Analysis of the physico-chemical properties of the soil and climatic attribute on vegetation in Central Himalaya

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Abstract: The present study was undertaken in moist temperate forest of Taknaur reserve forest of Uttarkashi in Central Himalaya, India. The aim of the study was to evaluate the effects of climatic attributes and physico-chemical properties of soils on structure and composition of forest vegetation. On the basis of altitude, slope, aspect, and species composition four forest types were selected for the study. Physical and chemical properties of the soil as, soil type, water holding capacity, moisture percentage, total nitrogen, available phosphorus, available potassium, organic carbon, C:N ratioand pH were analyzed for three different depths viz., (i) (0–10 cm), (ii) (11–20 cm), and (iii) (21–30 cm) in all the selected forest types. Phytosociological and diversity parameters viz., density (ha^{-1}), basal cover (m^2ha^{-1}), species richness, Shannon–Wiener diversity index ($\overline{H}$) and concentration of dominance (Cd) were also calculated for each forest type. It was remarked to notice that the entire study area has the sandy loam soil. Water holding capacity was ranged from 15.67 to 22.58. Phosphorus was higher in the soil of lower horizons of all the forest types. pH of all the forest types was slightly acidic. The values of physical and chemical properties of the soil in all the forest types were higher than the values previously recorded for the similar forests of the central Himalaya. The possible reason being luxuriant vegetation and undisturbed nature of these forest types, which is evident from higher values of diversity and other phytosociological parameters.
[J P Mehta, Shreshthamani and V P Bhatt. **Analysis of the physico-chemical properties of the soil and climatic attribute on vegetation in Central Himalaya.** *Nat Sci* 2014;12(11):46-54]. (ISSN: 1545-0740). http://www.sciencepub.net/nature. 8

Keywords: Basal cover, Climate, Density, Diversity, Forest type, Soil type, C:N ratio, Organic carbon.

1. Introduction

The knowledge of climatic conditions and forest soil of any region eases to understand the growth, reproduction and compostion of forest vegetation. The innermost theory for ecology is that climate exerts the dominant control on the spatial distribution of the major vegetation types on a global scale, while on a smaller scale, the contribution of secondary factors such as soil type or topography are important as well (Woodward, 1987, Whittaker, 1975). Climate has long been identified as a primary control on the composition, growth and geographic distribution of plants (Forman 1964, Box 1981). Numerous studies have attempted to correlate climax vegetation and soils (Daubenmire 1979; Daubenmire and Daubenmire 1968; Jensen et al. 1990; Neiman 1988; Sexton 1986; Tisdale and Bramble-Brodahl 1983). In addition, the soil and vegetation have a complex interrelation because they develop together over a long period of time. Soil analysis shows the forest types and plant density of any area because the different species of plants need different types of soils. The selective absorption of nutrient elements by different plant species and their capacity to return them to the soil brings about changes in soil properties (Singh et al. 1986).

Presence of plant elements in soil would give good information towards the knowledge of nutrient cycling and bio-chemical cycle in the soil–plant ecosystem (Pandit and Thampan 1988). Forests in general have a greater influence on soil conditions than most other plant ecosystem types, due to a well-developed ‘O’ horizon, moderating temperature, and humidity at the soil surface, input of litter with high lignin content, high total net primary production, and high water and nutrient demand (Binkley and Giardina 1998). Moreover, different tree species can differ significantly in their influence on soil properties as well as soil fertility (Augusto et al. 2002). The properties of the soil are the important factor for the growth of the plants. Among them, the most important factor is soil fertility, i.e., the essential nutrients available in the soil, for the growth of plants. Soil as a stable and renewable resource is a foundation of organisms' survival. It is considered as a part of an ecosystem, having specific properties and varying from one region to another. Some of these properties including the percentage of nitrogen, phosphorus, potassium, soil acidity, soil salinity and pH affect vegetation cover in an ecosystem (Zarinkafsh, 1987). The numerous failures of the previous studies of climate-soil-vegetation relationship suggest that a basic relationship does not exist or something fundamental has been overlooked. The sporadic successes in correlating climate and soils with vegetation appear to be locally significant, but are not applicable elsewhere. Johnson and Simon (1987) had some success in broad relational correlations.

