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Physical Properties of Soils in Relation to Forest Composition in Moist Temperate Valley Slopes of the Central Western Himalaya

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ABSTRACT : The present study was undertaken in moist temperate forest of Mandal-Chopta area in the Garhwal region of Uttarakhand, India. The aim of the present study was to assess the physical properties of soils in relation to the forest structure and composition. Twelve forest types according to the altitude, slope aspect and species compositions were selected for the study. Physical properties of soil *i.e.*, soil colour, soil texture (per cent of sand, silt and clay), moisture content, water holding capacity, porosity, bulk density (gm/cm^3) and void ratio were analyzed for three different depths *viz*., (i) 'upper' (0-10 cm), (ii) 'middle' (11-30 cm) and (iii) 'lower' (31-60 cm) in all the selected forest types. Phytosociological and diversity parameters *viz*. total basal cover (Gha^{-1}), stem density (Nha^{-1}), tree species richness, Simpson concentration of dominance and Shannon-Wiener diversity index were also calculated for each forest type. This study also provides the comparisons between the results of physical analysis of the present study with numerous other previous studies in the temperate Himalayan region of the Uttarakhand.

Keywords : Tree diversity, Tree density, Soil moisture, Porosity, Bulk density, Altitude.

INTRODUCTION

The growth and reproduction of forest cannot be understood without the knowledge of soil. Forest soil is the medium that produces nature's most significant association of plants and animals, distinguished by immense practical usefulness and indefinite richness of pattern. The soil and vegetation have a complex interrelation, because they develop together over a long period of time, the selective absorption of nutrient elements by different tree species and their capacity to return them to the soil brings about changes in soil properties (Singh et al., 1986). The vegetation influences the physical properties of soil to a great extent. The vegetation improves the soil structure, infiltration rate, water holding capacity, hydraulic conductivity and aeration (Iiorkar and Toley, 2001). The effects of the textural properties of soil are frequently reflected in the composition and the rate of growth of forest vegetation. The relation between soil and vegetation has been an important aspect for natural ecosystem. Braun-Blanquet (1934) has pointed out the close relationship between the natural evolution of the vegetation and the development of the soil. The composition of forest soil changes constantly by the growth of trees and ground cover vegetation, activity of organisms and effect of climatic agents. Under the influence of these factors, mineral and organic matter undergoes gradual decomposition or disintegration.

Moreover, different tree species can differ significantly in their influence on soil properties as well as soil fertility (Augusto et al., 2002). The adequate theoretical and practical knowledge of various forest soils and the complex relationship between the life of various trees and other plants of the forest is therefore necessary to study. Hence, the underground life of a forest is the key for adequate understanding of its above-surface life. Therefore, foresters are slowly coming to realize that knowledge of

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soils is essential to know the silviculture and management of the forests. The importance of soil characteristics is more obvious in reforestation. The ultimate aim of the reforestation is not to obtain the mere survival of trees, but the production of the highest possible yields of sound and valuable timber. This can be accomplished only by a careful matching of soil conditions and tree species.

Himalayan forests play an important role in tempering the inclemency of the climate, in cooling and purifying the atmosphere, in protecting the soil, in holding the hill slopes in position and in buffering up huge reserves of soil nutrients. The Garhwal Himalaya has vast variations in the climate, topography and soil conditions, which form a very complex ecosystem. The knowledge of physical properties of soils of different forest types of Garhwal Himalaya is meager. Recently works on phytosociology and soil-vegetation interrelationship in the different forest types of the region is done by Sharma et al. (2009a, 2009b, 2010a, 2010b, 2010c) and Gairola (2010). Keeping the aforesaid facts in view, the aim of the present study was to assess the physical properties of soils in relation to the forest structure and composition in different forest types of moist temperate Mandal-Chopta forest area.

Material and methods

Study area

The present study was conducted in Mandal-Chopta forest area, which forms a large (nearly 1100 ha), prestigious, and botanically valuable reserve complex (Trishula Reserve forest of Kedarnath forest division) in the Garhwal region (western Himalaya) of Chamoli district of Uttarakhand state, India (Figure 1). It occurs at 30° 27.560' N latitude and 79° 15.234' E longitude along an altitudinal gradient of 1500 m asl to 2900 m asl. It is a rich moist temperate forest situated 12 km away from the district headquarter, Gopeshwar. Recently Gairola et al. (2010) have recorded 338 species (334 Angiosperms and 4 Gymnosperms) belonging to 93 families (91 Angiosperms and 2 Gymnosperms) and 249 genera (246 Angiosperms and 3 Gymnosperms) from the study area. The study area is characterized by

