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Role of Topography on Characteristics, Fertility Status and Classification of the Soils of Almora District in Uttarakhand

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Topographic position is one of the most dominant factors that govern soil development in the hilly areas. Ten soil profiles representing different landform units *i.e.* hill top, side slope, broad valley and narrow valley terraces were chosen to investigate the soil morphological, physical and chemical characteristics and their relationships with topography in Almora district of Uttarakhand. Soil properties varied remarkably among the studied profiles. The soils were moderately shallow to very deep in depth (32–160 cm), non-saline (EC 0.03–0.45 dS m^{-1}), acidic in nature (pH 5.1–6.6), low to high in organic carbon (OC) (0.03–2.91%) with low to moderate CEC [1.6–19.4 cmol(p^+)kg^{-1}]. Base saturation ranged from 45.9 to 75.1% in which calcium (Ca^{2+}) and magnesium (Mg^{2+}) were the dominant cations on exchangeable sites followed by potassium (K^+) and sodium (Na^+). The studied soils were dominated by silt fraction followed by clay, except in Dhamas (P4), Dhaili (P5) and Kosi (P10) which showed high sand content. Hill top profiles showed the highest OC. The upper soil layers of hill top and broad valley terrace profiles showed higher availability of soil macronutrients, whereas micronutrients were higher than agronomic critical limits in all profiles. Three soil profiles were classified as Entisols and keyed out as Typic Udifluvents (Kosi), Lithic Udorthents (Dhamas) and Typic Udorthents (Dhaili). Majkhali (P7) soils were placed under Inceptisol soil order and were classified as Dystric Eutrudepts. The remaining soils were placed under Alfisol soil order and keyed out as Hapludalf at great group level. Among the Alfisols, Someshwar (P9) was classified as Oxyaquick Hapludalfs, Sitlakhet (P1) was classified as Ultic Hapludalfs, Salla Routela (P2) and Chaubattia (P3) were classified as Mollic Hapludalfs, while Kausani (P6) and Hawalbagh (P8) soils were keyed out as Typic Hapludalfs. The soils in Almora district of Uttarakhand exhibited wide variations with topographic positions and proper soil management will help in maintaining sustainable production of this area.

Key words: Topography, soil classification, soil fertility, Almora district

The sustainable agricultural development of hills and mountainous regions and their ecological protection have become a primary concern in recent years (FAO 2015). A systematic appraisal of our soil resources in relation to their genesis, classification, pedological and mineralogical characteristics is essential to ensure healthy soils for sustainable production systems. Information about soil potentials and problems in a specific area can be used for developing effective land use planning and sustainable land management practices (Mahapatra *et al*. 2005; Reddy and Naidu 2016). The hills and mountainous region are unlike the plains with respect to topographic features. In addition, they have a wide range of macro and micro-climate, parent material and vegetation which influence soil genesis and characteristics. Topographic position was found to be one of the dominant factors that govern the soil development in the hilly areas (Nagdev *et al*. 2017). Understanding the soils in hills and mountainous ecosystem, their characteristics and classification was the main concern for several researchers, who studied and analyzed the relation between different soil attributes and physiographic factors such as relief, slope and altitude (Saran *et al*. 2011; Maurya *et al*. 2014; Kharlyngdoh *et al*. 2015).

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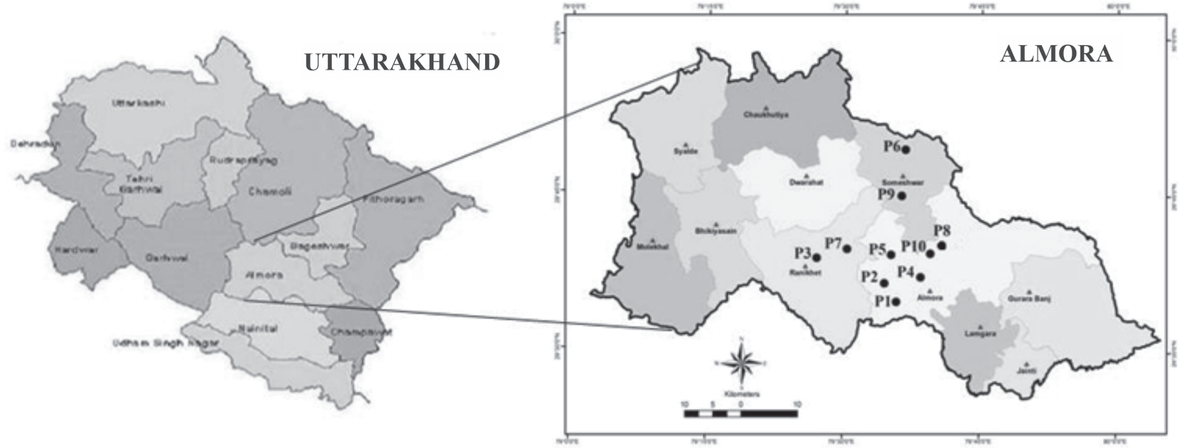

Fig. 1. Location of soil profiles in Alomra District, Uttarakhand

Others assessed soil development on the toposequence basis which provides a useful model to evaluate the interaction between soil pedogenic and geomorphic processes; and to understand relationships between soil, landform and land cover at a spatial dimension (Ahmad *et al*. 2009; Tufaila *et al*. 2014). Singh *et al*. (1999) found that the soils of well managed terraces were more developed than soils of poorly managed terraces in Kumaon hills. Maurya *et al*. (2014) evaluated the effect of elevation on the chemical properties of fallow and forest land soils of Central Himalaya. Surya *et al*. (2015) investigated the genesis and characteristics of soils derived from various metamorphic rocks in Kumaon Himalayas, and the soils were classified under three soil orders *viz.* Entisols, Inceptisols and Alfisols. However, information on the effects of topographic positions on properties and fertility status of soils in Almora district are still limited. Hence, the current research was carried out to study the characteristics, classification and fertility status of soils developed in different landforms in Almora district, Uttarakhand.