The forest of Garhwal region of central Himalaya has vast variations in the climate, topography, and soil conditions, which form a very complex ecosystem. Since, the vegetation zones in the Garhwal region clearly reflect edaphic and climatic variations (Bhatta 1981; Bhatt and Purohit 2009) and at the same time the knowledge of physical and chemical properties of soils and climatic conditions of different forest types of temperate region of Garhwal region of central Himalaya is meager. Therefore, the adequate theoretical and practical knowledge of climatic and various forest soils and the complex relationship between the lives of various plants of the forest is necessary to study. However, the present study was undertaken to understand the effects of climatic variables and the soil properties in relation to the forest structure in different forest types of moist temperate Taknaur reserve forest of Uttarkashi Forest Division of Central Himalaya, India.

2. Materials and Methods

2.1 Study Area

The study has been carried out in Taknaur reserve forest of Uttarkashi Forest Division of Central Himalaya. Geographically the forest division extends from 30° 24′ 30″ to 31° 27′ 30″ N latitude and 78° 09′ 40″ to 79° 25′ 05″ E longitude and occupies an area of about 224370.60 ha while the study area stretches between 30° 49′ 41″ to 30° 54′ 06″ N latitude and 78° 35′ 08″ to 78° 40′ 33.7″ E longitude and covers an area of about 66755.90 ha, which is 29.75% of the division, while altitudinally, the area ranges from 1280m amsl to 3500m amsl.

The study area is characterized by undulating topography with gentle slopes on the 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 podzolic soils. Soils are generally gravelly and large boulders are common in the area. Numerous high ridges, deep gorges and precipitous cliffs, rocky crags 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 the rainy season.

For understanding the study area, it was divided in four sites along gradients of altitudes as **Site 1 (1280-1900m amsl)**, **Site 2 (1900-2500m amsl)**, **Site 3 (2500-3000m amsl)** and **Site 4 (3000-3500m amsl)** as per its geographical condition and vegetation type (Table 1 and Fig 1). Physiographic factors (i.e., altitude, latitude) and aspect across different forest types were measured by GPS (Garmin, Rino-130).