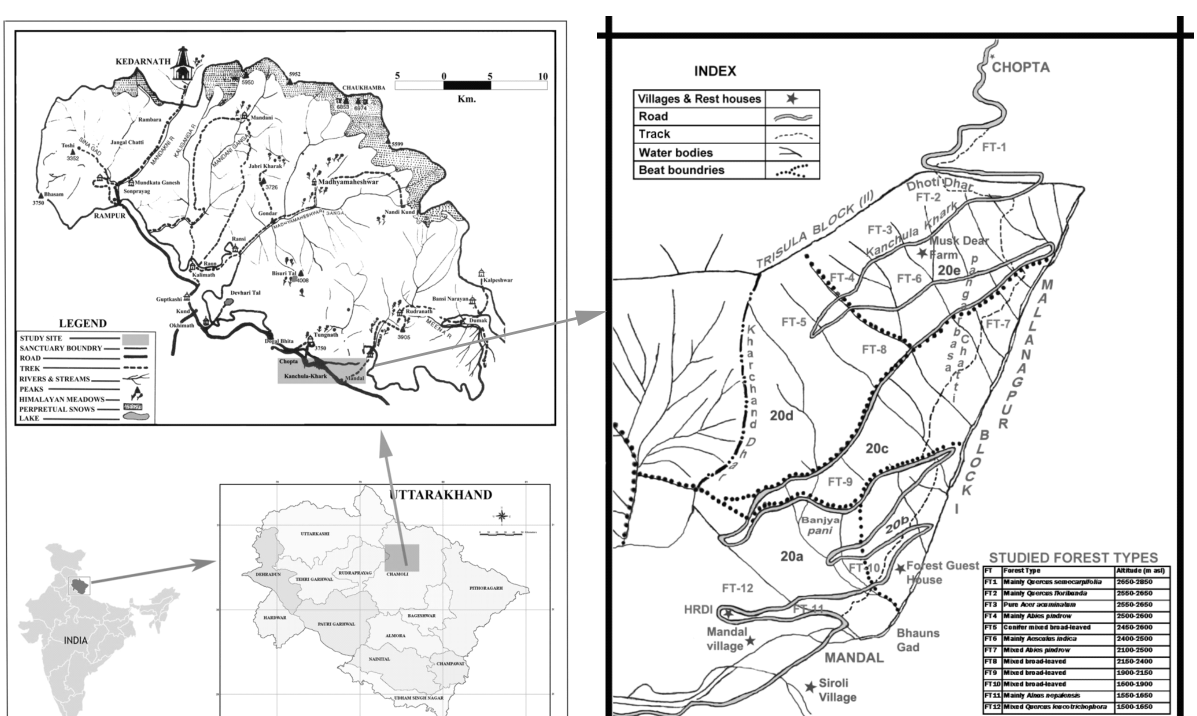

Fig. 1. Map of the study area.

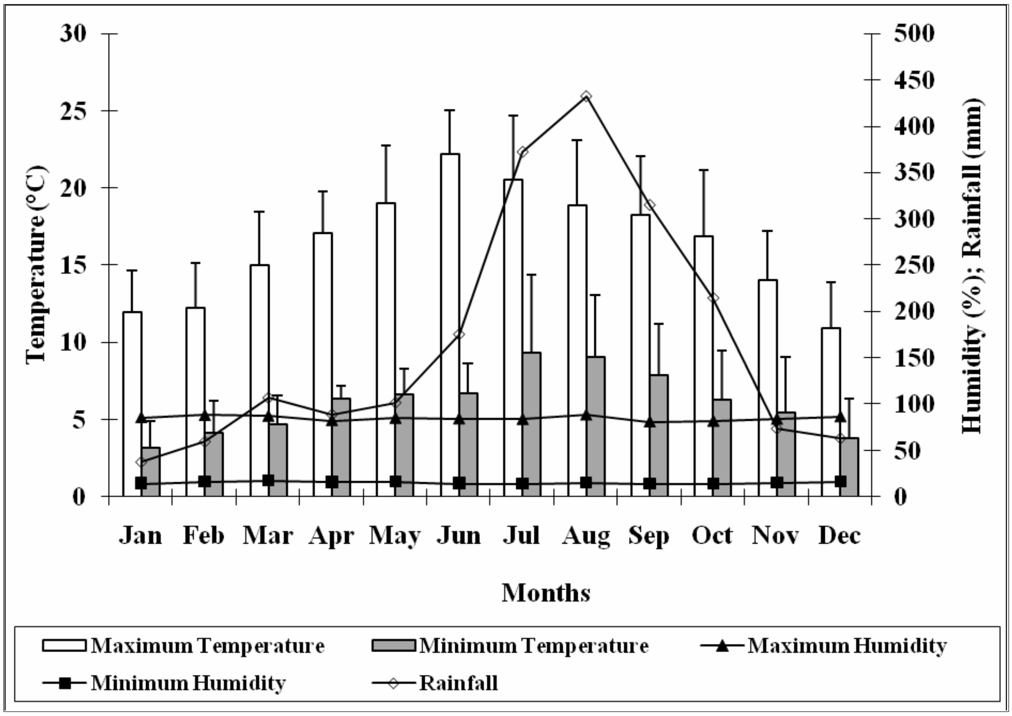

Fig. 2. Meteorological data of the study area (1998-2007) (Source: Uttarakhand Forest Department).

undulating topography with gentle slopes on northern, northeastern and northwestern faces and somewhat steep slopes on southern and southwestern directions. The soil types found in the region are brown and black forest soils and podozolic soils. Soils are generally gravelly and large boulders are common in the area. Numerous high ridges, deep gorges and precipitous cliffs, rocky crages and narrow valleys are part of the topography of the region. The topography of the area has also been influenced by landslides, which are common during rainy season. Geologically, the rocks in the study sites are complex mixture of mainly sedimentary, low grade metamorphosed with sequence capped by crystalline nappe. The study area lies in the central axis of the great Himalaya, which consists of belts of metamorphic rocks; includes gneisses, granites and schists, known as the central crystalline groups. Most of the rocks in the study area are fine to coarse-grained schists, all very much interleaved. Most of the schist is biotite mica, quartz and feldspar but the presence of a certain amount of garnet mica, schist is indicative of a low to moderate degree of metamorphism. Meteorological details (1998-2007) of the study are given in Figure 2. Mean annual maximum and minimum temperature were recorded as 16.41±3.60 °C and 6.14±1.98 °C respectively. Mean annual rainfall was recorded as 2044.47±476.01 mm. Mean Relative humidity round the year ranged from 15% to 86%.

Sampling and data analysis

During the reconnaissance survey of the study area twelve forest types according to altitude, slope aspect and species compositions were selected for the study (Table 1). Each forest type was named according to the composition of dominant tree species as per Prakash (1986), *viz.*, ≥ 75% as pure; 50-75% as mainly; 25-50% as mixed and < 25% miscellaneous. Physiographic factors *i.e.*, altitude, and aspect across different forest types were measured by GPS (Garmin, Rino-130).

