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Physico-chemical properties of soils in cool-temperate forests of the "Nanda Devi Biosphere Reserve" in Uttarakhand (India)

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The study area is very diverse due to its protectness on one hand and thus there is a vast scope of scientific study on the other hand. The parent material of the study area represents crystalline rocks and comprises of garnetiferous mica, schists, garnet mica and mica quartzite. The soil bulk density varies from 1.14 to 1.91 gm cm^{-3} under various soil depths ranging from 0 to 15, 15 to 30 and 30 to 45 cm. Whereas, an average water holding capacity ranged from 36.50 ± 0.52 to 67.39 ± 1.79% for 0 to 45 cm soil depth. The soil was found acidic in nature, which ranged from 5.09 ± 0.06 to 6.46 ± 0.05 for 0 to 45 cm depth. With increasing soil depths, the percentage of gravel particles (>4.75 mm) was found in ascending proportion under *Abies pindrow*, *Betula utilis* and *Quercus semecarpifolia* dominated forests. Whereas, this sequence was observed entirely different under other forests. However, fine particles showed the marked variation among other forests. While they were found to be in higher percentage in *Pinus wallichiana* and *A. pindrow* dominated forests under 30 to 45 and 0 to 15 cm depths, respectively. The least percentage of fine particles was found in *Q. semecarpifolia* dominated forest under 30 to 45 cm soil depth. The organic carbon was highest (6.10 ± 0.39%) and lowest (0.52 ± 0.13%) as observed under *Q. semecarpifolia* and *A. pindrow* dominated forests for 0to 15 and 30 to 45 cm depths during March to June, 1998 and December to March, 1999 respectively. Whereas, the seasonal variation of C : N : P ratio was highest (118.571:4.286:1) and lowest (8.000:2.682:1) when observed under *A. pindrow* dominated forest for 0 to 15 and 15 to 30 cm soil depths during June to September and September to December, 1998 respectively.

Key words: Forest, soil, nutrients, N, P, K.

INTRODUCTION

The present study was conducted in the buffer zone of "Nanda Devi Biosphere Reserve". This is situated in the Himalayan highlands biogeographic province-2B in India. The area is completely protected since 7th January, 1939 when it was declared as a sanctuary, now it has been included in the list of 'World Heritage Site' since 1992. It is reputedly one of the most spectacular wildernesses area having qualitative and quantitative unique biota, cultural heritage, religious faith, soils and distinct climate in the world. Geographically, it falls between 30°17'N and

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30°41'N latitude and 79°40' E and 80° 05' E longitude and make headwaters of Dhauliganga and Rishiganga, tributaries of the India's National River Ganga in Uttarakhand state. The study area represents one of the most fascinating and characteristics vegetation all over the world not in terms of diversity but also in terms of density.

These fascinating features of the study area had attracted keen interest and attention of the people towards the scientific study, exploration and visits within the temperate forests and sub-alpine zone of the Indian Himalayan region. Such unique feature of the biota and natural habitats (wildlife, forests, grasslands, etc.) is due to climatic variation of the region on one hand and various physico-chemical properties of cool temperate forest soils on the other hand. Similar studies have been conducted by many workers on plant species composition; productivity and litter quality have been recognized as factors affecting the soil characteristics (Shaw, 1930; Jenny, 1941; Birkeland, 1984; Among all elements, phosphorus availability is known to affect the plant production. For most of the soils, more than 80% of the soil phosphorus becomes immobile and unavailable for plant uptake due to adsorption, precipitation or conversion to the organic form (Holford, 1997).

While nitrogen is the primary limiting nutrients in most of the ecosystems, phosphorus availability may limit plant production in cool-temperate and alpine environments (Korner, 1989). Though, the phosphorus concentrations in vegetation of the Indian Himalaya are known to be less than that reported for other temperate forests of the world (Zobel and Singh, 1997). The dynamics of this element and soil physico-chemical properties under varying vegetation in cool-temperate forests and sub-alpine zone of the Indian Himalaya is not fully explored. The aim of the present study was to estimate the physical and chemical properties of soils under various forest canopy regimes and to estimate the seasonal dynamics of various nutrients in natural soil pool under six representative forest ecosystems that exist in a protected area of the Uttarakhand State in India. The study area is shown in Figure 1.

MATERIALS AND METHODS

The soil samples under various forest types were collected using a set of soil cores of 10 cm diameter and 15 cm length at quarterly interval. These cores were used to sample soil at 0 to 15, 15 to 30 and 30 to 45 cm depths separately at about 30 randomly selected points. The soil core of each depth was carefully placed in a metallic sample box, weighed for fresh weight and oven dried at 70°C until constant weight. Samples of 10 cores of each depth were pooled together and sub-sample of pooled soil for each depth in each forest type was analyzed for the natural constituents. For determining the soil colour, water holding capacity, pH and particulate matters, 10 cores of 0 to 15, 15 to 30 and 30 to 45 cm were extracted at the initial stage of the study and fresh soil samples were used. The soil colour was identified using a 'Munsell Soil Colour Chart'.

While, the soil bulk density (g cm^3) was calculated as weight/volume method. Whereas, the method for soil particulate fractions was self examined for the present study. It was assessed by passing 500 g of soils through a sieve set of various pore sized. Aquas mixture of soil and distilled water (1:5) was used to assess the pH value. The organic carbon of soil samples was determined by Tropical Soil Biology and Fertility (TSBF) Methods (Anderson and Ingram, 1993), which is based on modified Walkley and Black (1934) and Nelson and Sommers (1975) methods.

Total nitrogen of forest soil was determined by Kjeldhal Digestion Method (Anderson and Ingram, 1993; Lindoner and Harlely, 1942; Novosamsky et al., 1983). Whereas, the available phosphorus was determined by colorimetric method, exchangeable potassium and calcium were determined by the Flame Photometry (Jackson, 1958). The nutrient mass of forests soil was computed as the product of mass and mean concentration of that element.

RESULTS

The bulk density of forest soils varied from 1.14 to 1.94 gcm^{-3}. No much variation was observed between conifer and broad-leaved dominated forests. Only significant variation was observed between two conifers dominated forests (1.37 to 1.74 g cm^{-3}) and two broad-leaved forests (1.34 to 1.79 g cm^{-3}) under 0 to 15 cm soil depth. As a general rule, the soil chroma became lighter with increased depth, except under *Cedrus deodara* (Deodar) dominated forest, where the soil colour under 15-30 cm was dark grayish brown, 0 to 15 and 30 to 45 cm. As such, it remains very dark grayish brown soil under both depth classes. The same situation have also been observed under *Pinus wallichiana* (Kail) dominated forest, where 0 to 15 and 30 to 45 cm soil depth, the colour was found dark grayish brown, under 30 to 45 cm soil depth, it was grayish brown (Table 1).