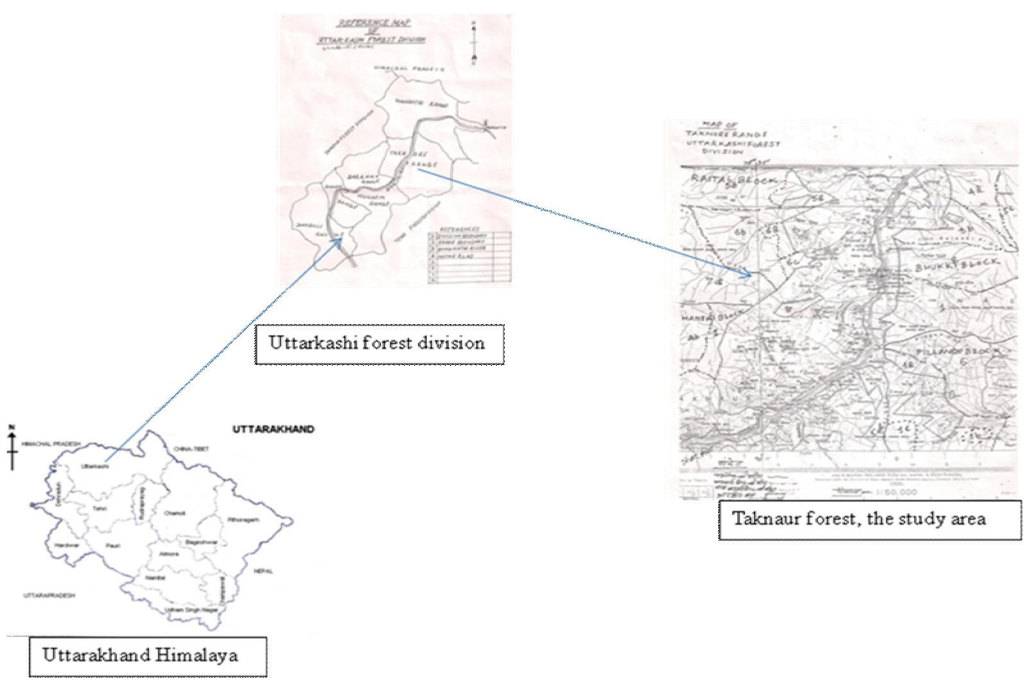

Fig.1. Location map of study area

2.2 Methodology

2.2.1 Vegetation analysis

The composition of the forest types was analyzed by using nested quadrat method as per Kent and Coker (1992). Trees were analyzed by 10 x $10m^2$ 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) by 4pi. The basal cover was multiplied with respective densities of the species to obtain total basal cover (ha^{-1}). For each species, values of frequency, density, and abundance were calculated following Curtis and McIntosh (1950). Species richness (SR) was simply taken as a count of total number of species in that particular forest type.

2.2.2 Soil sampling and analysis

Composite soil samples were collected from three different depths viz., (i) upper (0–10 cm), (ii) middle (11–20 cm) and (iii) lower (21–30 cm) for assessing the physical and chemical properties of the soil in all the selected forest types. The pH of soil was determined directly with the help of control dynamics digital pH meter (model Ap 175E/C). Walkley and Black's rapid titration method as modified by Walkley (1947) was adopted for organic carbon estimation. The factor of 1.724 was used to convert the organic carbon (%) into soil organic matter (%). Available phosphorus was determined in the soil by Olsen et al. (1954) method. Potassium was extracted by neutral normal ammonium acetate method (Morwin and Peach 1951) and was determined by the flame photometer (Evans Electro Selenium Ltd; Holsted Essex, England). Total nitrogen was measured by using the standard Kjeldhal procedure (Bremner and Mulvaney 1982). Total carbon (%) was divided by the total nitrogen (%) to get the values of C:N ratio. All the soil tests were conducted at the district soil testing laboratory, Uttarakashi

3. Results and Discussion

The climatic data for Taknaur reserve forest (Uttarkashi Forest Division) during the study period are set in table 2. It is always observed that the climatic attributes (temperature and rainfall) regulates the vegetation pattern (distribution, stratification, density and diversity) of any region.The present study also verify this rule of the nature. It is evedent from the table 2 that maximum annual rainfall (1146.40 mm) was recorded in site 2 whereas, the minimum (696.72 mm) was recorded at site 4 (Conifer forest). The site 1st (Pine-oak forest) recieved 999.33mm annual rainfall and 1036.51 mm annual rainfall was recorded in site 3rd (mixed broad leaved foret). It clears that the high rainfall favours the mixed braod leaved forest and low rainfall occurs in the coniferous and Pine invading regions. With the increase in water holding capacity and moisture percentage across the aspects and gradient the luxirient and diversified vegetation was observed, while droping down in the water content in the soil along the aspects and gradient the coniferous forest was observed (Table 1 and 2). In addition, in the Pine dominating forest, the annual mean temeprature was found higher (27.83ºC) while in mixed broad leaved forest and *Abies pindrow* dominating forest the annual mean temperature was quite low (19.25 and 17.95 ºC respectively). It was remarkable to notice in the presnt study that in extremely dry regions, there was virtually no vegetation. Similar regularity exists across a warm-cold gradient (Whittaker, 1975). The average relative humidity on monthly basis varies from 36 to 76% in chir pine forest during April and August respectively. In oak forest the relative humidity varies between 49% in April to 87% in August.