Materials and Methods

The study area belongs to Almora district, Uttarakhand which is a part of Kumaon hills region in Western Himalayas. Ten soil profiles (Fig. 1) from varying altitudes *viz.* Sitlakhet (P1), Salla Routela (P2) and Chaubatia (P3) representing the hill top (1600 to 2000 m above msl); Dhamas (P4), Dhaili (P5), Kausani (P6) and Majkhali (P7) representing side slope (1400 to 1750 m above msl); and Hawalbagh (P8) and Someshwar (P9) representing broad valley (1200 to 1400 m above msl) and Kosi (P10) representing narrow valley (1187 m above msl) were selected for the present study (Table 1). The study area is characterized with monsoonal type of climate. The mean annual rainfall in the study area varies from 1000 to 1335 mm with an average of 1100 mm. The average mean annual temperature (MAT) is 17.7 °C (varying from 16.0 to 19.2 °C). In summer, the average mean temperature (MST) is 19.2 °C which varies between 17.5 and 20.9 °C. In winter, the average mean temperature (MWT) is 12.1 °C which varies between 9.9 and 13.6 °C.

Soil profiles were exposed and described according to the USDA procedures (Soil Survey Staff 2014). Soil samples collected from each horizon were air-dried and ground to pass through 2-mm sieve. Particle size distribution of the soils was determined by international pipette method (Jackson 1979). The clay fraction (<2 µm) was separated and fine clay fraction (<0.2 µm) was obtained by centrifugation procedures as described by Jackson (1979). The fine clay to total clay ratio was worked out for soil layers that exhibited clay accumulation.

Soil pH was measured in water and 0.01*M* $CaCl_2$ in 1:2.5 soil: solution ratio. Soil electrical conductivity (EC) was measured in 1:2.5 soil: water ratio. Soil organic carbon (OC) was determined by wet digestion method as described by Walkley and Black (1934). The cation exchange capacity (CEC) and exchangeable cations were determined by ammonium acetate method (Jackson 1973). The exchangeable Al+H were extracted using 1*N* KCl and determined by titrating the extract against 0.025 *N* NaOH using phenolphthalein as indicator (Page *et al*. 1982). Available N, P, K and S were determined by alkaline potassium permanganate (Subbiah and Asija 1956), Bray's-1 extraction (Bray and Kutrz 1945), neutral ammonium acetate (Jackson 1973) and calcium chloride extraction method (Williams and

Table 1. Site characteristics of soil profiles

Profile	Location	Altitude above msl (m)	Landform/ Physiography	Slope	Erosion	Drainage	Land use
P1 (Sitlakhet)	N 29°35′6.4″ E 79°33′1.6″	1964	Top hill terraces	10 – 15%	Moderate	Somewhat excessive	Agro-forestry
P2 (Salla Routela)	N 29°35′45.9″ E 79°33′20.6″	1602	Top hill terraces	10 – 15%	Moderate	Somewhat excessive	Agro-horticulture
P3 (Chaubatia)	N 29°37′17.0″ E 79°27′32.4″	1991	Top hill terraces	10 – 15%	Moderate	Somewhat excessive	Orchards
P4 (Dhamas)	N 29°36′29.1″ E 79°35′31.0″	1409	Middle hill terraces/side slope	10– 15%	Severe	Excessive	Cultivated
P5 (Dhaili)	N 29°37′59.7″ E 79°34′34.8″	1399	Middle hill terrace/ side slope	15 – 30%	Severe	Excessive	Cultivated
P6 (Kausani)	N 29°51′11.9″ E 79°35′42.9″	1661	Middle hill terrace/ side slope	10 – 15%	Moderate	Somewhat excessive	Uncultivated terrace
P7 (Majkhali)	N 29°40′50.5″ E 79°30′34.2″	1756	Middle hill broad terraces/side slope	3 – 5%	Moderate	Well	Cultivated
P8 (Hawalbagh)	N 29°38′13.4″ E 79°37′40.0″	1187	Broad valley terrace	3 – 5%	Slight	Well	Cultivated
P9 (Someshwar)	N 29°47′12.2″ E 79°35′36.8″	1407	Broad valley terrace	1 – 3%	Slight to nil	Well	Cultivated
P10 (Kosi)	N 29°37′57.5″ E 79°37′33.5″	1159	Narrow valley/ River terrace	1 – 3%	Slight	Excessive	Cultivated

Steinbergs 1959), respectively. Soil micronutrients were extracted by DTPA at pH 7.3 using 1:2 soil: solution ratio as outlined by Lindsay and Norvell (1978). The extractable Fe, Mn, Cu and Zn were estimated by atomic absorption spectrometer. Taxonomic classification of soils up to sub-group level was done as per Keys to Soil Taxonomy (Soil Survey Staff 2014).