Vegetation analysis

The composition of the forest types was analyzed by using nested quadrat method as per Kent and Coker

Table 1. Details of the forest types studied

FT	Forest Type* (as per Prakash, 1986)	SA (facing)	Altitude (m asl)	Tree species#
FT1	Mainly *Quercus semecarpifolia*	E	2850-2650	***Quercus semecarpifolia,*** *Abies pindrow, Lyonia ovalifolia, Rhododendron arboreum, Sorbus cuspidata.*
FT2	Mainly *Quercus floribunda*	NE	2650-2550	***Quercus floribunda,*** *A. pindrow, L. ovalifolia, Persea duthiei, R. arboreum.*
FT3	Pure *Acer acuminatum*	S	2650-2550	***Acer acuminatum,*** *A. pindrow, Aesculus indica, Diospyros montana, L. ovalifolia, Neolitsea pallens, P. duthiei, Quercus floribunda, R. arboreum.*
FT4	Mainly *Abies pindrow*	NE	2600-2500	***A. pindrow,*** *A. acuminatum, P. duthiei, Q. floribunda, R. arboreum.*
FT5	Conifer mixed broad-leaved	NE	2600-2450	***A. pindrow, A. acuminatum, A. indica,*** *Corylus jacquemontii, L. ovalifolia, P. duthiei, R. arboreum, Taxus baccata.*
FT6	Mainly *Aesculus indica*	NE	2500-2400	***A. indica,*** *A. pindrow, Betula alnoides, P. duthiei, Q. floribunda.*
FT7	Mixed *Abies pindrow*	S	2500-2100	***A. pindrow,*** *A. indica, B. alnoides, Carpinus viminea, Daphniphyllum himalense, Dodecademia grandiflora, Euonymus tingens, L. ovalifolia, N. pallens, P. duthiei, Q. floribunda, R. arboreum.*
FT8	Mixed broad-leaved	NE	2400-2150	***P. duthiei, Q. floribunda,*** *A. pindrow, Abies spectabilis, A. indica, B. alnoides, Buxus wallichiana, C. viminea, D. himalense, Diospyros montana, Fraxinus micrantha, Juglans regia, L. ovalifolia, N. pallens, Quercus leucotrichophora, R. arboreum.*
FT9	Mixed broad-leaved	NE	2150-1900	***P. duthiei, D. himalense, Q. leucotrichophora,*** *A. nepalensis, B. alnoides, C. viminea, D. montana, L. ovalifolia, N. pallens, Pyrus pashia, R. arboreum, Symplocos paniculata, Ulmus wallichiana.*
FT10	Mixed broad-leaved	N	1900-1600	***D. himalense, Q. leucotrichophora, B. alnoides,*** *C. viminea, Cupressus torulosa, D. montana, Fraxinus micrantha, L. ovalifolia, Persea odoratissima, P. pashia, R. arboreum, U. wallichiana.*
FT11	Mainly *Alnus nepalensis*	NE	1650-1550	***A. nepalensis,*** *Ficus roxburghii, P. odoratissima, Pinus roxburghii, P. pashia, R. arboreum.*
FT12	Mixed *Quercus leucotrichophora*	NE	1650-1500	***Q. leucotrichophora,*** *A. nepalensis, F. roxburghii, L. ovalifolia, Myrica esculenta, P. pashia, R. arboreum, Toona cilata, U. wallichiana.*

Abbreviations: SA= Slope Aspect; E=East, NE-North-East; S= South; N= North.
* = Forest types used as FT1 to FT12 in the successive tables; # = Species in bold are dominant tree species.

(1992). Trees (≥ 10 cm dbh) were analyzed by 10 m × 10 m sized quadrats as proposed by Curtis and McIntosh (1950) and Phillips (1959). The basal cover was calculated by dividing the square of Cbh (circumference at breast height *i.e.* 1.37 m) with 4π. The basal cover was multiplied with respective densities of the species to obtain total basal cover (Gha^{-1}). For each species, values of frequency, density and abundance were calculated following Curtis and McIntosh (1950). The importance value index (IVI) was calculated by summing up relative density, relative frequency and relative dominance, following Phillips (1959). Species richness (SR) was simply taken as a count of total number of species in that particular forest type. Shannon-Wiener diversity index was calculated as per Shannon and Weaver (1963) and Concentration of dominance (Cd) was calculated as per Simpson (1949):

$$\overline{H} = -\sum_{i=1}^{s}\left(\frac{N_i}{N}\right)\log_2\left(\frac{N_i}{N}\right)$$

$$Cd = \sum_{i=1}^{s} \frac{N_i}{N}^2$$

Where, $\overline{H}$ is Shannon-Wiener diversity index, N_i is IVI of a species, N is total IVI of all the species, Cd is Concentration of dominance.

Soil sampling and analysis

Composite soil samples were collected from three different depths *viz.*, (i) 'upper' (0-10 cm), (ii) 'middle' (11-30 cm) and (iii) 'lower' (31-60 cm) for assessing the physical properties of the soil in all the selected forest types. The soil tests were conducted at Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun, India. Soil texture was analysed by Hydrometer method (Black, 1965). Percentages of soil separate *viz.*, fine sand, coarse sand, silt and clay were calculated and textural classes were determined using Triangular Diagram as per U.S.D.A system. The soil colour determination was done with the help of Munsell Soil Colour Chart in terms of Hue, Value and Chroma characteristics. The water holding capacity (WHC) of the soil samples was determined by the method suggested by Mishra (1968). The moisture content of the soil samples was calculated as per following standard method given by Mishra (1968). The Bulk density of soil was measured by taking an undisturbed block of soil (by metal cylinder) for determining its volume. The exact volume of the soil taken by a metal cylinder was determined by measuring the cylinder volume. The soil was then dried and weighed. The Bulk Density was calculated as: $\text{Bulk Density}\,(\rho_b) = \frac{W}{V}\,\text{gm/cm}^3$, Where, W is the oven dried weight of soil and V is the volume of the soil core. Porosity (P) is expressed in per cent by volume and was calculated from the bulk density (BD) and particle density (PD) of soil as per Brady (1996). Soil porosity was determined as; $\text{Soil Porosity}\,(f_r) = \left(1.0 - \frac{\text{Bulk Density}}{\text{Particle Density}}\right) \times 100$ and Void Ratio (e) was calculated as; $\text{Void Ratio}\,(e) = \frac{\text{Particle Density}}{\text{Bulk Density}} - 1.0$. A one-tailed Pearson correlation coefficient was calculated between various soil physical parameters and phytosociological parameters using SPSS-16 package.