Physical and chemical properties of the soil of the study area are presented in table 2. The temperate forest soil of Himalaya is generally considered as sandy loam which is also verified from the present study. The table 2 clearly explains that all the forest types in the study region have the sandy loam soil which indicates that the soil is new. Nitrogen is an essential element for all growth processes in plants, especially in cold regions. If it is not available, the plant remains stunted and comparatively undeveloped. Ecologists have long considered temperate forests systems to be limited by N availability (Mitchell and Chandler 1939). The present study also reveals that temeperate forest has less amount of nitrogen. Soil nitrogen is supposed to be the most limiting nutrient in a majority of ecosystems (Fenn et al. 1998). The values of total nitrogen varied in different forest types from 0.66 kg^{-1} to 0.73 kg^{-1}. In the study area, values of total nitrogen, ranged between 0.66 % (Site 1) and 0.73 % (Site 3) (Table 2). The values of total nitrogen in the present study are higher than the values recorded by earlier workers *viz* Khera et al. (2001), Srivastava et al. (2005), Semwal (2006) Pande et al. (2001) Sharma et al. (2010a) Thadani and Ashton (1995), Kumar et al. (2004), Nazir (2009), and Sharma et al. (2010c) in other parts of central Himalaya. The values of total nitrogen in the study area were higher in upper layers as compared to lower layers. This could be attributed to higher water holding capacity and the presence of heavy litter and humus contents in the upper layers of the studied forest types. The availability of nitrogen depends to a large extent on the amount and properties of organic matter (de Hann 1977). Therefore, the high amount of organic matter in the forest types in the upper layers may also be the reason for richness of nitrogen in the upper layers as compared to lower layers.

Available Phosphorus is inevitable for the vital growth processes in plants. It is observed that Phosphorus is found in all terrestrial systems in the form of organic and inorganic matter, while organic Phosphorus forms are the major available source of phosphorus. Soil organic matter has the inorganic form of Phosphorus transformed into insoluble form in many soils. The rates of weathering also control phosphorus availability to plants. The amount of Phosphorus indicates the character of soil to allow specific plants to grow at a particular site, which is also useful to identify the vegetation type of the area. Phosphorus in turn controls the input levels of plant residues (Brown *et al.* 1994). The carbon–phosphorus and nitrogen–phosphorus ratios vary according to the parent material, which depends upon degree of weathering and by other means (Paul and Clark 1996). It has been reported that a large proportion of Phosphorus is stored in the forms that are unavailable to plants (Murphy 1958), for example, H_2PO_4, which becomes available at low pH values and suffers from fixation by hydrous oxides and silicate minerals (Soromessa *et al*. 2004). Values of available Phosphorus in the present study area varied between 16.12kg ha^{-1} in Oak-mixed-Conifer forest (Site 2) and 33.15kg ha^{-1} in Pine-oak forest (Site 1) (Table 2). The values of available Phosphorus in the present study are much higher to those recorded by some other investigators in other parts of the Garhwal region of central Himalaya (Khera et al. 2001; Kharkwal 2002; Usman et al. 2000; Srivastava et al. 2005; Nazir 2009; Sharma et al. 2010c; Semwal 2006; Pande et al. 2001; Kumar et al. 2004; Pande et al. 2004; Jha and Dimri 1991; Sharma et al. 2010a; Sharma and Badoni 2000; Rawal 1991 and Thadani and Ashton 1995). The Phosphorus was also found higher in the lower horizons of all the forest types, which may be due to the leaching properties of the soils.

The potassium is found in soluble form in all parts of plants, and is responsible for the carbohydrate and protein formations. Potassium activates the enzymes of the plants, which in turn help in the metabolism of the plants, starch synthesis, nitrate reduction, and also plays a role in sugar degradation. Potassium performs very vital processes like regulating transpiration and respiration, influencing enzyme action, and synthesis of carbohydrates and proteins, etc. (Brady 1996). The decrease of potassium is caused by leaching and drainage, which results in the destruction of vegetation (Basumatary and Bordoloi 1992). Values of available potassium in the present study area varied between 154.97 kg ha^{-1} in Conifer-oak mixed forest (Site 4) and 207.10 kg ha^{-1} in mixed broad leaved conifer forest (site 3) (Table 2). The values of available potassium in the present study are much higher to those recorded by some other investigators in other parts of the central Himalaya as, Khera et al. 2001; Kharkwal 2002; Usman et al. 2000; Srivastava et al. 2005; Nazir 2009; Sharma et al. 2010c; Semwal 2006; Pande et al. 2001; Kumar et al. 2004; Pande et al. 2004; Jha and Dimri 1991; Sharma et al. 2010a; Sharma and Badoni 2000; Rawal 1991 and Thadani and Ashton 1995). Since exchangeable potassium in soil largely depends on the composition of parent rock material, no specific reason can be assigned to its differential quantities at different altitudes and sites in various parts of Garhwal region of central Himalaya.