The water holding capacity of different forest soils under 0 to 45 cm depth ranged from 36.50 to 67.39 under *P. wallichiana* (Kail) and *Betula utilis* (Bhojpatra) forests, respectively. Whereas, the pH value ranged from 5.09 to 6.46 under *P, wallichiana* (Kail) and *Quercus semecarpifolia* (Kharsu) dominated forests, respectively (Table 2).

With increasing soil depths, the percentage of gravel particles (>4.75 mm) was found in ascending proportion under *Abies pindrow* (Ragha), *B. utilis* (Bhojpatra) and *Q. semecarpifolia* (Kharsu) dominated forests. Whereas, this sequence was observed entirely different under other forests of the study area. However, fine particles showed the marked variation among other forests. While they were found to be higher percentage in *P. wallichiana* (Kail) and *A. pindrow* (Ragha) dominated forests under 30 to 45 and 0 to 15 cm depths, respectively. The least percentage of fine particles was found in *Q. semecarpifolia* (Kharsu) dominated forest under 30 to 45 cm soil depth (Table 3).

The organic carbon was highest (6.10 ± 0.39%) and lowest (0.52 ± 0.13%) as observed under *Q. semecarpifolia* and *A. pindrow* dominated forests for 0 to 15 and 30 to 45 cm soil depths during March to June, 1998

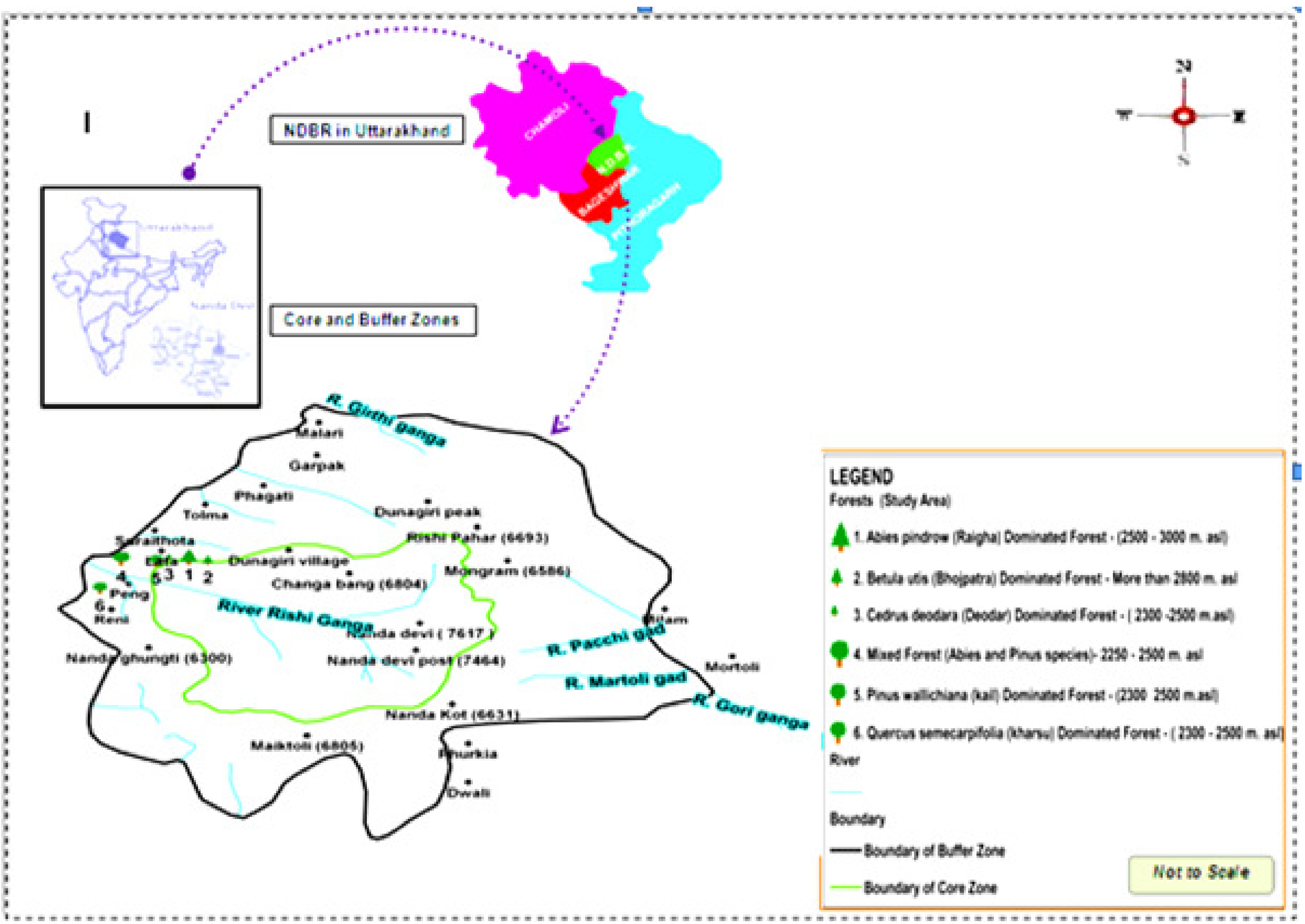


Figure 1. Location map of the study area (Nanda Devi Biosphere Reserve).

and December to March, 1999 respectively. The seasonal variation of soil moisture, organic carbon, total and exchangeable forms of various nutrients (N, P, K and Ca) are shown in Table 4 and data are illustrated in Figures 2 to 7. Whereas, the seasonal variation of C : N : P ratio

Table 1. Bulk density and soil colour based on Munsell soil color chart under studies forests.

Forests (Vernacular name)	Soil depth	Bulk density (gm cm^{-3})	Soil color status		
			Hue	Value	Chroma
Abies pindrow (Ragha)	0 - 15	1.14	2.5 Y	5/4	Light olive brown
	15 - 30	1.49	2.5 Y	7/2	Light gray
	30 - 45	1.49	2.5 Y	7/4	Pale yellow
Betula utilis (Bhojpatra)	0 - 15	1.34	2.5 Y	5/4	Light olive brown
	15 - 30	1.94	2.5 Y	6/4	Light yellowish brown
	30 - 45	1.88	2.5 Y	4/4	Olive brown
Cedrus deodara (Deodar)	0 - 15	1.37	2.5 Y	3/2	Very dark grayish brown
	15 - 30	1.58	2.5 Y	4/2	Dark grayish brown
	30 - 45	1.49	2.5 Y	3/2	Very dark grayish brown
Mixed Forest	0 - 15	1.34	2.5 Y	4/2	Dark grayish brown
	15 - 30	1.49	2.5 Y	5/2	Grayish brown
	30 - 45	1.79	2.5 Y	6/2	Light brownish gray
Pinus wallichiana (Kail)	0 - 15	1.74	2.5 Y	4/2	Dark grayish brown
	15 - 30	1.58	2.5 Y	4/2	Dark grayish brown
	30 - 45	1.72	2.5 Y	5/2	Grayish brown
Quercus semecarpifolia (Kharsu)	0 - 15	1.79	2.5 Y	3/2	Very dark grayish brown
	15 - 30	1.70	2.5 Y	4/2	Dark grayish brown
	30 - 45	1.91	2.5 Y	5/2	Grayish brown

Table 2. Water holding capacity (%) and pH (1:5) value under selected forests.