Results and Discussion

Soil morphological characteristics

The soils in this area were moderately shallow to very deep in depth. Soils at Dhamas (P4) were moderately shallow, whereas at Dhaili (P5) it was moderately deep. All other soils were very deep (>150 cm). Soil profiles P4, P5 and P10 exhibited only A and C horizons whereas other soils had A, B and C horizons. The Munsell colour of soil matrix was dominated by 10YR hue in both dry and moist conditions (Table 2). The sub-surface horizons in broad valley terraces (P8) and narrow valley land (P10) showed redder hue of 7.5YR and 5YR. On the other hand, Dhaili profile (P5) that developed on slate rock was olive black in colour with a hue of 5Y, which reflected the colour of the parent material. Someshwar soil profile exhibited distinct reddish mottles (5YR 6/8 and 5YR 4/4) in the Bt horizon (Table 2). The studied profiles were found to have good drainage conditions which were indicated by soil colours such as light and dark yellowish brown, pale brown, brown and dark brown in both surface and sub-surface layers (Rehman *et al*. 2017). Earlier studies from Almora region also reported that 10YR hue of soil colour was prevalent in both dry and moist conditions (Walia *et al*. 2013; Surya *et al*. 2015). Granular soil structure was found to be common at surface horizons. Sub-surface layers were found to develop sub-angular blocky structure as a result of increasing clay content and soil compaction (Jena *et al*. 2016). The dry consistencies of the soils varied from slightly hard to hard, while in the moist condition it ranged from very friable to firm.

Soil physical and chemical characteristics

Soil physical and chemical properties are presented in table 3. Texture of the soils varied from loamy sand to silty clay. Textural data revealed that the content of sand ranged from 10.4 to 86.0%, silt from 9.2 to 59.2% and clay from 3.8 to 47.4%. It was

Table 2. Morphological characteristics of soil profiles

Depth (cm)	Horizon	Matrix colour		Structure[a]	Consistency[b]	Coarse fragments (%)	Roots[c]
		Dry	Moist				
P1 (Sitlakhet)							
0 – 25	Ap	10YR 4/3	10YR 3/2	gr	sh fr ss sp	-	m
25 – 55	Bw1	10YR 4/3	10YR 3/2	m1 sbk	- fr ss sp	-	m
55 – 85	Bt2	10YR 4/3	10YR 3/3	m2 sbk	-fr ss sp	5-10	m
85 – 105	Bt3	10YR 5/4	10YR 3/4	m2 sbk	- fr ss sp	5-10	f
105 – 135	BC	10YR 6/4	10YR 3/4	m1 sbk	- fr ss sp	10-15	-
135 – 160$^+$	C	10YR 6/4	10YR 4/4	M	- fr ss sp	40-50	-
P2 (Salla Routela)							
0 – 15	Ap	10YR 4/4	10YR 2/2	gr	sh fr ss sp	-	m
15 – 35	Bw1	10YR 4/3	10YR 3/3	m1sbk	- fr ss sp	-	c
35 – 65	Bt2	10YR 4/3	10YR 3/4	m2 sbk	-fr ss sp	5-10	-
65 – 100	Bt3	10YR 4/4	10YR 3/4	c2 sbk	- fi ss sp	5-10	-
100-125	Bw4	10YR 5/4	10YR 4/4	c2 sbk	- fi ss sp	5-10	-
125-150$^+$	C	10YR 5/4	10YR4/4	M	- fi ss sp	25-30	-
P3 (Chaubattia)							
0 – 22	A	10YR 5/3	10YR 3/3	gr	sh fr ss sp	3-5	m
22 – 50	Bw1	10YR 5/3	10YR 4/3	m1sbk	- fr ss sp	3-5	m
50 – 73	Bt2	10YR 4/3	10YR 3/3	m2sbk	- fr ss sp	3-5	c
73 – 90	Bt3	10YR 4/3	10YR 3/3	c2sbk	- fr ms sp	3-5	f
90 – 120	BC	10YR 6/4	10YR 4/4	m2sbk	- fr ss sp	5-10	-
120-150$^+$	C	10YR 6/4	10YR 5/4	M	- fr ss sp	20-25	-
P4 (Dhamas)							
0 – 15	Ap	10YR5/4	10YR4/3	gr	sh fr ss sp	-	m
15 – 32	C	10YR5/4	10YR3/4	sg	- fr ss po	10-15	f
32 $^+$	R	Indurated bedrock					
P5 (Dhaili)							
0 – 15	Ap	5Y3/2	5Y 2.5/1	gr	sh fr ss so	5-10	m
15 – 52	AC	5Y3/2	5Y 2.5/1	f1 sbk	- fr ss po	10-15	m
52 – 82$^+$	C	5Y3/2	5Y 2.5/1	M	- fr ss po	40-50	-
P6 (Kausani)							
0 – 18	A	10YR 5/4	10YR 4/4	gr	sh fr ss sp	3-5	m
18 – 45	BA	10YR 5/5	10YR 4/3	f1 sbk	- fr ss sp	3-5	m
45 – 88	Bt	10YR 5/4	10YR 3/4	m2 sbk	- fr ss sp	5-10	f
88 – 120	BC	10YR 5/4	10YR 3/4	m1 sbk	- fr ss po	15-20	-
120 - 150$^+$	C	10YR 6/4	10YR4/4	M	- fr ss po	30-40	-
P7 (Majkhali)							
0 – 20	Ap	10YR 6/3	10YR 4/3	f1sbk	sh fr ss sp	3-5	m
20 – 43	Bw1	10YR 6/4	10YR 4/4	m1sbk	- fr ss sp	3-5	m
43 – 85	Bt2	10YR 5/4	10YR 4/4	m2 sbk	- fr ms sp	5-10	f
85 – 120	Bt3	10YR 6/3	10YR 4/3	c3 sbk	- fr ms sp	5-10	-
120-150$^+$	C	10YR 7/3	10YR 5/3	M	- fr ss sp	20-25	-
P8 (Hawalbagh)							
0 – 15	Ap	10YR 4/4	10YR 3/4	m1sbk	h fr ms sp	5-10	m
15 – 37	Bt1	10YR5/4	10YR 3/4	m3 sbk	- fi vs sp	3-5	c
37 – 60	Bt2	10YR4/4	10YR 3/4	c3 sbk	- fi vs sp	-	-
60 – 88	Bt3	7.5YR 4/4	7.5YR 3/4	m3 sbk	- fi vs sp	-	-
88 – 115	Bt4	5YR 4/4	5YR 3/4	m3 sbk	- fi vs sp	-	-
115–150$^+$	BC	7.5YR5/4	7.5YR 3/4	m2 sbk	- fr ms sp	5-10	
P9 (Someshwar)*							
0 – 20	Ap	10YR 4/3	10YR 3/3	gr	h fr ss sp	5-10	m
20 – 50	Bt1	10YR 5/4	10YR 3/4	m2 sbk	- fi ms sp	3-5	f
50 – 90	Bw2	10YR 4/2	10YR 3/3	m2 sbk	- fi vs mp	-	-
90 – 125	Bw3	10YR 4/3	10YR 3/3	m3 sbk	- fi vs mp	-	-
125 – 150$^+$	BC	10YR 5/4	10YR 4/2	m2 sbk	- fr ss sp	-	-