It has been reported that forest soils should be slightly acidic for nutrient supply to be balanced (Leskiw 1998). A fertile soil generally has a pH range between 5.5 and 7.2, which makes the essential elements and nutrients available to the flora. Values of pH in the study area varied between 5.16 (Site 2) and 6.71 (Site 4) (Table 2). Two forest types (mixed oak-conifer fores and mixed broad leaved conifer forest) had soils with pH below 6.0. This may be due to high organic matter content and the undisturbed nature of the soils in the study area. Robertson and Vitousek (1981) and Adams and Sidle (1987) have also recorded low pH in undisturbed natural forests as compared to disturbed ecosystems. The reduction in pH can be attributed to accumulation and subsequent slow decomposition of organic matter, which releases acids (de Hann 1977). The values of pH in present study are similar to those values of pH recorded by Kharkwal 2002; Usman et al. 2000; Srivastava et al. 2005; Sharma et al. 2010c; Semwal 2006; Pande et al. 2001; Kumar et al. 2004; Pande et al. 2004.

The carbon:nitrogen ratio indicates the availability of carbon and nitrogen (C:N) in the soil (Miller 2001). When fresh organic material undergoes decomposition in soil, the rate of decomposition and the amount of humus formed are related to the C:N ratio of the residue. When the proportions are equal, the rate of decomposition increases as the C:N ratio narrows in the soil. This ratio indicates the availability of N in floor material, rate of decay of the forest floor (Fisher and Binkley 2000), and the quality of the organic matter under the canopy (Cote et al. 2000), which can also be linked to the soil microbial biomass (Hogberg 2004). The C:N ratio reflects the release of N in the soil through organic matter decomposition and therefore indicates the degree of decomposition of organic matter in the forest soils (Ulrich 1971). The vegetation influences the C:N ratio and the C:N ratio determines the stand composition (Fisher and Binkley 2000). Values of the C:N ratio in the study area ranged between 2.44 (Site 4) and 3.56 (Site 2) (Table 3). The values of C:N ratio in the present study were similar to Sharma et al. 2010c but much lesser to the values recorded by other workers in central Himalaya, *viz* Khera et al. 2001, Kharkwal 2002; Usman et al. 2000; Srivastava et al. 2005; Sharma et al. 2010c; Semwal 2006; Pande et al. 2001; Kumar et al. 2004; Pande et al. 2004. As all the forest types were young in nature and were undisturbed, C:N ratios were near or below 5. Kawahara and Tsutsuni (1972) have reported that generally the soil of a forest attains the steady state when the C:N ratio reaches 10 and at that level the release of nutrients is rapid due to mineralization.