Forests (Vernacular name)	WHC (%±SE)	pH (Value±SE)
Abies pindrow (Ragha)	47.38±1.34	5.76±0.08
Betula utilis (Bhojpatra)	67.39±1.79	6.31±0.05
Cedrus deodara (Deodar)	49.17±1.19	5.33±0.10
Mixed Forest	44.78±0.86	5.50±0.05
Pinus wallichiana (Kail)	36.50±0.52	5.09±0.06
Quercus semecarpifolia (Kharsu)	56.22±0.85	6.46±0.05

±SE refers to standard error in the data.

was highest (118.571:4.286:1) and lowest (8.000:2.682:1) as observed under *A. pindrow* dominated forest for 0-15 and 15-30 cm soil depths during June to September and September to December, 1998, respectively (Table 5).

DISCUSSION

The growth of vegetation directly as well as indirectly influences the status of nutrients available in the natural soil pool, when the status of parent materials is similar to the status of various nutrients in the soil. In the present study, due to highly acidic nature of *Pinus* dominated forest soils, the water holding capacity of soil was also observed in lowest quantity. This reflects that the acidic nature of the soil cannot hold the high amount of water and moisture content. It is due to ignitious properties of pine needles on one hand and high porosity among the soil particles on other. The phosphorus concentration in soil pool showed correlation with total nitrogen than organic carbon. Immobilization of phosphorus in soils from the Himalayan region in particular and mountain regions in general is a major point of discussion for the people concerned with forest health and soil nutrients. The relatively lower concentration of phosphorus in tree leaves as reported by other workers (Adhikari et al., 1995; Bhatt, 1988) might be an adoptive mechanism of plants growing in the region. Among the six selected forest type, the *B. utilis* (Bhojpatra) dominated forest soils showed relatively good amount of available phosphorus as compared to the soils of other studies forests. This could be due to the fact that litters of other species dominated forests are more preferred for agriculture in

Table 3. Percentage contribution of various soil texture classes under different depths of the selected forests soils.

Particle size	Forests (Values parenthesis in %±SE): Soil depths (cm)																	
	A. pindrow			*B. utilis*			*C. deodara*			Mixed Forest			*P. wallichiana*			*Q. semecarpifolia*		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
4.75 mm	26.37 ±1.21	32.03 ±1.03	35.0 ±1.1	12.0 ±1.1	15.95 ±1.45	30.66 ±1.07	26.67 ±1.19	31.46 ±0.63	29.5 ±1.4	16.7 ±0.9	30.4 ±0.8	17.9 ±1.1	26.4 ±1.1	24.86 ±0.60	27.7 ±0.6	24.41 ±0.9	24.8 ±1.1	25.31 ±1.4
2.36 mm	3.69 ±0.34	4.17 ±0.27	4.71 ±0.6	4.82 ±0.3	4.95 ±0.60	6.54 ±0.3	3.90 ±0.10	3.28 ±0.24	2.98 ±0.4	3.26 ±0.3	4.38 ±0.3	4.54 ±0.3	3.82 ±0.3	3.20 ±0.4	5.61 ±0.6	4.42 ±0.3	4.64 ±0.3	9.43 ±1.5
1.18 mm	8.33 ±0.53	8.11 ±0.48	7.35 ±0.4	17.5 ±0.4	14.28 ±0.5	13.65 ±0.6	8.15 ±0.41	6.14 ±0.24	6.44 ±0.4	10.9 ±0.4	9.70 ±0.4	11.41 ±0.5	10.22 ±0.3	8.61 ±0.45	6.45 ±0.6	19.54 ±0.5	11.58 ±0.5	9.17 ±0.8
600 mic	8.74 ±0.53	6.26 ±0.37	6.83 ±0.44	17.45 ±0.6	14.47 ±0.86	10.36 ±0.47	8.70 ±0.20	6.26 ±0.4	6.38 ±0.5	15.7 ±1.0	7.53 ±0.2	10.6 ±0.5	11.51 ±0.7	7.51 ±0.41	6.19 ±0.5	9.24 ±0.52	10.46 ±0.5	9.95 ±0.6
300 mic	12.95 ±0.53	14.08 ±0.92	12.61 ±0.5	24.55 ±0.5	22.77 ±1.01	14.71 ±0.49	23.87 ±0.78	14.34 ±0.43	20.44 ±1.19	18.6 ±.0.9	14.39 ±0.8	24.27 ±0.4	26.50 ±1.2	21.23 ±1.58	17.17 ±0.7	18.73 ±1.06	19.28 ±0.8	18.40 ±0.9
100 mic	22.50 ±0.74	24.59 ±0.68	23.49 ±0.71	19.84 ±0.84	22.41 ±0.55	16.92 ±0.44	21.97 ±0.69	26.09 ±0.49	25.17 ±0.88	25.27 ±0.4	20.88 ±0.7	24.24 ±0.7	17.13 ±0.9	21.44 ±1.19	16.84 ±1.44	15.59 ±1.17	21.86 ±0.5	23.74 ±1.12
75 mic	11.99 ±0.29	8.36 ±0.71	7.65 ±0.21	3.21 ±0.6	4.31 ±0.35	5.12 ±0.21	5.64 ±0.36	9.13 ±0.18	6.79 ±0.66	6.39 ±0.8	8.52 ±0.6	5.73 ±0.3	3.53 ±0.4	9.26 ±0.65	12.14 ±0.3	6.33 ±0.60	6.00 ±0.5	3.61 ±0.6
< 75 mic	5.43 ±0.06	2.40 ±0.41	2.33 ±0.56	0.69 ±0.1	0.86 ±0.22	2.04 ±0.19	1.10 ±0.24	3.30 ±0.04	2.27 ±0.4	3.17 ±0.5	4.25 ±0.4	1.29 ±0.1	0.91 ±0.2	1.89 ±0.28	7.86 ±0.53	1.74 ±0.4	1.39 ±0.2	0.39 ±0.2
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 4. Seasonal variation of nutrients under various soil depths in six representative forests of the "Nanda Devi Biosphere Reserve".