Table 2. Values of forest composition and diversity parameters

FT	Gha^{-1}	Nha^{-1}	SR	Cd	$\overline{H}$
FT1	58.25	600	5	0.413	1.6
FT2	72.51	493	5	0.33	1.95
FT3	62.41	1180	9	0.467	1.74
FT4	41.25	380	5	0.461	1.45
FT5	46.39	627	8	0.175	2.7
FT6	86.56	580	5	0.399	1.72
FT7	84.03	1390	12	0.144	3.19
FT8	76.83	1200	16	0.129	3.33
FT9	37.37	1007	13	0.135	3.14
FT10	84.25	1470	13	0.139	3.09
FT11	32.77	520	7	0.458	1.69
FT12	35.08	990	10	0.253	2.43

Abbreviations: Nha^{-1}= Trees per hectare; Gha^{-1}= Basal area per hectare (m^2ha^{-1}); SR= Species Richness; $\overline{H}$= Shannon-Wiener Diversity Index; Cd= Simpson Concentration of dominance.

Results and discussion

The structure of soil and its physical constitution like size and shape of soil particles in the soil classify the nature of soil (Jongmans et al., 2001). The physical properties of soil help to control erosion and increase the soil fertility (Sharma and Bhatia, 2003). The physico-chemical properties are responsible for determining the nutrient status of the soil, which vary according to the nature of the climate, parent material, physiographic position and the vegetation (Behari et al., 2004). The information about dominant and associated tree species in different forest types is placed in Table 1. Results of forest composition and diversity analysis are given in Table 2. The values of soil texture at various depths in the different forest types are given in Table 3 and of soil colour are given in Table 4. The results of moisture content and water holding capacity are placed in Table 5. The values of Pearson correlation coefficients between forest composition and soil physical parameters are given in Table 6. Comparison between physical properties of soils at different altitudes and in various forest types of different parts of Uttarakhand Himalaya (earlier reported values) and their

Table 3. Variation in soil texture of different forest types at different depths

Forest Type	Soil Layer	Depth (cm)	Clay (%)	Silt (%)	Fine Sand (%)	Coarse Sand (%)	Texture Type
FT1	Upper	0-10	16	40	42	2	Loam
	Middle	11-30	18	39	41	2	Loam
	Lower	31-60	20	37	42	1	Loam
		Average ±SD	18.0±2.0	38.7±1.5	41.7±0.6	1.7±0.6	Loam
FT2	Upper	0-10	19	35	44.5	1.5	Loam
	Middle	11-30	16	39	43	2	Loam
	Lower	31-60	20	32	47	1	Loam
		Average ±SD	18.3±2.1	35.3±3.5	44.8±2.0	1.5±0.5	Loam
FT3	Upper	0-10	20	30	48.5	1.5	Loam
	Middle	11-30	19	32	47	2	Loam
	Lower	31-60	20	37	40.5	2.5	Loam
		Average ±SD	19.7±0.6	33.0±3.6	45.3±4.3	2.0±0.5	Loam
FT4	Upper	0-10	20	36	42.5	1.5	Loam
	Middle	11-30	20	37	38	5	Loam
	Lower	31-60	19	35	40	6	Loam
		Average ±SD	19.7±0.6	36.0±1.0	40.2±2.3	4.2±2.4	Loam
FT5	Upper	0-10	20	30	42	8	Loam
	Middle	11-30	20	30	46	4	Loam
	Lower	31-60	15	34	46	5	Loam
		Average ±SD	18.3±2.9	31.3±2.3	44.7±2.3	5.7±2.1	Loam
FT6	Upper	0-10	16	30	48	6	Sandy Loam
	Middle	11-30	18	27	47	8	Sandy Loam
	Lower	31-60	15	23	52	10	Sandy Loam
		Average ±SD	16.3±1.5	26.7±3.5	49.0±2.6	8.0±2.0	Sandy Loam
FT7	Upper	0-10	17	29	46	8	Sandy Loam
	Middle	11-30	14	26	54	6	Sandy Loam
	Lower	31-60	14	28	50	8	Sandy Loam
		Average ±SD	15.0±1.7	27.7±1.5	50.0±4.0	7.3±1.2	Sandy Loam
FT8	Upper	0-10	20	26	50	4	Sandy Clay Loam
	Middle	11-30	18	25	51	6	Sandy Loam
	Lower	31-60	16	25	55	4	Sandy Loam
		Average ±SD	18.0±2.0	25.3±0.6	52.0±2.6	4.7±1.2	Sandy Loam
FT9	Upper	0-10	20	29	46	5	Loam
	Middle	11-30	19	25	49	7	Sandy Loam
	Lower	31-60	20	26	46	8	Sandy Clay Loam
		Average ±SD	19.7±0.6	26.7±2.1	47.0±1.7	6.7±1.5	Sandy Loam
FT10	Upper	0-10	16	26	52	6	Sandy Loam
	Middle	11-30	19	29	48	4	Loam
	Lower	31-60	16	24	54	6	Sandy Loam
		Average ±SD	17.0±1.7	26.3±2.5	51.3±3.1	5.3±1.2	Sandy Loam
FT11	Upper	0-10	13	21	62	4	Sandy Loam
	Middle	11-30	14	22	60	4	Sandy Loam
	Lower	31-60	15	23	57	5	Sandy Loam
		Average ±SD	14.0±1.0	22.0±1.0	59.7±2.5	4.3±0.6	Sandy Loam
FT12	Upper	0-10	20	24	50	6	Sandy Clay Loam
	Middle	11-30	18	24	54.5	3.5	Sandy Loam
	Lower	31-60	17	23	56	4	Sandy Loam
		Average ±SD	18.3±1.5	23.7±0.6	53.5±3.1	4.5±1.3	Sandy Loam