Phytosociological data of the study area is provided in table 4. The highest total density was evidanced from site 2 (2630 individual ha^{-1}) followed by site 3 (1640 individual ha^{-1}) while, lowest was observed at site 1 (1070 individual ha^{-1}). The highest total basal cover (TBC) was recorded in Site 2 (Mixed oak- conifer forest, mainly *Quercus leucotrichophora, Buxus wallichiana, Lyonia ovalifolia, Cedrus deodara* and *Pinus wallichiana*: 16954.24 m^2 ha^{-1}) followed by site 3 (Mixed broad leaved conifer forest: 13644.60 m^2 ha^{-1}) and Site 4 (Conifer forest mixed, *Abies pindrow* 9729.24 m^2 ha^{-1}), whereas the lowest total basal cover (TBC) was recorded in Site 1 (Pine-oak forest: 7180.65 m^2 ha^{-1}). Species richness ranged between 7 (Pine-oak forest, *Pinus roxburghii-Quercus leucotrichophora*, Site 1) to 23 (Mixed broad leaved conifer forest Site 3). 22 and 13 species were recoded in Site 2 and 4 respectively. Diversity is a combination of two factors, the number of species present, referred to as species richness and the distribution of individuals among the species, referred to as evenness or equitability. Single species populations are defined as having a diversity of zero, regardless of the index used. Species diversity therefore, refers to the variations that exist among the different forms. Species diversity (Shannon–Wiener diversity index) was aslo recorded highest (0.718) for Site 1 followed by site 4 (conifer forest: 0.343) while lowest (0.237) was recorded for site 2 (table 4). The range of diversity in the present study area is certainly lower than any other temeperate forests of Central Himalaya (Ralhan et al*.*, 1982, Gairola et al. 2012). Values on concentration of dominance (Cd) are similar as reported by Whittaker (1965) and Risser and Rice (1971) have reported the range of values of Cd for certain temperate vegetation from 0.19 to 0.99. The values of concentration of dominance (Cd) of the present study were ranged from 0.074 to 0.218, for temperate forests of Taknaur reserve forest (Table 4). Mean (Cd) values of 0.31 to 0.42 (Mishra et al. 2000) and 0.07 to 0.25 (Shivnath et al. 1993) were reported earlier from other parts of Himalaya. The higher value of Cd in the forest growing on upper altitude was due to lower species richness (Bhatt and Purohit, 2009).

High values of phytosociological parameters and chemical properties of the soil complement each other and show that these forest types are very fertile. The high potassium contents were reported under *Quercus semecarpifolia* and *Quercus floribunda* forest types between 2500 and 3000m amsl. Tomlinson and Tomlinson (1990), Sharpe et al*.*, (1992), and Srivastava et al*.*, (2005) are of the view that the oak individuals are related with higher potassium release, which may be the main reason for the higher content of potassium in the soil of these forest types. The values of physical and chemical properties of soil of the present study in all the forest types were higher than the values recorded earlier for similar forests of the central Himalaya. The possible reason for this is the luxuriant vegetation and undisturbed nature of these forest types, which is evident from the higher values of diversity and other phytosociological parameters.

Table: 1. Details of the forest types studied in the study area.

Sites	Forest type	Direction	Altitude (m amsl)	Species composition
Site 1	Pine–oak forest	South-west	1200-1800	***Pinus roxburghii***, *Quercus leucotrichophora* and *Rhododendron arboreum*
Site 2	Mixed oak- conifer forest	North	1800-2400	***Quercus floribunda***, *Lyonia ovalifolia, Buxus wallichiana, Cedrus deodara* and *Pinus wallichiana*
Site 3	Mixed broad leaved conifer forest	North-West	2400-3000	***Quercus floribunda,*** *Swida microphylla Lyonia ovalifolia, Cedrus deodara, Pinus wallichiana* and *Picea smithiana*
Site 4	Conifer forest	North-East	3000-3500	***Abies pindrow***, *Picea smithiana,* and *Cedrus deodara*

Table: 2. Climatic variables and Physico-chemical properties of the soil of different forest type in the study area.

Sites	Climatic variable Temp (°C)	(Mean) Rainfall (mm)	WHC (%)	Average Moisture (%)	Soil Type			Available Minerals N (Kg^{-1})	P (Kg^{-1})	K (Kg^{-1})	pH
Site 1	27.83	999.33	15.67	18.8	Sand	58.6	Sandy loam	0.66	33.15	205.27	6.09
					Silt	30.13					
					Clay	11.26					
Site 2	24.17	1146.40	22.58	24.66	Sand	54.16	Sandy loam	0.71	16.12	163.60	5.16
					Silt	31.43					
					Clay	14.1					
Site 3	19.25	1036.51	23.40	26.33	Sand	58.33	Sandy loam	0.73	28.87	207.10	5.46
					Silt	31.1					
					Clay	10.06					
Site 4	17.95	696.72	17.58	20.5	Sand	48	Sandy loam	0.68	21.75	154.97	6.71
					Silt	24.46					
					Clay	10.33					

Table: 3. Organic carbon, soil organic matter, and C:N ratio in the soils of different forest types of study area.

