.8	0.8	0.2	0.1	52	2.3	0.47	-	13.9	5.4	2.2
Cr	23+	Weathered shale																	
Pedon 10 (Harer): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-14	57.5	22.7	19.8	5.2	0.25	0.74	9.4	2.7	1.0	0.3	0.2	45	2.7	0.47	1.44	38.4	14.5	7.8
AC	14-29	60.4	21.2	18.4	5.3	0.26	0.52	7.8	2.5	0.9	0.3	0.2	50	2.6	0.42	-	35.7	13.2	6.5
CA	29-49	60.7	23.5	15.8	5.3	0.26	0.21	6.8	2.1	0.8	0.2	0.2	49	2.6	0.43	-	30.8	14.5	8.0
Cr	49+	Weathered sandstone																	
Pedon 11 (Dagog): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-13	75.3	15.1	9.6	6.4	0.21	0.64	4.6	2.1	0.7	0.2	0.1	68	3.0	0.48	-	20.5	9.0	4.6
AC	13-43	77.8	13.8	8.4	6.6	0.19	0.24	3.8	1.6	0.8	0.2	0.1	70	2.0	0.45	-	18.1	8.5	4.2
Cr	43+	Conglomeratic substratum																	
Scrubland / grassland soils																			
Pedon 12 (Sokru): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-9	75.4	14.2	10.4	5.3	0.13	0.64	5.8	1.5	0.8	0.1	0.1	50	1.9	0.56	1.42	15.3	7.2	3.9
AC	9-20	79.2	11.0	9.8	5.4	0.09	0.44	4.6	1.3	0.7	0.1	0.1	52	1.9	0.47	-	12.9	4.4	2.4
Cr	20+	Weathered sandstone																	
Pedon 13 (Chuhair): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-10	61.4	20.5	18.1	5.5	0.25	0.48	8.2	2.7	1.1	0.4	0.3	55	2.5	0.44	1.48	32.9	14.6	7.5
AC	10-24	62.3	19.4	18.3	5.6	0.25	0.24	8.1	2.7	1.1	0.5	0.2	56	2.5	0.44	-	36.7	13.3	7.2
CA	24-38	64.5	17.5	18.0	5.6	0.27	0.09	7.4	2.6	1.1	0.3	0.2	57	2.4	0.41	-	32.6	13.6	6.9
Cr	38+	Weathered sandstone																	
Pedon 14 (Bag): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-12	63.5	17.4	19.1	5.8	0.22	0.62	8.8	3.3	1.2	0.3	0.3	58	2.8	0.46	1.46	36.5	14.8	7.4
AC	12-28	63.8	17.8	18.4	5.9	0.22	0.34	7.5	2.7	1.2	0.3	0.2	59	2.3	0.41	-	35.4	14.4	6.7
CA	28-46	64.5	17.1	18.4	5.9	0.24	0.12	7.4	2.6	1.2	0.4	0.2	59	2.2	0.40	-	34.8	13.3	6.5
Cr	46+	Weathered sandstone																	
Pedon 15 (Bhirdi): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-8	78.3	13.2	8.5	6.8	0.19	0.48	4.7	2.4	0.8	0.1	0.1	72	3.0	0.55	-	17.9	8.7	4.2
AC	8-35	78.6	14.1	7.3	6.9	0.16	0.12	3.4	1.5	0.7	0.2	0.1	73	2.1	0.46	-	15.9	8.4	4.0
Cr	35+	Conglomeratic substratum																	
Pedon 16 (Chakol): Loamy skeletal, mixed, thermic family of *Lithic Udorthents*																			
A	0-16	74.8	15.7	9.5	6.8	0.20	0.58	5.2	2.6	0.8	0.2	0.1	72	3.3	0.58	1.55	18.7	9.7	5.2
AC	16-41	75.6	16.1	8.3	6.9	0.19	0.16	3.8	1.8	0.8	0.2	0.1	75	2.3	0.46	-	16.3	8.5	4.1
Cr	41+	Conglomeratic substratum																	

Physico-chemical Characteristics

Physico-chemical characteristics of the soils are presented in Table 3. The sand content in the soils of Binwa watershed ranged from 16.1 to 79.2% with a mean value of 57.5%, silt content ranged from 11.0 to 51.4% with a mean value of 24.8% and clay content ranged from 7.3 to 33.2% with a mean value of 17.7%. The increase in clay content with soil depth was too small to qualify for the argillic horizons in Mandehar, Phatahar, Keori and Bandian pedons. Verma *et al.* (1976) reported a substantial increase in clay content (about 14%) in the B horizon in soils of wet temperate zone of Himachal Pradesh.