Table 4. Variation in colour of the soils at different depths in different forest types

Forest Type	Soil Layer	Depth (cm)	Hue	Value	Chroma	Colour Type
FT1	Upper	0-10	10YR	4	4	Dark yellowish brown
	Middle	11-30	10YR	5	8	Yellowish brown
	Lower	31-60	10YR	6	6	Brownish yellow
FT2	Upper	0-10	10YR	4	4	Dark yellowish brown
	Middle	11-30	10YR	5	8	Yellowish brown
	Lower	31-60	10YR	4	4	Dark yellowish brown
FT3	Upper	0-10	10YR	5	4	Yellowish brown
	Middle	11-30	10YR	5	6	Yellowish brown
	Lower	31-60	10YR	6	6	Brownish yellow
FT4	Upper	0-10	10YR	4	4	Dark yellowish brown
	Middle	11-30	10YR	5	6	Yellowish brown
	Lower	31-60	10YR	6	6	Brownish yellow
FT5	Upper	0-10	10YR	5	6	Yellowish brown
	Middle	11-30	10YR	5	6	Yellowish brown
	Lower	31-60	10YR	6	6	Brownish yellow
FT6	Upper	0-10	10YR	3	3	Dark brown
	Middle	11-30	10YR	5	4	Yellowish brown
	Lower	31-60	10YR	5	6	Yellowish brown
FT7	Upper	0-10	10YR	5	3	Brown
	Middle	11-30	10YR	6	4	Light yellowish brown
	Lower	31-60	10YR	7	4	Very pale brown
FT8	Upper	0-10	10YR	3	2	Very dark yellowish brown
	Middle	11-30	10YR	3	2	Very dark yellowish brown
	Lower	31-60	10YR	3	3	Dark brown
FT9	Upper	0-10	10YR	3	2	Very dark yellowish brown
	Middle	11-30	10YR	5	4	Yellowish brown
	Lower	31-60	10YR	3	2	Very dark yellowish brown
FT10	Upper	0-10	10YR	4	3	Dark brown
	Middle	11-30	10YR	5	3	Brown
	Lower	31-60	10YR	5	3	Brown
FT11	Upper	0-10	10YR	4	3	Dark brown
	Middle	11-30	10YR	4	4	Dark yellowish brown
	Lower	31-60	10YR	5	3	Brown
FT12	Upper	0-10	10YR	5	4	Yellowish brown
	Middle	11-30	10YR	5	4	Yellowish brown
	Lower	31-60	10YR	5	3	Brown

comparison with the values of the soils of the study area have been shown in Table 7. The results of physical properties of the soil of present study are well within the reported ranges of values recorded in similar forest types at same altitudes elsewhere in the Uttarakhand Himalaya (Table 7).

Soil texture

Soil texture is an important soil characteristic, because

Table 5. Moisture content and water holding capacity at various depths in different forest types

Forest Type	Moisture Content (%)				Water Holding Capacity (%)			
	Depth (cm)			Average ±SD	Depth (cm)			Average ±SD
	0-10	11-30	31-60		0-10	11-30	31-60	
FT1	36.0	40.5	42.0	39.50±3.12	94.21	110.00	95.50	99.91±8.75
FT2	44.0	36.0	31.5	37.17±6.33	96.68	83.74	60.10	80.19±18.53
FT3	36.5	37.0	35.0	36.17±1.04	76.52	81.02	66.40	74.63±7.52
FT4	42.5	39.0	35.0	38.83±3.75	80.71	79.23	78.10	79.35±1.31
FT5	37.5	37.0	32.0	35.50±3.04	77.53	78.45	66.70	74.21±6.56
FT6	29.5	15.5	22.5	22.50±7.00	105.30	83.02	77.60	88.65±14.69
FT7	29.0	16.0	18.0	21.00±7.00	80.78	51.40	42.10	58.11±20.17
FT8	31.0	29.0	21.0	27.00±5.29	85.58	81.02	66.10	77.56±10.19
FT9	35.0	22.0	30.0	29.00±6.56	99.43	63.77	78.00	80.41±17.95
FT10	37.0	17.0	27.0	27.00±10.00	88.56	57.19	61.90	69.20±16.93
FT11	15.0	23.0	15.0	17.67±4.62	59.52	52.34	52.40	54.74±4.14
FT12	14.0	13.0	12.0	13.00±1.00	63.09	72.68	65.70	67.17±4.95

Table 6. Pearson correlation coefficients between forest composition and soil physical parameters

	MAL	MC	WHC	BD	PO	Nha^{-1}	Gha^{-1}	$\overline{H}$	Cd	SR
MAL	1.000	-	-	-	-	-	-	-	-	-
MC	0.812**	1.000	-	-	-	-	-	-	-	-
WHC	0.664*	0.621*	1.000	-	-	-	-	-	-	-
BD	-0.348	-0.533	-0.396	1.000	-	-	-	-	-	-
PO	0.349	0.539	0.401	-1.000**	1.000	-	-	-	-	-
Nha^{-1}	-0.336	-0.329	-0.372	0.407	-0.410	1.000	-	-	-	-
Gha^{-1}	0.312	0.043	0.154	0.071	-0.073	0.431	1.000	-	-	-
$\overline{H}$	-0.346	-0.313	-0.329	0.081	-0.086	0.749**	0.261	1.000	-	-
Cd	0.297	0.257	0.231	0.013	-0.010	-0.643*	-0.246	-0.975**	1.000	-
SR	-0.439	-0.360	-0.373	0.255	-0.259	0.852**	0.190	0.903**	-0.802**	1.000