Contd...

P10 (Kosi)							
0 – 25	Ap	10YR4/4	10YR3/4	gr	sh fr ss ps	5-10	m
25 – 50	A2	10YR 4/4	10YR3/4	f1sbk	- vfr ss sp	5-10	c
50 – 70	AC	10YR4/4	10YR3/4	f1sbk/sg	- vfr so so	5-10	-
70 – 90	C1	10YR4/4	10YR3/4	sg	- vfr so po	10-15	-
90 – 115	C2	7.5YR4/4	7.5YR3/4	sg	- vfr so po	10-15	-
115 – 150^{+}	C3	10YR4/4	10YR3/4	sg	- vfr so po	10-15	-

[a] f-fine, m-medium, c-coarse, 1-weak, 2- moderate, 3- strong, gr- granular, sbk- subangular blocky, M- massive, sg- single grain
[b]sh- slightly hard, h- hard, vfr- very friable, fr- friable, fi- firm, so, non-sticky, ss- slightly sticky, ms- moderately sticky, vs- very sticky, po, non-plastic, sp- slightly plastic, mp- moderately plastic
[c]f- few, c- common, m- many
*Few faint mottles (5YR 6/8) in Ap horizon, common fine distinct mottles (5YR 6/8 and 5YR 4/4) in Bt horizon

observed that the sand content increased and silt content decreased with depth in all the profiles except in P5 which showed a reverse trend. Clay content was relatively higher in B horizon as compared to A and C horizons. The coarser texture of surface horizon may be attributed to leaching of finer particles during intensive rainfall in this area, whereas comparatively finer texture observed in the sub-surface horizons is due to clay illuviation from upper horizons as well as *in-situ* clay formation through weathering of primary minerals (Dressalegn *et al.* 2014) leading to formation of argillic (Bt) / cambic (B_W) horizons. In addition, the argillic (Bt) horizons showed a higher fine clay / total clay ratio (table 3). Soils developed on broad valley terraces showed finer soil texture in both surface and sub-surface horizons which can be attributed to the frequent deposition of finer soil particles from upper topographic position (Kharlyngdoh *et al.* 2015) as well as illuviation of clay from surface to sub-surface horizons.

The soils were acidic in nature and their pH ranged from strongly acidic to neutral (5.1-6.6). The acidic nature of soils is due to leaching of bases during heavy rains and the area occurs on sloppy landscape. Soil pH showed an increasing trend with depth as a result of decreasing organic matter and leaching of bases toward the deeper soil layers. However, Sitlakhet profile (P1) exhibited the reverse trend where soil pH decreased with depth. Exchangeable acidity ranged from 0.07 to 3.26 cmol(p^+)kg^{-1} and generally decreased with soil depth except in Sitlakhet soil which showed a reverse trend. The exchangeable acidity was found to be negatively correlated with soil $pH_{(CaCl2)}$ (r = -0.57, $p < 0.01$).

The soils were non saline with EC values ranging from 0.03 to 0.45 dS m^{-1}. Soil base saturation ranged from 45.9 to 75.1% and was positively correlated with soil $pH_{(CaCl2)}$ (r = 0.73, $p < 0.01$). Calcium and Mg^{2+} were the dominant cations on exchangeable sites followed by K^+ and Na^+. Wide variations in CEC of the soils were observed in different profiles with values ranging from 1.6 to 19.4 cmol(p^+)kg^{-1}. The change in CEC within each profile showed different trends. Profiles P1 to P5 and P9 exhibited a decreasing trend of CEC with depth, while other profiles showed irregular CEC with depth. The variation in CEC between and within soil profiles can be attributed to the difference in soil texture, clay mineralogy and organic matter content (Reddy and Naidu 2016). Soil OC ranged from medium to high in surface horizons (0.54-2.91%) and decreased with soil depth. The obtained results revealed the effect of land use, land cover, soil texture and topographic position on OC content. The relatively low temperatures at higher altitudes along with high organic inputs resulting from grass and forest cover have enhanced OC accumulation on the hill top soil profiles. Broad valley profiles (P8 and P9) which are under intensive cultivation showed lower OC than the hill top soils. However, they were relatively similar to side slope profiles which are either uncultivated (P6) or cultivated for shorter time (P7). The lowest OC content was found on side slope (P4 and P5) and narrow valley (P10) areas due to their coarse texture (Augustin and Cihacek, 2016). Similar trend was also observed by Gorai *et al*. (2013).