Sampling season	Forests (Values parenthesis in %±SE): Soil depths (cm)																	
	A. pindrow			*B. utilis*			*C. deodara*			Mixed Forest			*P. wallichiana*			*Q. semecarpifolia*		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
	Soil Moisture																	
Mar., 1998-Jun., 1998	52.21 ±2.29	58.42 ±3.91	77.66 ±1.19	84.74 ±2.33	73.75 ±1.75	72.56 ±3.84	48.78 ±1.62	52.69 ±1.16	54.66 ±0.54	55.28 ±2.55	61.46 ±2.22	73.44 ±2.47	42.28 ±3.85	58.51 ±4.06	69.93 ±2.25	62.23 ±0.85	73.54 ±2.05	78.04 ±1.19
Jun., 1998-Sep. , 1998	56.75 ±3.16	66.49 ±0.58	71.38 ±0.93	66.22 ±1.88	70.25 ±1.17	77.70 ±1.28	39.96 ±3.00	55.00 ±6.16	69.83 ±2.43	67.02 ±1.59	74.42 ±2.07	82.65 ±1.24	68.49 ±2.64	76.05 ±1.74	85.12 ±0.85	64.78 ±2.33	81.14 ±3.37	88.54 ±1.49
Sep., 1998-Dec.,1998	28.11 ±1.57	31.62 ±0.62	38.56 ±0.48	27.10 ±0.35	33.91 ±1.08	42.44 ±0.89	17.92 ±1.74	24.14 ±0.94	30.49 ±0.11	34.24 ±1.01	37.53 ±0.69	41.57 ±0.50	20.26 ±1.30	26.27 ±0.78	30.92 ±0.42	67.72 ±1.32	72.22 ±0.58	75.37 ±0.61
Dec., 1998-Mar., 1999	24.84 ±1.50	36.36 ±1.60	33.92 ±1.76	37.37 ±1.47	41.18 ±5.50	50.58 ±1.07	33.64 ±0.85	36.03 ±1.33	47.35 ±1.49	46.67 ±0.09	44.33 ±0.75	47.05 ±0.93	30.57 ±1.29	33.41 ±2.65	47.68 ±0.53	53.09 ±1.22	68.46 ±1.22	68.73 ±1.57
	Organic Carbon (OC)																	
Mar., 1998-Jun., 1998	3.40 ±0.42	2.78 ±0.31	1.29 ±0.28	2.70 ±0.30	1.56 ±0.26	1.23 ±0.39	2.48 ±0.33	3.35 ±0.30	2.88 ±0.12	2.21 ±0.12	2.32 ±0.11	1.73 ±0.32	2.51 ±0.30	1.94 ±0.11	1.50 ±0.23	6.10 ±0.39	5.15 ±0.24	4.93 ±0.32
Jun., 1998-Sep. , 1998	3.32 ±0.09	2.19 ±0.72	1.92 ±0.12	3.38 ±0.39	1.04 ±0.29	0.81 ±0.24	1.47 ±0.28	2.24 ±0.08	1.05 ±0.10	4.32 ±0.08	3.40 ±0.12	1.34 ±0.03	1.88 ±0.04	2.24 ±0.05	1.24 ±0.09	3.25 ±0.03	2.36 ±0.05	1.19 ±0.05

Table 4. Contd.