*. Correlation is significant at the 0.05 level; **. Correlation is significant at the 0.01 level.
Abbreviations: MAL= Average Altitude; MC= Moisture Content; WHC= Water Holding Capacity; BD= Bulk Density; PO= Porosity; Nha^{-1}= Trees per hectare; Gha^{-1}= Basal area per hectare; SR= Species Richness; $\overline{H}$ = Shannon-Wiener Diversity Index; Cd= Simpson Concentration of dominance.

it determines water intake rates (absorption), water storage in the soil, the ease of tilling the soil, the amount of aeration (vital to root growth) and influence the soil fertility. The effects of the textural properties of soils are frequently reflected in the composition and rate of growth of forest vegetation (Kruedener, 1927). The silvicultural features of forest soils may greatly modify the ecological significance of soil texture. The trees on the peddled clay soil suffer, at least periodically, from an excess of water and deficient aeration. For this reason, non- aggregated heavy soils support conifers. The roots of these trees remain largely within the surface layer of raw humus and thus, partly avoid the ill effects of poorly aerated mineral soil. Contrariwise, heavy soils coagulated in to aggregates, have more favourable conditions of aeration and support a wide range of hardwoods and conifers.

Clay, silt and sand contents in the study area ranged between 14.0% and 19.7%, 22.0% and 38.7%, and 43.4%

Table 7. Comparison between physical properties of soils at various altitudes and forest types in different parts of Uttarakhand Himalaya (earlier reported values) and the study area

Forest Type	(Source) Locality	Altitude (m asl)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g/cm^3)	Porosity	Moisture Content (%)	Water Holding Capacity (%)
Mixed broadleaf	(1) Nainital, Kumaun	1300-1500	90.90-91.30	3.80-4.30	4.80-4.90	1.00-1.20	53.40-60.40	5.50-12.20	29.80-43.70
Mixed broadleaf	(1) Nainital, Kumaun	1500-1800	91.30-92.70	3.10-4.20	4.10-4.50	1.00-1.20	53.80-61.50	8.50-15.40	37.00-40.00
-	(2) Kumaun	1580-1950	60.00-61.00	20.00-25.00	16.00-17.20	-	-	32.00-40.00	-
Quercus leucotrichophora	(3) Kumaun	1600	56.10	25.00	18.60	0.89	-	43.10	51.30
Oak mixed coniferous	(4) Kewars, Pauri Garhwal	1600-2100	-	-	-	-	-	13.50-19.90	-
Q. leucotrichophora	(5) Pauri Garhwal	1600-2100	25.85-56.81	30.17-51.36	10.06-28.85	0.90-1.33	48.84-65.38	15.10-23.57	37.61-58.14
Q. leucotrichophora	(6) Buvakhal, Pauri Garhwal	1600-2100	-	-	-	-	-	21.70-40.80	32.60-46.30
Q. leucotrichophora	**(7) Mandal-Chopta, Chamoli Garhwal**	**1650-1500**	**58.00**	**23.67**	**18.33**	**1.29**	**51.25**	**13.00**	**67.17**
Alnus nepalensis	**(7) Mandal-Chopta, Chamoli Garhwal**	**1650-1550**	**64.00**	**22.00**	**14.00**	**1.18**	**55.47**	**17.67**	**54.74**
Q. leucotrichophora	(8) Pauri Garhwal	1700-1850	24.10-42.80	3.80-16.80	51.70-72.10	-	-	13.50-30.30	51.60-78.40
Mixed broadleaf	(5) Chamoli Garhwal	1700-2200	25.22-59.57	29.42-50.21	10.11-24.57	0.89-1.35	48.07-65.76	10.21-26.44	12.33-43.22
Mixed broadleaf	(9) Mandal, Chamoli Garhwal	1800	-	-	-	-	-	36.00	-
Mixed broadleaf	(1) Nainital, Kumaun	1800-2000	90.70-91.90	4.10-4.80	3.90-4.50	1.10-1.30	51.10-57.30	4.60-6.20	25.10-28.30
Mixed broadleaf	**(7) Mandal-Chopta, Chamoli Garhwal**	**1900-1600**	**56.67**	**26.33**	**17.00**	**1.02**	**61.55**	**27.00**	**69.20**
Q. leucotrichophora	(10) Badiyargarh, Tehri Garhwal	1900-2400	17.10-34.40	17.10-34.40	54.10-79.30	-	-	-	28.10-81.20
Mixed broadleaf	(9) Huddu, Chamoli Garhwal	2000	-	-	-	-	-	40.00	-
-	(2) Kumaun	2000-2600	52.30-53.50	29.00-32.00	11.60-21.60	-	-	44.30-46.50	-
Mixed broadleaf	**(7) Mandal-Chopta, Chamoli Garhwal**	**2150-1900**	**53.67**	**26.67**	**19.67**	**0.79**	**70.26**	**29.00**	**80.41**
Quercus floribunda	(6) Dudhatoli, Pauri Garhwal	2300-2600	-	-	-	-	-	16.50-23.20	22.50-38.60
Conifer mixed broadleaf	(9) Duggal-Bhitta, Chamoli Garhwal	2350-2400	-	-	-	-	-	45.00-47.40	-
Mixed broadleaf	**(7) Mandal-Chopta, Chamoli Garhwal**	**2400-2150**	**56.67**	**25.33**	**18.00**	**1.16**	**56.11**	**27.00**	**77.56**
Abies pindrow	**(7) Mandal-Chopta, Chamoli Garhwal**	**2500-2100**	**57.33**	**27.67**	**15.00**	**1.26**	**52.30**	**21.00**	**58.11**
Aesculus indica	**(7) Mandal-Chopta, Chamoli Garhwal**	**2500-2400**	**57.00**	**26.67**	**16.33**	**0.91**	**65.55**	**22.50**	**88.65**
Quercus semecarpifolia	(6) Pauri Garhwal	2500-3000	-	-	-	-	-	15.10-21.90	32.70-47.50
Conifer mixed broad-leaved	**(7) Mandal-Chopta, Chamoli Garhwal**	**2600-2450**	**50.33**	**31.33**	**18.33**	**0.85**	**67.92**	**35.50**	**74.21**
A. pindrow	**(7) Mandal-Chopta, Chamoli Garhwal**	**2600-2500**	**44.33**	**36.00**	**19.67**	**0.87**	**67.13**	**38.83**	**79.35**
-	(11) Kumaun	2600-3000	50.70-54.20	27.30-33.30	15.90-18.50	-	-	37.40-44.50	-
A. pindrow	(5) Tapovan, Chamoli Garhwal	2600-3100	21.24-27.87	51.29-57-29	15.56-23.96	0.80-1.29	50.38-69.23	9.43-17.21	23.54-62.78
A. pindrow	(6) Dudhatoli, Pauri Garhwal	2600-3100	-	-	-	-	-	32.50-38.50	38.60-44.70
Acer acuminatum	**(7) Mandal-Chopta, Chamoli Garhwal**	**2650-2550**	**47.33**	**33.00**	**19.67**	**1.10**	**58.49**	**36.17**	**74.63**
Q. floribunda	**(7) Mandal-Chopta, Chamoli Garhwal**	**2650-2550**	**46.33**	**35.33**	**18.33**	**0.89**	**66.60**	**37.17**	**80.19**
Conifer mixed broadleaf	(9) Pangarbasa, Chamoli Garhwal	2700-2750	-	-	-	-	-	50.60-50.70	-
Conifer mixed broadleaf	(9) Kanchula-Kharak, Chamoli Garhwal	2800	-	-	-	-	-	50.90	-
Mixed broadleaf	(9) Chopta, Chamoli Garhwal	2800	-	-	-	-	-	51.00	-
Q. semecarpifolia	**(7) Mandal-Chopta, Chamoli Garhwal**	**2850-2650**	**43.33**	**38.67**	**18.00**	**1.17**	**56.00**	**39.50**	**99.91**
Q. leucotrichophora	(12) Pranmati watershed, Chamoli Garhwal	Montane	33.00	-	-	-	-	-	-
Q. leucotrichophora	(12) Almora, Kumaun	Montane	27.00-28.00	-	-	-	-	-	-