Soil fertility

Soil available macronutrients and DTPA extractable micronutrients are presented in table 4. Available N, P and K ranged from 25.0 to 314.3, 1.89 to 50.4, 32.6 to 907.0 kg ha^{-1}, respectively. Available S varied from 0.1 to 21.7 mg kg^{-1}. Available macronutrients were higher in the surface horizons compared to sub-surface layers. They showed positive correlation with OC content and the highest correlation was observed with available N (r = 0.76, $p < 0.01$). Based on the critical limits of soil micro-nutrients suggested by Lindsay and Norvell (1978) *i.e.* 4.5, 1.0, 0.2 and 0.6 mg kg^{-1} for Fe, Mn, Cu and

Table 3. Physical and chemical characteristics of soil profiles

Depth (cm)	Particles size distribution Sand (%)	Silt (%)	Clay (%)	Texture class[a]	Fine clay/ Total clay	OC (%)	pH (1:2.5) H_2O	$CaCl_2$	EC (dS m^{-1})	CEC	Exch. cations Ca^{+2}	Mg^{+2}	K^+	Na^+	Exch. $Al^{+3}+H^+$	ECEC	BS (%)
										cmol(p^+) kg^{-1}							
P1 (Sitlakhet)																	
0 – 25	28.9	49.3	21.8	l	0.34	2.85	5.8	5.0	0.09	15.5	5.94	2.07	0.44	0.17	0.45	9.1	55.7
25 – 55	23.9	52.4	23.7	sil	0.39	2.08	5.4	4.7	0.08	15.0	5.67	1.91	0.23	0.13	0.47	8.4	52.9
55 – 85	22.4	44.0	33.6	cl	0.45	1.48	5.2	4.6	0.07	11.5	4.15	1.38	0.18	0.09	0.40	6.2	50.5
85 – 105	23.1	42.0	34.9	cl	0.51	1.14	5.1	4.5	0.07	11.1	4.58	0.69	0.17	0.07	1.62	7.1	49.6
105 – 135	21.2	38.4	34.4	cl	0.36	0.58	5.1	4.2	0.04	8.6	3.02	0.96	0.16	0.05	2.13	6.3	48.8
135 – 160$^+$	31.5	36.6	31.9	cl	0.29	0.20	5.1	4.3	0.05	7.9	2.61	0.82	0.14	0.05	3.26	6.9	45.9
P2 (Salla Routela)																	
0 – 15	21.4	55.5	23.1	sil	0.36	2.91	6.2	5.9	0.45	17.5	4.67	6.05	1.42	0.21	0.24	12.6	70.5
15 – 35	19.7	54.5	25.8	sil	0.46	1.12	6.3	6.1	0.27	13.6	3.54	4.77	0.81	0.13	0.21	9.5	67.9
35 – 65	19.2	43.2	37.6	cl	0.46	0.11	6.1	5.6	0.16	13.3	4.31	3.90	0.31	0.14	0.22	8.9	65.2
65 – 100	17.4	44.4	38.2	sicl	0.46	0.09	6.2	5.6	0.10	12.1	4.04	2.78	0.29	0.16	0.19	7.5	60.0
100 – 125	24.6	42.4	33.4	cl	0.38	0.05	6.3	5.8	0.10	11.1	3.75	2.65	0.25	0.15	0.15	7.0	61.5
125 – 150$^+$	32.3	36.9	30.8	cl	0.33	0.05	6.4	5.9	0.10	7.7	2.53	2.46	0.24	0.13	0.10	5.5	69.8
P3 (Chaubattia)																	
0 – 22	36.0	42.9	21.1	l	0.30	2.33	5.1	4.7	0.25	14.4	4.96	2.87	0.24	0.68	0.46	9.2	60.9
22 – 50	33.1	44.0	22.9	l	0.34	1.97	5.4	4.8	0.08	16.3	5.78	3.15	0.23	0.67	0.39	10.2	60.5
50 – 73	30.9	35.4	33.7	cl	0.45	1.26	5.6	5.1	0.07	10.8	4.79	1.78	0.18	0.09	0.31	7.2	63.3
73 – 90	32.0	37.8	30.2	cl	0.39	1.07	5.8	5.2	0.07	10.6	4.78	1.97	0.19	0.10	0.30	7.3	66.7
90 – 120	41.4	33.1	25.5	l	0.20	0.41	5.9	5.4	0.06	9.6	4.57	2.16	0.18	0.07	0.29	7.3	72.5
120-150$^+$	45.4	30.0	24.6	l	0.17	0.15	6.1	5.8	0.06	8.6	4.16	2.05	0.20	0.07	0.24	6.7	75.1
P4 (Dhamas)																	
0 – 15	65.0	24.1	10.9	sl	–	0.76	5.58	4.95	0.18	4.9	1.30	1.67	0.21	0.05	0.24	3.5	65.4
15 – 32	70.4	20.3	9.3	sl	–	0.23	5.64	5.08	0.13	4.3	1.17	1.53	0.14	0.06	0.18	3.1	67.8
P5 (Dhaili)																	
0 – 15	59.1	34.7	6.2	sl	–	0.78	5.1	4.5	0.27	5.4	2.01	0.67	0.46	0.15	0.21	3.5	60.5
15 – 52	51.4	40.2	8.4	l	–	0.42	5.3	4.5	0.05	4.2	1.75	0.54	0.19	0.12	0.18	2.8	61.5
52 – 82$^+$	56.0	40.2	3.8	sl	–	0.19	5.6	5.0	0.05	2.6	1.11	0.40	0.17	0.11	0.14	1.9	68.1
P6 (Kausani)																	
0 – 18	32.6	51.1	16.3	sil	0.31	1.12	5.2	4.5	0.16	13.5	5.74	2.05	0.35	0.13	0.43	8.7	61.1
18 – 45	19.5	59.2	21.3	sil	0.35	0.99	5.3	4.9	0.11	16.0	6.48	2.95	0.34	0.12	0.32	10.2	62.0
45 – 88	25.3	45.6	29.1	cl	0.39	0.98	5.4	5.1	0.06	15.2	6.28	3.15	0.23	0.11	0.3	10.1	64.2
88 – 120	42.3	37.1	20.6	l	0.29	0.28	5.4	5.1	0.06	13.2	6.02	2.13	0.21	0.11	0.28	8.8	64.0
120 - 150$^+$	50.4	31.0	18.6	l	0.25	0.09	5.8	5.6	0.06	9.0	4.43	1.52	0.19	0.09	0.25	6.5	69.4

Contd...