Sep., 1998-Dec.,1998	1.47 ±0.11	0.68 ±0.02	0.90 ±0.01	0.90 ±0.14	0.80 ±0.09	1.03 ±0.17	1.42 ±0.17	1.40 ±0.22	1.35 ±0.60	6.05 ±0.27	3.63 ±0.12	1.68 ±0.16	1.00 ±0.41	1.04 ±0.41	0.52 ±0.16	1.62 ±0.12	1.97 ±0.24	3.61 ±0.11
Dec., 1998-Mar., 1999	3.50 ±0.09	0.71 ±0.05	0.52 ±0.13	1.75 ±0.76	1.52 ±0.73	1.33 ±0.71	3.36 ±0.17	1.52 ±0.05	1.39 ±0.05	3.29 ±0.09	2.81 ±0.03	2.81 ±0.31	0.79 ±0.06	2.95 ±0.02	2.28 ±0.18	2.75 ±0.03	1.17 ±0.08	2.94 ±0.06
Total Nitrogen (N)																		
Mar., 1998-Jun., 1998	0.189 ±0.2	0.177 ±0.020	0.168 ±0.018	0.133 ±0.019	0.094 ±0.006	0.089 ±0.014	0.211 ±0.024	0.100 ±0.010	0.028 ±0.005	0.211 ±0.02	0.072 ±0.01	0.072 ±0.01	0.205 ±0.02	0.072 ±0.015	0.028 ±0.01	0.211 ±0.015	0.122 ±0.015	0.067 ±0.010
Jun., 1998-Sep. , 1998	0.120 ±0.001	0.178 ±0.015	0.267 ±0.001	0.100 ±0.001	0.239 ±0.001	0.278 ±0.024	0.150 ±0.001	0.128 ±0.015	0.095 ±0.015	0.133 ±0.02	0.167 ±0.03	0.233 ±0.02	0.155 ±0.02	0.083 ±0.001	0.111 ±0.01	0.167 ±0.009	0.186 ±0.016	0.261 ±0.015
Sep., 1998-Dec.,1998	0.266 ±0.017	0.228 ±0.015	0.172 ±0.020	0.283 ±0.020	0.211 ±0.015	0.161 ±0.015	0.200 ±0.020	0.133 ±0.001	0.072 ±0.001	0.200 ±0.01	0.122 ±0.01	0.100 ±0.01	0.183 ±0.01	0.157 ±0.005	0.056 ±0.01	0.211 ±0.006	0.178 ±0.005	0.100 ±0.009
Dec., 1998-Mar., 1999	0.211 ±0.022	0.167 ±0.019	0.067 ±0.001	0.211 ±0.015	0.150 ±0.019	0.072 ±0.001	0.217 ±0.019	0.117 ±0.001	0.033 ±0.001	0.250 ±0.01	0.144 ±0.01	0.117 ±0.01	0.239 ±0.02	0.117 ±0.001	0.100 ±0.01	0.289 ±0.024	0.172 ±0.005	0.122 ±0.015
Available Phosphorus (P)																		
Mar., 1998-Jun., 1998	0.088 ±0.002	0.080 ±0.003	0.065 ±0.002	0.092 ±0.02	0.075 ±0.001	0.049 ±0.0007	0.072 ±0.003	0.058 ±0.002	0.047 ±0.002	0.077 ±0.02	0.058 ±0.03	0.056 ±0.02	0.081 ±0.02	0.071 ±0.001	0.047 ±0.02	0.082 ±0.001	0.084 ±0.002	0.084 ±0.002
Jun., 1998-Sep. , 1998	0.028 ±0.001	0.035 ±0.002	0.046 ±0.003	0.058 ±0.002	0.077 ±0.003	0.096 ±0.001	0.033 ±0.002	0.059 ±0.002	0.087 ±0.003	0.050 ±0.03	0.063 ±0.02	0.078 ±0.01	0.039 ±0.02	0.049 ±0.007	0.084 ±0.02	0.075 ±0.002	0.079 ±0.005	0.087 ±0.006
Sep., 1998-Dec.,1998	0.079 ±0.002	0.085 ±0.002	0.092 ±0.002	0.095 ±0.002	0.082 ±0.002	0.075 ±0.005	0.092 ±0.002	0.074 ±0.002	0.058 ±0.002	0.079 ±0.04	0.064 ±0.02	0.039 ±0.03	0.056 ±0.03	0.047 ±0.003	0.030 ±0.03	0.085 ±0.002	0.078 ±0.001	0.083 ±0.002
Dec., 1998-Mar., 1999	0.090 ±0.003	0.068 ±0.002	0.056 ±0.001	0.089 ±0.002	0.078 ±0.002	0.064 ±0.003	0.089 ±0.001	0.072 ±0.002	0.062 ±0.002	0.100 ±0.03	0.094 ±0.02	0.076 ±0.03	0.085 ±0.02	0.051 ±0.002	0.067 ±0.02	0.075 ±0.002	0.088 ±0.002	0.088 ±0.003
Exchangeable Potassium (K)																		
Mar., 1998-Jun., 1998	0.360 ±0.001	0.300 ±0.001	0.200 ±0.001	0.349 ±0.008	0.317 ±0.049	0.254 ±0.063	0.236 ±0.016	0.189 ±0.063	0.221 ±0.008	0.246 ±0.01	0.197 ±0.02	0.297 ±0.06	0.180 ±0.01	0.213 ±0.047	0.221 ±0.03	0.300 ±0.018	0.255 ±0.10	0.157 ±0.014
Jun., 1998-Sep. , 1998	0.179± 0.036	0.234 ±0.017	0.358 ±0.049	0.179 ±0.036	0.234 ±0.017	0.247 ±0.009	0.189 ±0.024	0.228 ±0.007	0.257 ±0.045	0.246 ±0.01	0.246 ±0.01	0.357 ±0.02	0.129 ±0.04	0.142 ±0.014	0.168 ±0.02	0.176 ±0.007	0.299 ±0.024	0.251 ±0.014
Sep., 1998-Dec.,1998	0.186 ±0.014	0.169 ±0.013	0.139 ±0.047	0.273 ±0.018	0.257 ±0.039	0.176 ±0.02	0.165 ±0.05	0.187 ±0.06	0.232 ±0.03	0.350 ±0.02	0.202 ±0.01	0.195 ±0.01	0.253 ±0.01	0.269 ±0.10	0.190 ±0.06	0.384 ±0.012	0.220 ±0.014	0.193 ±0.008
Dec., 1998-Mar., 1999	0.223 ±0.018	0.230 ±0.072	0.168 ±0.013	0.124 ±0.013	0.175 ±0.016	0.190 ±0.009	0.223 ±0.018	0.168 ±0.008	0.133 ±0.060	0.209 ±0.01	0.145 ±0.01	0.115 ±0.01	0.217 ±0.01	0.195 ±0.035	0.099 ±0.02	0.357 ±0.019	0.303 ±0.015	0.229 ±0.024
Exchangeable Calcium (Ca)																		
Mar., 1998-Jun., 1998	0.89 ±0.01	0.92 ±0.03	1.22 ±0.02	0.77 ±0.08	0.87 ±0.01	1.24 ±0.001	0.85 ±0.001	0.89 ±0.001	0.95 ±0.01	0.97 ±0.01	0.99 ±0.01	1.26 ±0.01	0.79 ±0.01	0.83 ±0.01	0.96 ±0.01	1.12 ±0.001	1.19 ±0.001	1.26 ±0.01
Jun., 1998-Sep. , 1998	0.99 ±0.17	1.03 ±0.04	1.34 ±0.01	0.71 ±0.01	0.79 ±0.001	1.20 ±0.01	0.67 ±0.01	0.79 ±0.001	1.03 ±0.04	0.87 ±0.07	0.93 ±0.04	1.22 ±0.03	0.80 ±0.01	0.88 ±0.04	1.09 ±0.09	0.89 ±0.001	1.13 ±0.01	1.39 ±0.01
Sep., 1998-Dec.,1998	0.95 ±0.01	1.17 ±0.05	1.23 ±0.01	0.95 ±0.01	0.98 ±0.01	1.27 ±0.03	0.78 ±0.001	0.84 ±0.001	1.00 ±0.01	0.86 ±0.06	0.93 ±0.01	1.33 ±0.01	0.88 ±001	0.89 ±0.001	1.17 ±0.01	0.96 ±0.01	1.25 ±0.01	1.48 ±0.01
Dec., 1998-Mar., 1999	0.83 ±0.01	0.97 ±0.01	1.30 ±0.01	0.82 ±0.01	0.89 ±0.01	1.31 ±0.001	0.86 ±0.01	0.89 ±0.001	1.07 ±0.06	0.88 ±0.05	0.95 ±0.01	1.43 ±0.01	0.89 ±0.01	0.92 ±0.03	1.19± 0.002	1.09 ±0.05	1.23 ±0.001	1.33 ±0.01

Table 5. Seasonal variation of C: N: P ratio under selected forests soils.