Sources: 1= Khera et al. (2001), 2= Kharkwal (2002), 3= Usman et al. (2000), 4= Srivastava et al. (2005), 5= Nazir (2009), 6= Sharma et al. (2010b), 7= Present study, 8= Semwal (2006), 9= Pande et al. (2001), 10= Kumar et al. (2004), 11= Rawal (1991), 12 = Thadani and Ashton (1995).

and 64.0%, respectively (Table 3). The values of soil texture reported in the present study are different than that of the values reported by Khera et al. (2001) for Kumaun Himalaya and are similar to the values recorded by Rawal (1991), Usman et al. (2000) and Kharkwal (2002) for Kumaun Himalaya and Kumar et al. (2004), Semwal (2006) and Nazir (2009) for Garhwal Himalaya (Table 7). These values suggest that the general pattern of soil texture is similar at these altitudes in Garhwal and Kumaun Himalayas and is suitable for growth of this kind of vegetation on the hilly slopes of the Uttarakhand Himalaya.

General soils with a low content of fine soil material (*i.e.*, sandy soils) support only trees, which have low requirements for moisture and nutrients. On the other hand soils with a high content of fine particles (*i.e.*, loam soils) support the tree species which have high requirements for moisture and nutrients, such as species of spruce and fir (Coile, 1933; Hosley, 1936). The nature of soil is largely a function of the vegetation it supports. In all the forest types, growing at higher altitudes (FT1 to FT5) the soil texture type was loam. The major tree species in these forests was *Abies pindrow*. At middle and lower altitudes the dominant soil texture class was sandy loam intermingled with sandy clay loam at few soil depths in some forest types. Wilkinson and Humphreys (2006) also suggested that shallow soil is more strongly controlled by topographic factors, which is also prevalent in hilly areas of Garhwal Himalaya. A balanced combination of sand, silt and clay composition makes loamy soil, which is the best one for the plant growth (Pidwirny, 2004). As soils of the study area were mainly loamy in nature, therefore they supported the luxuriant vegetation.

Soil colour

A vertical section of the soil in the land area exposes more or less distinct horizontal layers. It shows the distinctive characters of the soil profile. The surface layer is darker in colour because of its higher organic matter contents such as litter, humus, minerals, residues of the dead flora and fauna. The colouring of soils occurs because of a variety of factors. Colour alone does not affect a soil, but it is often a reliable indicator of other soil properties. In the present study soils tend to have distinct vitiations in colour at different depths and forest types. The colour of soil in the forest types varied from yellowish brown to dark brown (Table 4). Brown soils are rich in humus with surface horizon up to 30 mm deep. Parent material of soil is responsible for its pH, structure, colour and texture.