P7 (Majkhali)																
0 – 20	34.8	42.1	23.1	l	0.23	1.18	5.5	5.2	0.06	10.2	2.52	3.29	0.35	0.66	0.20	7.0	67.1
20 – 43	33.8	42.4	23.8	l	0.25	0.63	5.6	5.2	0.06	11.0	2.41	3.45	0.29	0.67	0.21	7.0	62.1
43 – 85	24.7	40.1	35.2	cl	0.27	0.47	5.7	5.1	0.06	11.8	3.21	2.96	0.38	0.74	0.40	7.7	61.6
85 – 120	29.8	37.6	32.6	cl	0.25	0.19	5.8	5.3	0.04	9.7	2.55	2.39	0.58	0.71	0.26	6.5	64.6
120-150+	45.7	24.7	29.6	scl	0.18	0.15	6.1	5.7	0.05	7.8	2.01	2.16	0.44	0.67	0.23	5.5	67.4
P8 (Hawalbagh)																	
0 – 15	15.6	56.5	27.9	sicl	0.35	1.15	6.1	5.6	0.18	12.5	3.49	4.57	0.39	0.27	0.23	9.0	69.8
15 – 37	10.6	48.1	41.3	sic	0.44	0.80	6.2	5.7	0.13	10.3	2.93	3.23	0.26	0.2	0.15	6.8	64.3
37 – 60	10.4	45.2	44.4	sic	0.44	0.77	5.8	5.4	0.09	10.2	2.29	3.77	0.23	0.25	0.16	6.7	64.0
60 – 88	11.0	41.6	47.4	sic	0.47	0.51	5.9	5.4	0.09	11.3	2.59	3.99	0.25	0.24	0.23	7.3	62.8
88 – 115	13.8	40.4	45.8	sic	0.53	0.39	6.0	5.6	0.07	11.3	2.87	3.87	0.27	0.23	0.09	7.3	64.1
115 – 150+	22.6	37.8	39.6	cl	0.39	0.23	6.2	5.7	0.03	8.9	2.56	3.16	0.24	0.14	0.09	6.2	68.4
P9 (Someshwar)																	
0 – 20	18.2	53.3	28.5	sicl	0.35	1.81	5.4	5.2	0.22	19.4	5.25	7.00	0.27	0.14	0.15	12.8	65.3
20 – 50	12.2	47.7	40.1	sic	0.44	0.47	6.0	5.7	0.15	17.1	5.10	5.51	0.25	0.14	0.15	11.2	64.3
50 – 90	14.8	44.7	40.5	sic	0.36	0.14	6.1	5.8	0.08	14.0	3.94	4.21	0.52	0.77	0.14	9.6	67.5
90 – 125	19.3	40.4	40.3	sic	0.35	0.09	6.3	5.8	0.05	13.5	3.24	4.19	1.03	0.79	0.12	9.4	68.8
125 - 150+	29.4	36.6	34.0	cl	0.33	0.07	6.3	6.0	0.06	11.5	3.15	3.56	0.85	0.65	0.12	8.3	71.5
P10 (Kosi)																	
0 – 25	76.7	13.4	9.9	sl	–	0.54	6.6	6.4	0.25	5.3	1.40	1.74	0.29	0.10	0.07	3.6	66.7
25 – 50	71.9	17.1	11.1	sl	–	0.14	6.6	6.0	0.18	6.0	1.62	2.01	0.21	0.08	0.07	4.0	65.8
50 – 70	83.6	11.8	4.7	ls	–	0.05	6.5	6.1	0.09	2.6	0.67	0.93	0.15	0.05	0.07	1.9	69.0
70 – 90	78.0	15.4	6.6	ls	–	0.03	6.3	5.6	0.06	3.0	0.94	0.67	0.13	0.10	0.07	1.9	61.1
90 – 115	78.7	13.6	7.7	ls	–	0.13	6.2	5.5	0.05	3.4	1.21	0.80	0.14	0.07	0.08	2.3	64.9
115 – 150+	82.6	12.8	4.6	ls	–	0.03	6.3	5.7	0.05	1.6	0.53	0.40	0.12	0.06	0.08	1.2	69.4

[a]l- loam, sil- silty loam, cl- clay loam, sicl- silt clay loam, sic- silty clay, sl- sandy loam, ls- loamy sand, scl- sandy clay loam