Soils of high and mid-hill soil zones are acidic (base saturation <60%) and belong to *Entisols, Inceptisols* and *Alfisols*, while those of low hill zone are non-acidic (base saturation >60%) and fit in *Entisols* and *Inceptisols*. Climate (high rainfall), parent material (chemical composition) and vegetation are considered as primary factors for explaining pH and base saturation differences within and between Himalayan soils. Mandal (1984) reviewed that majority of the *Alfisols* and *Inceptisols* in Himalayas are acidic in reaction.

The soil pH, EC, OC and CEC of Binwa watershed ranged from 5.2 to 6.9, 0.07 to 0.34, 0.09 to 1.28 and 3.4 to 14.9 with a mean value of 5.8, 0.22, 0.48 and 8.0, respectively. Higher values of bulk density, EC, water retention and base saturation were noticed in subsurface horizons of *Inceptisols* and *Alfisols*. Similar results were found earlier by Kumar (1996), Singh *et al*. (1991), Nagaraju *et al.* (2015) and Adebayo *et al.* (2021). The differences of CEC, base saturation and water retention percentage between and within the soil may be ascribed largely to the varied type and content of soil colloids and soil pH values. Sharma *et al*. (2004) explained effect of soil pH and soil colloids on these characteristics nicely.

Generally, NH_4OA_C-CEC was higher than sum total of exchangeable ions (Ca^{2+}, Mg^{2+}, Na^+ and K^+) in the soil. These findings are in agreement with those of Sarma *et al*. (1976) for some Benchmark soils of India namely, Trivandrum, Kunnamangalan, Thekkadi and Raichur series. Among all the basic cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), calcium was found to be dominant one in all the soils. Similar results were observed by Verma (1979); Singh (1987); Gupta and Verma (1992); Najar *et al*. (2009) and Dhale and Prasad (2009) in hill soils.

Higher Ca: Mg ratios in surface horizons as compared to the sub-surface horizons indicate the role of vegetation on soil development to a larger extent (Gangopadhayay *et al*., 1989). Besides adding Ca and Mg on the surface soils, plants play an important role of taking up these nutrients from lower to upper soil layers. CEC / clay ratio ranged from 0.40 to 0.61 with a mean value of 0.46 in the watershed. Such ratios can be expected in soils, which are mixed in mineralogy and have varying amounts of organic matter.

Taxonomic Classification of Soils

On the basis of characteristics and properties of sixteen pedons studied, soils of Binwa watershed have been classified taxonomically up to series level (Table 4).

Soils belong to *Paleudalfs, Hapludalfs, Dystrudepts, Eutrudepts* and *Udorthents* at the great group level. At series level, soils under different land uses in Binwa watershed have been taxonomically placed into ten tentative soil series *viz*., Sansal, Galua, Mandehr, Malapat, Kunsal, Phatahar,

Table: 4
Taxonomic classification of pedons studied

S.No.	Pedon	Soil zone	Major land use	Taxonomic classification	Extent (%)
1.	Sansal	High hill	Forest	Loamy skeletal, shallow, mixed, thermic, acid family of *Lithic Udorthents*	22.2
2.	Sokru	High hill	Scrubland	Loamy skeletal, shallow, mixed, thermic, acid family of *Lithic Udorthents*	7.6
3.	Galua	High hill	Agriculture	Coarse loamy, shallow, mixed, thermic, acid family of *Typic Dystrudepts*	0.5
4.	Mandehr	High hill	Agriculture	Loamy skeletal, shallow, mixed, thermic, acid family of *Lithic Udorthents*	0.6
5.	Harer	Mid-hill	Forest	Loamy skeletal, shallow, mixed, thermic, acid family of *Lithic Udorthents*	9.1
6.	Chuhair	Mid-hill	Scrubland	Loamy skeletal, shallow, mixed, thermic, acid family of *Lithic Udorthents*	4.7
7.	Bag	Mid-hill	Grassland	Loamy skeletal, shallow, mixed, thermic, acid family of *Lithic Udorthents*	2.7
8.	Mahalpat	Mid-hill	Agriculture	Fine silty, mixed, thermic, acid and family of *Typic Paleudalfs*	3.1
9.	Kunsal	Mid-hill	Agriculture	Fine loamy, mixed, thermic, acid family of *Typic Hapludalfs*	3.5
10.	Phatahar	Mid-hill	Agriculture	Fine loamy, mixed, thermic, acid family of *Typic Dystrudepts*	3.8
11.	Keori	Mid-hill	Agriculture	Fine loamy, mixed thermic acid family of *Typic Dystrudepts*	2.8
12.	Dagog	Low hill	Forest	Loamy skeletal, shallow, mixed, thermic non-acid family of *Lithic Udorthents*	2.4
13.	Bhirdi	Low hill	Scrubland	Loamy skeletal, shallow, mixed, thermic non-acid family of *Lithic Udorthents*	6.7
14.	Chakol	Low hill	Grassland	Loamy skeletal, shallow, mixed, thermic non-acid family of *Lithic Udorthents*	1.4
15.	Karsal	Low hill	Agriculture	Loamy skeletal, shallow, mixed, thermic, non-acid family of *Lithic Udorthents*	6.5
16.	Bandian	Low hill	Agriculture	Coarse loamy, shallow, mixed, thermic non-acid family of *Typic Eutrudepts*	5.4
	Area under non-productive landuses *viz.,* built-up, rock outcrops and waterbodies				17.0
	Total				100.0