Water holding capacity

The soil texture is an important factor for water holding capacity. It indicates how well a particular texture of soil holds the water. Sandy soils allow water to enter as well as pass away through it more rapidly. It warms up quickly and cools very soon in comparison to other textures of soil, which does not form a suitable habitat for plants growth. The soil texture, shape and size of particles in the soil and its physical condition, both of surface and profile layers affect vertical filtration and capability of soil to retain water. The standard moisture level is marked when water covers one-half of the pore space in soil structure. The soil is fully saturated when all the pore spaces get filled with water. At this stage, the saturated soil has no air in its pore spaces. The water retention and transmission properties vary according to soil texture (Kumar et al., 2002). While adequate moisture is required for decomposer organisms to operate efficiently, excessive moisture or anaerobic conditions resulting from prolonged inundation may impede the activity of soil flora and fauna and decomposition process (Groffman et al., 1996).

Values of WHC in the study area (Table 5) varied between 54.74% (FT11) and 99.91% (FT1) which are higher to the values of WHC recorded for most other forest types of Uttarakhand Himalaya, except to the values recorded by Kumar et al. (2004) and Semwal (2006) in some forests of Garhwal Himalaya (Table 7). Water holding capacity showed significantly positive correlation with altitude (0.664). The water holding capacity increased with an increase in the clay content at all the sites and was low on the sites where percent sand was higher. Sandy soils generally have less moisture holding capacity and subsequently nutrient retention characteristics than non-sandy soils (Perry, 1994), because it depends upon the texture and organic matter of the soil (Brady, 1996). In the present study the water holding capacity was higher in the upper horizons of all the forest types, it was also higher in some lower horizons, where the percentage of clay was higher.

Moisture content

At favourable moisture conditions, increasing temperature results in an exponential increase in decomposition rates. At a constant temperature, moisture content shows a parabolic affect on decomposition rates with a maximum rate at intermediate levels of moisture. High moisture content can limit free gas exchange leading to low oxygen concentration and potentially anaerobic conditions. At low moisture content, the lack of water limits microbial metabolism. Values of mean moisture content in the study area ranged between 13.00% (FT12) and 39.50% (FT1) (Table 5). These values of moisture content reported in the present study are higher to the values reported by Khera et al. (2001) for Kumaun Himalaya and Nazir (2009) for Garhwal Himalaya, whereas they are similar to the values recorded by all other investigators in Kumaun and Garhwal Himalaya (Table 7). The variation in moisture content in different sites of study area can be attributed to altitude, rain fall, forest cover, aspect and slope of the sites as well as to the water holding capacity of the soil and high water absorbing nature of some tree species (*i.e.*, *Quercus leucotrichophora, Q. floribunda, Q. semecarpifolia*, etc). The tree vegetation and their roots also help to retain soil moisture (Jha and Pande, 1980).

The soil moisture content was higher in the higher altitudinal types (*Q. semecarpifolia, Q. floribunda* and mixed broad-leaved forest types) and was lower in low altitudinal forest types. Singh and Singh (1986) have also reported that oak forests are characteristically moister. Although FT12 had *Q. leucotrichophora* as dominant tree species, still it had lowest moisture content. It could be due to two reasons; firstly because at lower attitudes rainfall was lower than higher altitudes; and secondly due to occurrence of high density of invasive exotic weeds like *Eupatorium adenophorum* at lower altitudes in this forest type. High positive correlation between WHC and moisture content (0.621) was recorded which shows that moisture content of the soil increases with the water holding capacity.

Bulk density, Porosity and Void ratio

The volume-weight relationship of soil in oven dry conditions is termed as the bulk density (Gupta and Sharma, 2008). Values of bulk density in the study area ranged between 0.79 gm/cm^3 (FT9) and 1.29 gm/cm^3 (FT12) (Figure 3). These values of bulk density are similar to values recorded by all the other investigators in different parts of Kumaun and Garhwal Himalayas at same altitude and forest types (Table 7). The negative correlation (-0.348) between bulk density and elevation was recorded. Our results are in accordance with the findings of Hanawalt and Whittaker (1976), who also found that the bulk density of soil decrease with increasing elevation. Negative correlation (-0.445) between bulk density and organic carbon was observed. Generally, bulk density and organic matter are inversely proportional, and

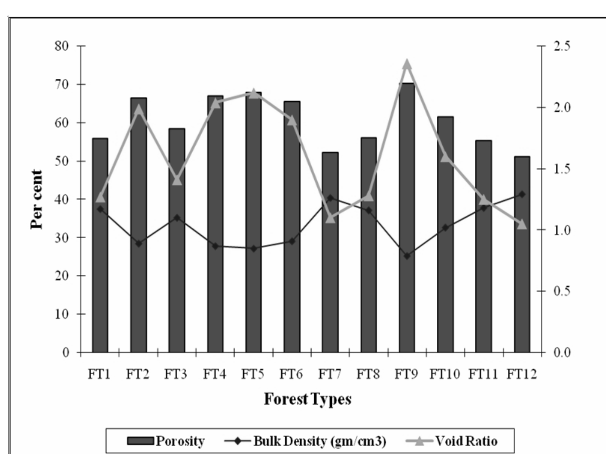

Fig. 3. Porosity, bulk density (gm/cm^3) and void ratio in different forest types

low bulk density in soil indicates occurrence of higher organic matter content, good granulation, high infiltration and good aeration conversely (NRC, 1981). Bulk density was also found to be negatively correlated with moisture content (-0.533) and WHC (-0.396). High bulk density leads to compaction of soil, which could be the reason for negative correlation of bulk density with moisture content and WHC.

The space in the soil, occupied by air and water, is termed as 'pore space or total porosity'. The pore space of a soil is largely determined by the arrangement of solid particles, and varies from 30% to 75%. Determination of the total porosity yields the simplest particle characterization of the soil pore system. Values of soil porosity in the study area oscillated between 51.25 (FT12) and 70.26 (FT9) (Figure 3). These values of soil porosity are similar to the values recorded by all the other investigators in different parts of Kumaun and Garhwal Himalayas at same altitudes and forest types (Table 7). As moderate pore spaces are required for soil to retain moisture, positive correlation was observed for Porosity with moisture content (0.539) and WHC (0.401).

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