Forests (Vernacular name)	Sampling season	Soil depths (cm)								
		0-15 cm			15-30 cm			30-45 cm		
		C	N	P	C	N	P	C	N	P
Abies pindrow (Ragha)	Mar., 1998 - Jun., 1998	38.636	11.364	1	34.750	2.213	1	19.846	2.585	1
	Jun., 1998 - Sep. , 1998	118.571	4.286	1	62.571	5.086	1	41.739	5.804	1
	Sep., 1998 - Dec., 1998	18.608	3.367	1	8.000	2.682	1	9.783	1.870	1
	Dec., 1998 - Mar., 1999	38.889	2.344	1	10.441	2.456	1	9.286	1.196	1
Betula utilis (Bhojpatra)	Mar., 1998 - Jun., 1998	29.348	1.446	1	20.800	1.253	1	25.102	1.816	1
	Jun., 1998 - Sep. , 1998	58.276	1.724	1	13.506	3.104	1	8.438	2.896	1
	Sep., 1998 - Dec., 1998	9.474	2.505	1	9.756	2.573	1	13.733	2.147	1
	Dec., 1998 - Mar., 1999	19.663	2.371	1	19.487	1.923	1	20.781	1.125	1
Cedrus deodara (Deodar)	Mar., 1998 - Jun., 1998	31.795	13.889	1	57.759	1.724	1	61.277	0.596	1
	Jun., 1998 - Sep. , 1998	44.546	4.546	1	37.966	2.170	1	12.069	1.092	1
	Sep., 1998 - Dec., 1998	15.435	2.174	1	18.919	13.514	1	23.276	1.241	1
	Dec., 1998 - Mar., 1999	37.752	2.438	1	21.111	2.450	1	22.419	0.532	1
Mixed Forest	Mar., 1998 - Jun., 1998	28.701	2.740	1	40.000	1.241	1	30.893	1.286	1
	Jun., 1998 - Sep. , 1998	86.400	2.660	1	53.968	2.650	1	17.180	2.987	1
	Sep., 1998 - Dec., 1998	76.582	2.532	1	56.719	1.906	1	43.077	2.564	1
	Dec., 1998 - Mar., 1999	35.400	2.500	1	29.894	1.532	1	36.974	1.539	1
Pinus wallichiana (Kail)	Mar., 1998 - Jun., 1998	30.988	2.531	1	27.324	1.014	1	31.915	0.596	1
	Jun., 1998 - Sep. , 1998	48.205	3.974	1	45.714	1.694	1	14.762	1.321	1
	Sep., 1998 - Dec., 1998	17.857	3.268	1	22.128	3.340	1	17.333	1.867	1
	Dec., 1998 - Mar., 1999	9.294	2.812	1	57.843	2.294	1	34.030	1.493	1
Quercus semecarpifolia (Kharsu)	Mar., 1998 - Jun., 1998	74.390	2.573	1	61.310	1.452	1	58.691	0.798	1
	Jun., 1998 - Sep. , 1998	43.333	2.227	1	29.873	2.354	1	13.678	3.000	1
	Sep., 1998 - Dec., 1998	19.059	2.482	1	25.256	2.282	1	43.494	1.205	1
	Dec., 1998 - Mar., 1999	36.667	3.853	1	13.296	1.955	1	33.409	1.386	1

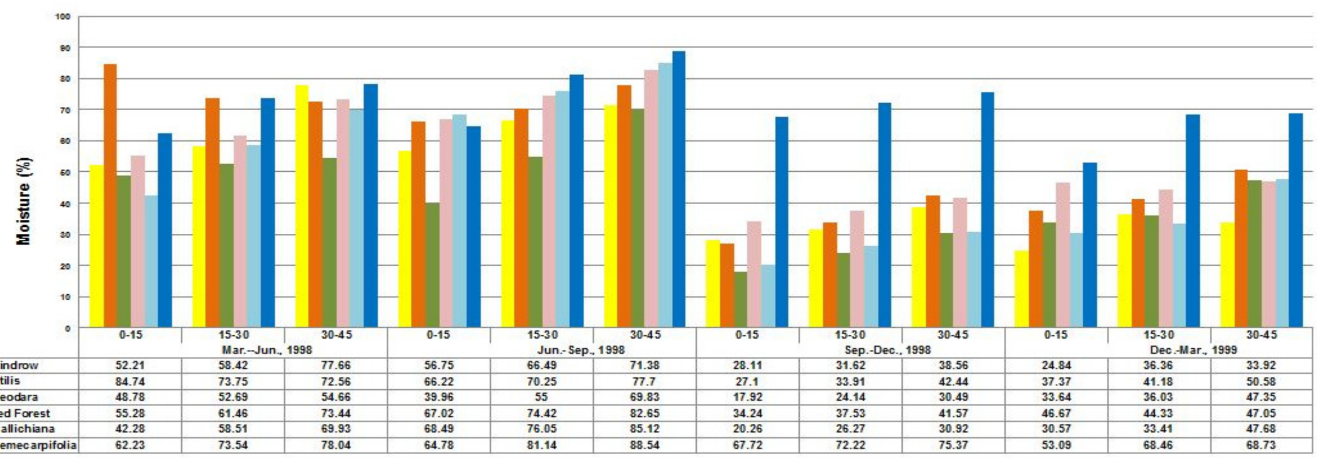
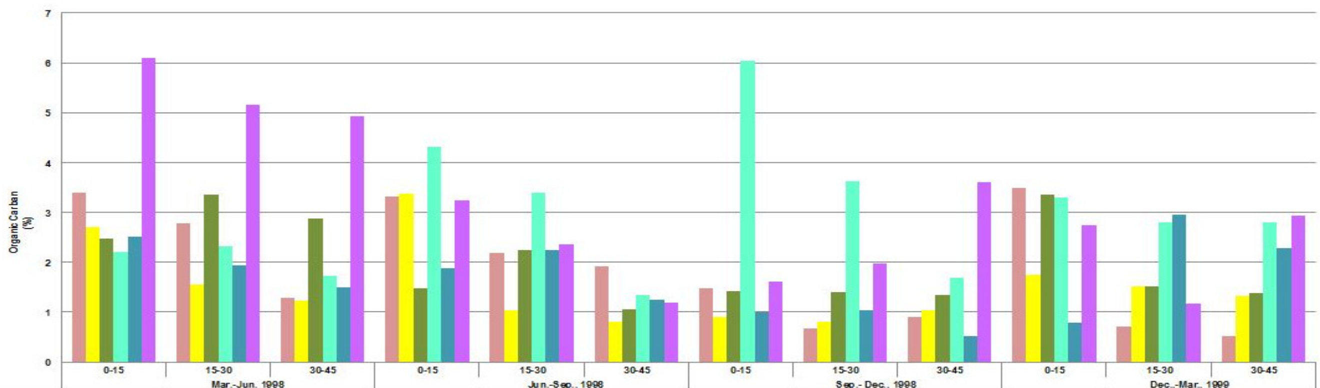


Figure 2. Moisture content (%) under various forest soil depths (cm).

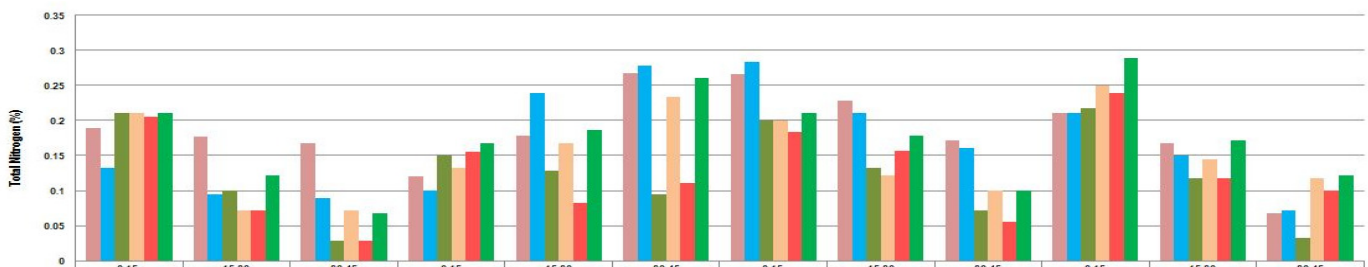
comparison to *B. utilis* dominated forest. Excessive collection of *P. wallichiana* (Kail) and *Q. semecarpifolia* (Kharsu) leaf litters are well known to be collected but the relatively lower inputs of total litter could be a major reason for poor soil nutrient status.