Keori, Harer, Karsal and Bandian (Table 5). Sansal and Galua series occupy highest (29.8%) and lowest area (0.5%) of the Binwa watershed, respectively.

Soils of Binwa watershed are the member of loamy skeletal to fine silty, very shallow to very deep, mixed, thermic acid / non-acid families of *Lithic / Typic Udorthents / Dysrudepts / Eutrudepts / Hapludalfs / Paleudalfs*. A soil series map was prepared using one soil association (Sansal: Not soil) and nine soil consociations as mapping units (Fig. 3).

Description of Soil Series

***Sansal soil series*:** Typically, Sansal soil is a member of loamy skeletal, mixed, thermic family of *Lithic Udorthents*. These soils have yellowish brown (dry), gravelly (15-40%); moderately acid (4.5-5.5); coarse sandy loam A horizon and brownish yellow (dry), very gravelly (40-80%); moderately acid; coarse sandy loam AC horizon.

***Galua soil series*:** Soil series Galua is a member of coarse loamy, mixed, thermic family of *Typic Dystrudepts*. These soils have yellowish brown (dry), moderately acid (4.5-5.5); slightly gravelly (<15%), sandy loam Ap horizon, light yellowish brown (dry), moderately acid, slightly gravelly, sandy loam BA horizon and yellowish brown (dry), moderately acid, slightly gravelly, sandy loam Bw1 horizon.

***Mandehr soil series*:** Mandehr soil is a member of loamy skeletal, mixed, thermic family of *Lithic Udorthents*. These soils have yellowish brown (dry), moderately acid (4.5-5.5); slightly gravelly (<15%), coarse sandy loam Ap horizon, yellowish brown (dry), moderately acid; gravelly (15-40%), coarse sandy loam AC horizon and light yellowish brown (dry), moderately acid; very gravelly (40-80%), coarse sandy loam CA horizon.

***Mahalpat soil series*:** Typically, Mahalpat soil is a member of fine silty, mixed, thermic family of *Typic Paleudalfs*. These soils have dark yellowish brown (dry), moderately acid (4.5-5.5); loam Ap horizon, strong brown (dry), moderately acid; loam AB horizon, and strong brown (dry) moderately acid, silty clay loam Bt1 and Bt2 and Bt3 horizon.

***Kunsal soil series*:** Fine loamy, mixed, thermic family of *Typic Hapludalfs*. These soils have yellowish brown (dry), moderately acid (4.5-5.5); loam Ap horizon, yellowish brown (dry), slightly acid (5.5-6.5); loam AB horizon, brownish yellow (dry), slightly acid; clay loam Bt1, yellowish brown (dry), slightly acid; clay loam Bt2 and brownish yellow (dry), slightly acid; loam BC horizon.