Forest Type	Organic carbon (%)	Soil organic matter (%)	Carbon:nitrogen ratio
Pine–oak forest	2.70	4.65	4.09
Mixed oak- conifer forest	3.56	6.15	5.01
Mixed broad leaved conifer forest	3.91	6.23	5.35
Conifer forest	2.44	4.21	3.58

Table: 4. Total density, total basal cover, concentration of dominance and species diversity ($\overline{H}$) of the studied forest in Garhwal region of central Himalaya.

Sites	Density (ha^{-1})	Total Basal Cover ($m^2 ha^{-1}$)	Species Richness	Cd	Shannon–Wiener diversity index $\overline{H}$
Pine–oak forest (1)	1070	7180.65	07	0.216	0.718
Mixed oak- conifer forest (2)	2630	16954.24	22	0.074	0.237
Mixed broad leaved conifer forest (3)	1640	13644.6	23	0.076	0.256
Conifer forest (4)	1134	9729.24	13	0.110	0.343

Acknowledgements

Authors are thankful to the editorial board and reviewers to improve the manuscript.

References

1. Adams PW and Sidle RC. Soil conditions in three recent landslides in southeast Alaska. *For Ecol Manag*, 1987; 18(2):93–102.
2. Augusto L, Ranger J, Binkely D, Rothe A. Impact of several common tree species of European temperate forests on soil fertility. *Ann For Sci*, 2002; 59(3):233–253.
3. Basumatary A, Bordoloi PK. Forms of potassium in some soils of Assam in relation to soil properties. *J Indian Soc Soil Sci*, 1992; 40(3):443–446.
4. Bhatt, VP, and Purohit, VK. Floristic structure and phytodiversity along an elevational gradient in Peepalkoti-Joshimath area of Garhwal Himalaya, India. *Nature and Science*, 2009; 7(9), 63-74.
5. Bhatta DD. Nepal Himalaya and change. In: Laal JS (ed), *Himalaya: Aspects of change*. New Delhi: *Oxford University Press*. 1981, p 253-77
6. Binkley D, and Giardina C. Why do species affect soils? The warp and woof of tree-soil interaction. *Biogeochemistry*, 1998, 42(1–2):89–106