The variations in soil particles are evident between the different forest communities. Though some variation could be due to heterogeneous soil conditions prior to forest community establishment, the possibility of vegetation altering soil chemistry of habitats by their



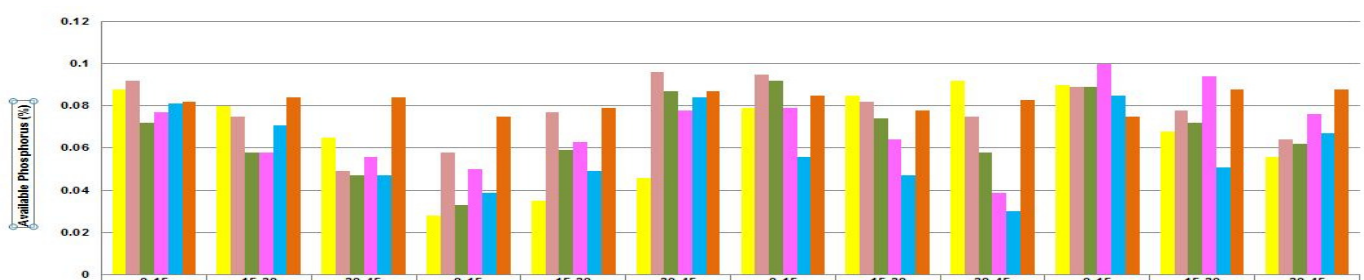
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
	Mar.-Jun. 1998			Jun.-Sep., 1998			Sep.- Dec., 1998			Dec.,-Mar., 1999		
A. pindrow	3.4	2.78	1.29	3.32	2.19	1.92	1.47	0.68	0.9	3.5	0.71	0.52
B. utilis	2.7	1.56	1.23	3.38	1.04	0.81	0.9	0.8	1.03	1.75	1.52	1.33
C. deodara	2.48	3.35	2.88	1.47	2.24	1.05	1.42	1.4	1.35	3.36	1.52	1.39
Mixed Forest	2.21	2.32	1.73	4.32	3.4	1.34	6.05	3.63	1.68	3.29	2.81	2.81
P. wallichiana	2.51	1.94	1.5	1.88	2.24	1.24	1	1.04	0.52	0.79	2.95	2.28
Q. semecarpifolia	6.1	5.15	4.93	3.25	2.36	1.19	1.62	1.97	3.61	2.75	1.17	2.94

Figure 3. Organic carbon content (%) under various forest soil depths (cm).



	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
	Mar.,-Jun., 1998			Jun.-Sep., 1998			Sep.-Dec., 1998			Dec.-Mar., 1999		
A. pindrow	0.189	0.177	0.168	0.12	0.178	0.267	0.266	0.228	0.172	0.211	0.167	0.067
B. utilis	0.133	0.094	0.089	0.1	0.239	0.278	0.283	0.211	0.161	0.211	0.15	0.072
C. deodara	0.211	0.1	0.028	0.15	0.128	0.095	0.2	0.133	0.072	0.217	0.117	0.033
Mixed Forest	0.211	0.072	0.072	0.133	0.167	0.233	0.2	0.122	0.1	0.25	0.144	0.117
P. wallichiana	0.205	0.072	0.028	0.155	0.083	0.111	0.183	0.157	0.056	0.239	0.117	0.1
Q. semecarpifolia	0.211	0.122	0.067	0.167	0.186	0.261	0.211	0.178	0.1	0.289	0.172	0.122

Figure 4. Total nitrogen content (%) under various forest soil depths (cm).

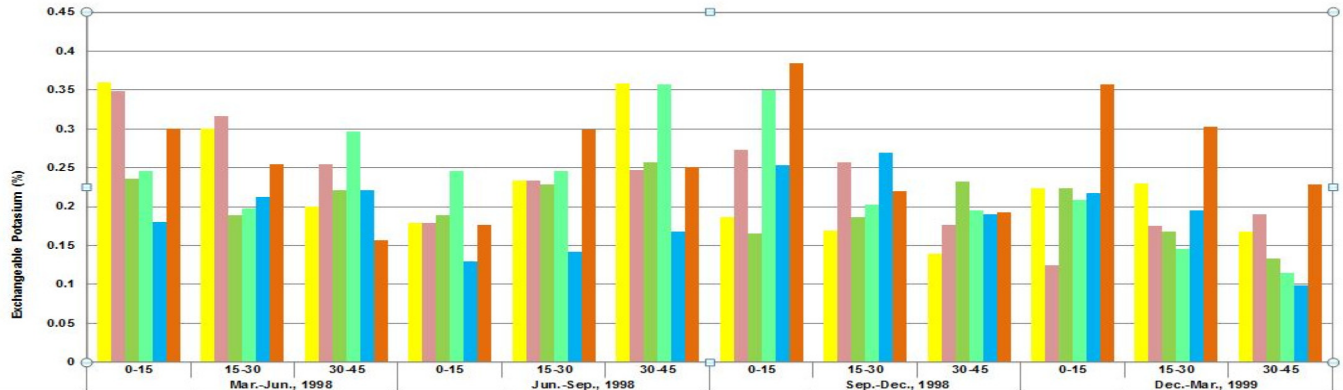


	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
	Mar.-Jun., 1998			Jun.-Sep., 1998			Sep.-Dec., 1998			Dec.-Mar., 1999		
A. pindrow	0.088	0.08	0.065	0.028	0.035	0.046	0.079	0.085	0.092	0.09	0.068	0.056
B. utilis	0.092	0.075	0.049	0.058	0.077	0.096	0.095	0.082	0.075	0.089	0.078	0.064
C. deodara	0.072	0.058	0.047	0.033	0.059	0.087	0.092	0.074	0.058	0.089	0.072	0.062
Mixed Forest	0.077	0.058	0.056	0.05	0.063	0.078	0.079	0.064	0.039	0.1	0.094	0.076
P. wallichiana	0.081	0.071	0.047	0.039	0.049	0.084	0.056	0.047	0.03	0.085	0.051	0.067
Q. semecarpifolia	0.082	0.084	0.084	0.075	0.079	0.087	0.085	0.078	0.083	0.075	0.088	0.088

Figure 5. Available phosphorus (%) under various forest soil depths (cm).