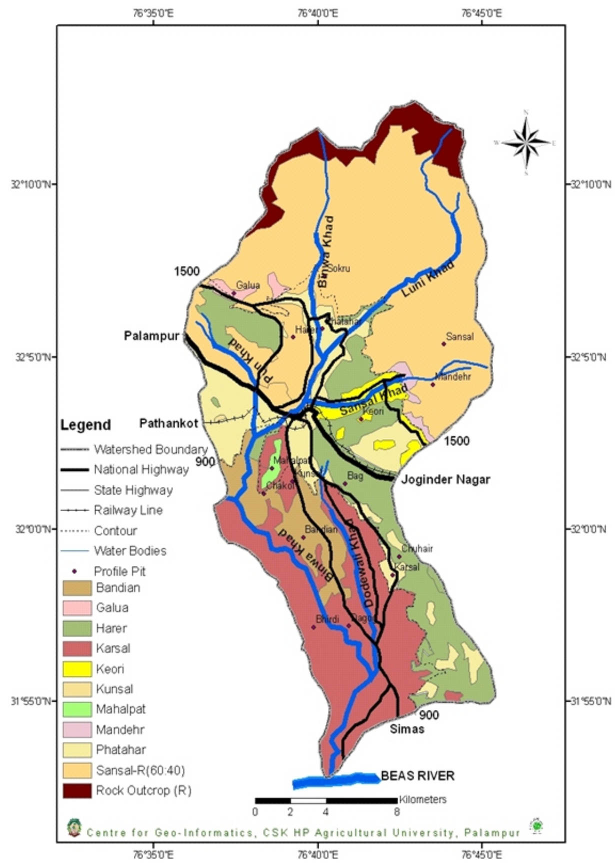

Fig. 3. Soil series map of Binwa watershed

Table: 5
Tentative soil series of Binwa watershed

S.No.	Tentative soil series	Major land use (s)	Soil zone	Extent (% of watershed area)
1.	Sansal	Forest/scrubland	High hill	29.8
2.	Galua	Agriculture	High hill	0.5
3.	Mandehr	Agriculture	High hill	0.6
4.	Mahalpat	Agriculture	Mid-hill	3.1
5.	Kunsal	Agriculture	Mid-hill	3.5
6.	Phatahar	Agriculture	Mid-hill	3.8
7.	Keori	Agriculture	Mid-hill	2.8
8.	Harer	Forest / scrubland / grassland	Mid-hill	16.5
9.	Karsal	Agriculture / forest / scrubland / grassland	Low hill	17.0
10.	Bandian	Agriculture	Low hill	5.4
	Area under non-productive landuses *viz.,* built-up, rock outcrops and waterbodies			17.0
	Total			100.0

***Phatahar soil series*:** Soils were classified as fine loamy, mixed, thermic family of *Typic Dystrudepts*. These soils have yellowish brown (dry), moderately acid (4.5-5.5); loam Ap horizon, yellowish brown (dry), moderately acid; slightly gravelly (<15%); loam BA horizon, yellowish brown (dry), slightly acid (5.5-6.5); slightly gravelly; loam Bw1 horizon and brownish yellow (dry), slightly acid; gravelly (15-40%); loam Bw2 horizon.

***Keori soil series*:** Keori soil is a member of fine loamy, mixed, thermic family of *Typic Dystrudepts*. These soils have light yellowish brown (dry), slightly gravelly (<15%); slightly acid (5.5-6.5); loam Ap horizon, brownish yellow (dry), slightly gravelly; slightly acid; loam Bw1 and brownish yellow (dry), gravelly (15-40%) slightly acid; loam Bw2.

***Harer soil series*:** Typically, Harer soil is a member of loamy skeletal, mixed, thermic family of *Lithic Udorthents*. These soils have brown (dry), gravelly (15-40%); moderately acid (4.5-5.5); fine sandy loam A horizon, yellowish brown (dry), gravelly, moderately acid; fine sandy loam AC horizon and light yellowish brown (dry), very gravelly (40-80%); moderately acid; fine sandy loam CA horizon.

***Karsal soil series*:** Karsal soil is a member of loamy skeletal, mixed, thermic family of *Lithic Udorthents*. These soils have brownish yellow (dry), slightly gravelly (<15%); neutral (6.5-7.5); coarse sandy loam Ap horizon and brownish yellow (dry), very gravelly (40-80%); neutral; coarse sandy loam AC horizon.

***Bandian soil series*:** Bandian soil series representing coarse loamy, mixed, thermic family of *Typic Eutrudepts*. These soils have light yellowish brown (dry), slightly gravelly (<15%); slightly acid (5.5-6.5); fine sandy loam Ap horizon, brownish yellow (dry), slightly gravelly, neutral (6.5-7.5); fine sandy loam Bw1 horizon and brownish yellow (dry), gravelly (15-40%); neutral; fine sandy loam Bw2 horizon.

4. CONCLUSIONS

Soils of Binwa watershed belong to ten soil series, each with unique characteristics, properties and productivity potentials. Soils of high and mid-hill soil zones are loamy skeletal to fine silty, very shallow to very deep and acidic (base saturation <60%) and belong to *Entisols, Inceptisols* and *Alfisols*, while those of low hill zone are loamy skeletal to coarse loamy, very shallow to deep and non-acidic (base saturation >60%) and fit in *Inceptisol*s and *Alfisols*. Generally, variations in landform and parent material account for spatial variability of soil characteristics and properties.

Steep to very steep side-slopes of lesser Himalayas and Shivalik hills are characterized by the presence of very gravelly, shallow *Orthents*, whereas, those of very gently to moderately sloping terraces by medium to deep, nil to slightly gravelly *Paleudalfs, Hapludalfs, Dystrudepts and Eutrudepts.*

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