Table 4. Depth distribution of soil macro and micronutrients in soil profiles

Profile	Available macronutrients				DTPA extractable micronutrients			
	N	P	K	S	Fe	Mn	Cu	Zn
	(kg ha^{-1})			(mg kg^{-1})	(mg kg^{-1})			
Sitlakhet (P1)								
0 – 25	314.3	36.9	283.8	9.6	58.0	26.2	1.59	0.99
25 – 55	234.2	18.8	141.6	4.7	58.2	15.8	1.03	0.75
55 – 85	196.5	8.3	87.8	1.6	57.1	12.4	0.93	0.23
85 – 105	142.2	4.4	82.3	0.3	34.8	6.4	0.81	0.16
105 – 135	117.1	3.7	66.6	0.1	30.8	2.8	0.71	0.12
135 – 160^{+}	33.5	3.4	71.8	0.1	16.8	1.7	0.47	0.05
Salla Routela(P2)								
0 – 15	284.9	50.4	907.0	21.7	26.8	61.1	2.45	5.60
15 – 35	129.6	30.8	494.9	12.0	12.9	27.1	1.62	0.74
35 – 65	50.2	5.4	143.4	7.4	3.7	16.2	0.98	0.17
65 – 100	41.8	5.6	122.7	4.6	3.7	9.3	1.04	0.18
100 – 125	45.4	5.3	115.7	4.3	3.1	9.3	0.78	0.15
125 – 150^{+}	35.4	3.3	95.3	0.8		1.6	2.8	0.51
0.15								
P3 (Chaubattia)								
0 – 22	297.5	14.6	96.5	8.4	43.6	10.7	2.66	0.61
22 – 50	188.9	10.8	62.9	2.3	27.9	7.3	1.00	0.19
50 – 73	117.1	3.7	61.4	1.4	17.7	4.0	0.64	0.13
73 – 90	154.7	2.6	70.0	1.9	17.9	3.6	0.73	0.20
90 – 120	80.1	2.5	89.5	1.2	8.0	1.3	0.31	0.09
120-150^{+}	25.4	2.1	80.4	0.7		6.4	1.0	0.12
0.08								
P4 (Dhamas)								
0 – 15	221.6	15.5	101.5	6.5	37.8	50.3	1.33	2.10
15 – 32	146.4	13.3	34.3	2.0	12.3	17.8	1.12	0.77
P5 (Dhaili)								
0 – 15	205.6	13.5	363.5	5.8	23.6	53.6	2.84	2.55
15 – 52	152.2	10.6	90.2	1.5	12.5	30.8	3.22	1.69
52 – 82^{+}	25.1	7.1	53.5	0.2	5.5	15.3	1.97	0.78
P6 (Kausani)								
0 – 18	267.6	11.4	151.7	2.8	46.1	71.4	2.31	1.33
18 – 45	230.0	7.0	108.2	1.8	34.8	52.0	1.79	1.13
45 – 88	171.4	9.1	107.2	1.0	26.6	35.7	1.19	0.77
88 – 120	104.5	4.9	86.2	0.6	6.6	15.2	0.36	0.21
120 – 150^{+}	85.1	3.5	90.6	0.5	4.2	10.6	0.31	0.15
P7 (Majkhali)								
0 – 20	271.4	20.2	135.3	8.2	30.5	31.4	2.25	0.79
20 – 43	154.7	14.1	110.6	2.4	22.2	22.9	1.71	0.25
43 – 85	129.6	4.8	127.6	2.0	40.4	10.7	1.43	0.19
85 – 120	41.8	5.1	75.6	1.0	38.9	7.6	1.35	0.17
120 – 150^{+}	34.5	3.9	70.7	0.6	15.6	4.4	0.92	0.11
P8 (Hawalbagh)								
0 – 15	296.9	26.0	254.5	10.2	38.4	54.1	2.10	2.25
15 – 37	271.8	12.2	131.2	3.8	15.1	20.1	1.61	0.27
37 – 60	259.2	9.9	128.7	2.7	22.0	17.3	1.51	0.17
60 – 88	234.2	3.7	148.3	12.1	10.8	8.4	0.93	0.11
88 – 115	217.4	3.9	143.6	11.9	6.8	7.5	0.60	0.20
115 – 150^{+}	171.4	1.9	137.7	6.1	2.9	4.7	0.53	0.23
P9 (Someshwar)								
0 – 20	284.0	15.8	180.8	14.4	83.6	45.6	3.62	2.29
20 – 50	133.8	7.9	190.9	2.9	17.2	34.1	1.45	0.26
50 – 90	46.0	6.6	173.9	2.2	10.3	15.2	1.17	0.25
90 – 125	37.6	8.2	137.1	1.8	10.4	14.5	1.25	0.30
125 – 150^{+}	34.8	5.4	90.4	1.2	7.3	6.4	0.74	0.27

contd...

P10 (Kosi)								
0 – 25	121.3	45.2	109.2	7.6	3. 4	7.4	0.81	1.45
25 – 50	83.6	22.3	75.7	1.0	3.8	3.1	0.47	0.17
50 – 70	54.4	20.5	34.7	0.3	5.3	3.0	0.31	0.21
70 – 90	34.8	16.5	40.6	0.2	4.7	1.2	0.18	0.12
90 – 115	50.2	15.6	37.1	0.1	8.5	4.5	0.27	0.21
115 – 150+	29.3	26.2	32.6	0.1	5.0	2.5	0.15	0.12

Table 5. Correlations between soil macro and micronutrients and different soil properties

Parameter	N	P	K	S	Fe	Mn	Cu	Zn
Sand	-0.34*	0.29	-0.30*	-0.33*	-0.31*	-0.19	-0.25	0.01
Silt	0.55**	-0.04	0.47**	0.44**	0.50**	0.53*	0.57**	0.30*
Clay	0.06	-0.45**	0.07	0.15	0.03	-0.18	-0.12	0.29
OC	0.75**	0.46**	0.48**	0.52**	0.76**	0.41**	0.46**	0.49**
pH(H_2O)	-0.43**	0.27	0.10	0.08	-0.61**	-0.33*	-0.43**	-0.11
CEC	0.48**	0.02	0.42**	0.46**	0.51**	0.38**	0.36**	0.21

*, ** significant at *P<0.05* and *P<0.01*, respectively.