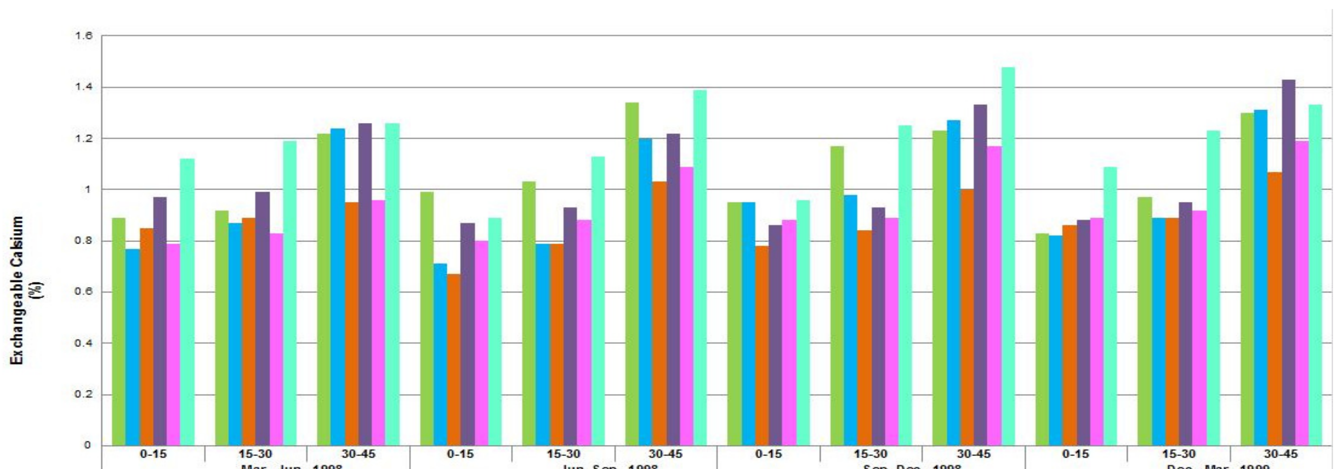
existence and growth in the cool-temperate environment are greater.

The highest and lowest amount of organic carbon under *Q. semecarpifolia* and *A. pindrow* dominated forests for 0 to 15 and 30 to 45 cm soil depths during March to June, 1998 and December to March, 1999 respectively is due to steep slope at *A. pindrow* forest and gentle slope at *Q. semecarpifolia* dominated forests.



	Mar.-Jun., 1998 0-15	Mar.-Jun., 1998 15-30	Mar.-Jun., 1998 30-45	Jun.-Sep., 1998 0-15	Jun.-Sep., 1998 15-30	Jun.-Sep., 1998 30-45	Sep.-Dec., 1998 0-15	Sep.-Dec., 1998 15-30	Sep.-Dec., 1998 30-45	Dec.-Mar., 1999 0-15	Dec.-Mar., 1999 15-30	Dec.-Mar., 1999 30-45
A. pindrow	0.36	0.3	0.2	0.179	0.234	0.358	0.186	0.169	0.139	0.223	0.23	0.168
B. utilis	0.349	0.317	0.254	0.179	0.234	0.247	0.273	0.257	0.176	0.124	0.175	0.19
C. deodara	0.236	0.189	0.221	0.189	0.228	0.257	0.165	0.187	0.232	0.223	0.168	0.133
Mixed Forest	0.246	0.197	0.297	0.246	0.246	0.357	0.35	0.202	0.195	0.209	0.145	0.115
P. wallichiana	0.18	0.213	0.221	0.129	0.142	0.168	0.253	0.269	0.19	0.217	0.195	0.099
Q. semecarpifolia	0.3	0.255	0.157	0.176	0.299	0.251	0.384	0.22	0.193	0.357	0.303	0.229

Figure 6. Exchangeable potassium (%) under various forest soil depths (cm).



	Mar.,-Jun., 1998 0-15	Mar.,-Jun., 1998 15-30	Mar.,-Jun., 1998 30-45	Jun.-Sep., 1998 0-15	Jun.-Sep., 1998 15-30	Jun.-Sep., 1998 30-45	Sep.-Dec., 1998 0-15	Sep.-Dec., 1998 15-30	Sep.-Dec., 1998 30-45	Dec.,-Mar., 1999 0-15	Dec.,-Mar., 1999 15-30	Dec.,-Mar., 1999 30-45
A. pindrow	0.89	0.92	1.22	0.99	1.03	1.34	0.95	1.17	1.23	0.83	0.97	1.3
B. utilis	0.77	0.87	1.24	0.71	0.79	1.2	0.95	0.98	1.27	0.82	0.89	1.31
C. deodara	0.85	0.89	0.95	0.67	0.79	1.03	0.78	0.84	1	0.86	0.89	1.07
Mixed Forest	0.97	0.99	1.26	0.87	0.93	1.22	0.86	0.93	1.33	0.88	0.95	1.43
P. wallichiana	0.79	0.83	0.96	0.8	0.88	1.09	0.88	0.89	1.17	0.89	0.92	1.19
Q. semecarpifolia	1.12	1.19	1.26	0.89	1.13	1.39	0.96	1.25	1.48	1.09	1.23	1.33

Figure 7. Exchangeable calcium (%) under various forest soil depths (cm).

Therefore, it is due to less accumulation of organic matter and slow decomposition rate at *Abies* stand while this situation is vice-versa at *Quercus* stand. The Himalayan soils are young formations and due to the presence of excessive calcium and aluminium, the plant available forms of nutrients are limited.

Although, the significant amount of organic matter is accumulated by the vegetation in the forest floor, the practice of removing most of these resources in the forests close to human habitations and periodic ground fires deprives the soils of much needed inputs that are required for growth and enrichment of vegetation and maintenance of soil fertility levels and ecosystem health.

Conclusion

In the study area a large amount of organic matter is annually accumulated in the forest floor ranging from 5.19 t ha^{-1} yr^{-1} to 7.19 t ha^{-1} yr^{-1} (Tiwari, 2002). During summer, microbial activity is an important biological phenomenon, which enhances the fertility of forest soils. Thus, the soils in these forests are gradually become organic in nature. This is one of the significant factors for enrichment of floral diversity in the study area.

This type of study is very significant to know the ecosystem health and quantification of soil nutrients in natural as well as man-made ecosystems. These nutrients (N, P, K, Ca, etc.) are vital factors, which are responsible for physiology of the vegetation in ecosystems. Thus, their quantification study is one of the significant aspects under scientific investigation.

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