Zn, respectively, the DTPA extractable micronutrients were found to be sufficient in the studied soils. The DTPA-Fe ranged from 1.1 to 83.6 with mean value of 20.5 mg kg^{-1}, DTPA-Mn 1.0 – 71.4 (mean 17.7 mg kg^{-1}), DTPA-Cu 0.12 – 3.62 (mean 1.18 mg kg^{-1}) and DTPA-Zn 0.05 – 5.60 (mean 0.64 mg kg^{-1}). The available micronutrient content decreased with soil depth and showed a positive correlation with OC content (Table 5). Sharma *et al.* (2003) reported that soluble chelating agents released upon the decomposition of soil organic matter (SOM) significantly increase the solubility and availability of micronutrients in soil. In addition, SOM plays an important role in shaping the depth distribution pattern of micronutrients in soil (Meliyo *et al*. 2015). The higher level of soil micronutrients in soil surface compared to sub-surface layers can be attributed to the greater decomposition of SOM, crop residues and applied organic manures in soil surface which result in higher levels of micronutrients (Yadav 2011). In addition, plant cycling may play an important role in controlling depth distribution of soil micronutrients. Nutrients absorbed through roots from the lower soil layers are re-deposited on the surface through crop residues and falling leaves (Jiang *et al*. 2009).

Soil Classification

The soils in the study area qualified to *udic* moisture regime based on the metrological data (MAT < 22, MST – MWT > 5 and the soils are not dry for as long as 90 cumulative days per year as shown in fig. 2). Based on soil morphological, physical and

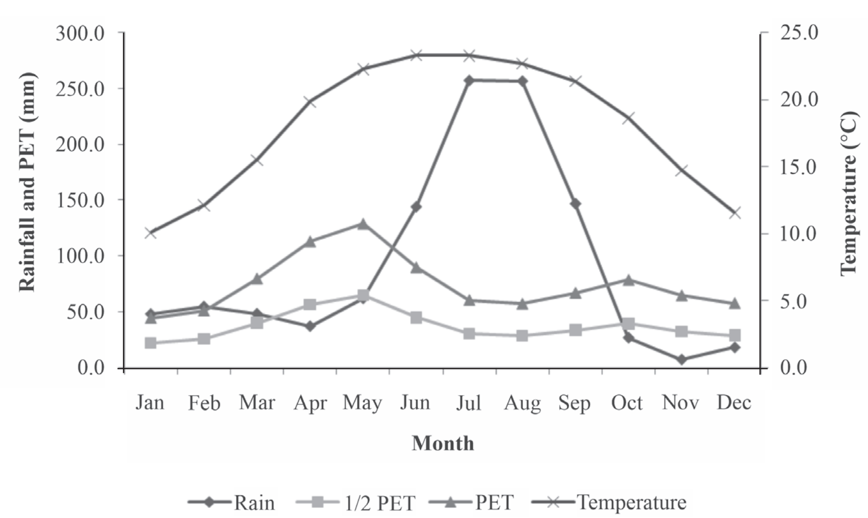

Fig. 2. Climatic moisture balance of the study area in Almora district

chemical characteristics, the studied soil profiles were classified under three orders *i.e.* Entisol, Inceptisol and Alfisol. Profiles P4, P5 and P10 were classified as Entisols as they showed no diagnostic epipedon or endopedon. Kosi (P10) soils which occur on nearly level topography in the narrow valley showed irregular decrease in organic carbon between 25 and 125 cm and hence keyed out as Fluvents in suborder level and placed under Udifluvents at great group level due to the presence of udic soil moisture regime. Further, these soils were classified as Typic Udifluvents at subgroup level. Dhamas (P4) and Dhaili (P5) were classified under Udorthents at great group level. At subgroup level, Dhamas soils (P4) were placed under Lithic Udotherrnts due to the presence of lithic contact at less than 50 cm depth from soil surface and Dhaili soils (P5) were found to belong to Typic Udorthents. Majkhali soils (P7) showed ochric epipedon and had well developed cambic endopedon. The increase in fine clay to total clay ratio in B horizon from the surface horizon was not sufficient (<1.2 times) to qualify for argillic endopedon and hence was classified under Inceptisol soil order and keyed out as Udepts at suborder level. The soil base saturation is more than 60%, hence qualifies as Eutrudepts at great group level and due to the absence of free carbonate throughout the profile the soils were placed under Dystric Eutrudepts at subgroup level. Soil profiles P1, P2, P3, P6, P8 and P9 had well developed argillic horizon and were classified as Alfisols and keyed out as Hapludalfs at great group level. Someshwar soils (P9) which remains saturated with water for 20 or more consecutive days were classified as Oxyaquic Hapludalfs. Sitlakhet soils (P1) exhibited a base saturation less than 60% and hence classified as Ultic Hapludalfs. After mixing the upper 18 cm of Salla Routela (P2) and Chaubattia (P3) soils, all the colour requirements of mollic epipedon were met and hence these soils have been classified as Mollic Hapludalfs. Soils of Kausani (P6) and Hawalbagh (P8) were classified as Typic Hapludalfs.

Role of topography on soil formation

In general, the high rainfall existing in the hilly area is favourable for high leaching which is reflected in low base saturation and acidic pH of the studied soils. In Almora region, topographic position was found to have an important role on soil genesis and its characterization. The soils of hill top and broad valley were deeper and more developed with thicker B horizon. On the other hand, soil profiles developed on steeper slopes were more susceptible to erosion which restricts soil development and resulting in thinner solum thickness. The soils on broad valley showed the highest clay content because of frequent deposition of fine particles from upper topographic positions. However, the narrow valley soils were deep with A-C profile, and showed the highest sand content which can be attributed to the washing out of fine soil particles from the profile during the time of flood. The hill top soils were highest in organic carbon content due to forest litter deposition along with prevailing lower temperature which decreases the decomposing rate of organic matter.

Conclusions

Soils of different landform units in Almora region showed varying degree of profile development and pedological characteristics. The variations in soil characteristics and the development of different types of soil were mostly due to the effects of topography, vegetation and climatic conditions of studied area. The obtained data can be used for developing effective land use planning for sustainable land management practices and overall development of this hilly region.

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