7. Box EO. Predicting physiognomic vegetation types with climate variables. *Vegetatio*, 1981, 45: 127–139.
8. Brady NC. The nature and properties of soil, 10th edn. Prentice Hall, New Delhi, 1996.
9. Bremner JM, and Mulvaney CS. Nitrogen total. In: Miller RH, Kieney DR (eds) Method of soil analysis- part 2: chemical and microbiological methods, 2nd edn. Agronomy series No. 9. *American Society for Agronomy and Soil Sciences, Madison*, 1982, pp 595–624.
10. Brown S, Anderson JM, Woomer PL, Swift MJ, and Barrios E. Soil biological processes in tropical ecosystems. In: Woomer PL, Swift MJ (eds) The biological management of tropical soil fertility. *Wiley, Chichester*, 1994; pp 15–46.
11. Cote L, Brown S, Pare D, Fyles J, Bauhus J. Dynamics of carbon and nitrogen mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood. *Soil Biol Biochem,* 2000; 32(8–9):1079–1090
12. Curtis JT, and McIntosh RP. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, 1950 ;31(3):434–455
13. Daubenmire R. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington Agricultural Experiment Station, Washington State University. 1979; p.131.
14. Daubenmire R, and Daubenmire Jean B. Forest vegetation of eastern Washington and north Idaho. Tech. Bull. 60. Pullman, WA: Washington Agricultural Experiment Station, Washington State University. 1968; p.104.
15. de Hann S. Humus, its formation, its relation with the mineral part of the soil and its significance for soil productivity. In: Organic matter studies, vol 1. International Atomic Energy Agency, Vienna, 1977; pp 21–30.
16. Fenn ME, Poth MA, Aber JD, Boron JS, Bormann BJ, Johnson DW, Lenly AD, McNulty SG, Ryan DF, Stottlemeyer R. Nitrogen excess in North American ecosystems: predisposing factors, ecosystem responses and management strategies. *Ecol Appl,* 1998; 8(3):706–733.
17. Fisher RF, and Binkley D. Ecology and management of forest soils, 3rd edn. Wiley, New York, 2000; p 489.
18. Forman RTT (1964). Growth under controlled conditions to explain the hierarchical distributions of a moss, *Tetraphis pellucida.* Ecological Monographs 34: 1–25.
19. Gairola S, Sharma CM, Ghildiyal SK, and Suyal S. Chemical properties of soil in relation to forest compostion in moist temperate valley slopes of Garhwal Himalaya. *Environmentalist*, 2012; DOI 10.1007/s10669-012-9420-7.
20. Hogberg NM. Carbon and nitrogen relations among soils, microbes and plants in boreal forests. *PhD Thesis, Swedish University of Agricultural Sciences*, 2004.
21. Jensen ME, Simonson GH, and Dosskey M. Correlation between soils and sagebrush-dominated plant communities of northeastern Nevada. *Soil Science Society of America Journal*, 1990; 54: 902-910.
22. Jha MN, and Dimri BM (). Soil nutrients and forest productivity in four natural stands. *J Indian Soc Soil Sci* 1991; 39:735–738.
23. Johnson CG, and Simon SA. Plant associations of the Wallowa-Snake Province, Wallowa-Whitman National Forest. R6-ECOL-TP-255a-86. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 1987; p 400.
24. Johnson DW, and Ball JT. Interactions between CO2 and nitrogen in forests: can we extrapolate from the seedling to the standlevel? In: Koch GW, Mooney HA (eds) Carbon dioxide and terrestrial ecosystems. Academic Press, San Diego, 1996; p 443.
25. Kawahara T, and Tsutsuni T (). Studies on the circulation of Carbon and Nitrogen in forest ecosystem. *Bull Kyoto Univ For* 1972, 44:141–158.
26. Kent M, and Coker P. Vegetation description and analysis. Belhaven Press, London,1992.
27. Kharkwal G. Spatial pattern of plant species diversity with particular reference to forest herbs along an altitudinal transect in Central Himalaya. PhD Thesis, Kumaun University, Nainital, Uttarakhand, India, 2002.
28. Khera N, Kumar A, Ram J, Tewari A (). Plant biodiversity assessment in relation to disturbances in mid-elevational forest of Central Himalaya, India. *Trop Ecol*, 2001; 42(1):83–95.
29. Kumar M, Rajwar GS, and Sharma CM (). Physico-Chemical properties of forest soils along altitudinal gradient in the Garhwal Himalayas. *J Hill Res,* 2004; 17(2):60–64.
30. Leskiw LA. Land capability classification for forest ecosystem in the oil stands region. Alberia Environmental Protection, Edmonton, 1998.
31. Miller C. Understanding the carbon-nitrogen ratio. Reprinted from ACRES. *A voice for Eco-agriculture*, 2001; 30(4):20.
32. Mishra A, Sharma CM, Sharma SD and Baduni NP. Effect of aspect on the structure of vegetation community of moist bhabar and tarai *Shorea robusta* forest in Central Himalaya. *Indian Forester*, 2000; 126(6), 634-642.

33. Mitchell HL, and Chandler RF. The nitrogen nutrition and growth of certain deciduous trees of Northeastern United States. The Blackrock Forest Bulletin no. 11. Cornwall-on-the-Hudson, NY, 1939.
34. Morwin HD, Peach PM. Exchangeability of soil potassium in and, silt and clay fractions as influenced by the nature of complementary exchangeable cations. *Proc Soil Sci Soc Am*, 1951;15:125–128.
35. Murphy HP. The fertility status of some soils of Ethiopia. College of Agriculture, Jimma,1958.
36. Nazir T. Estimation of site quality of important temperate forest covers on the basis of soil nutrient and growing stock in Garhwal Himalaya. D.Phil. Thesis, HNB Garhwal University, Srinagar (Garhwal), Uttarakhand, India, 2009.
37. Neiman KEJr. Soil characteristics as an aid to identifying forest habitat types in northern Idaho. Res. Pap. INT-390. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 1988; p.16.
38. Olsen SR, Cole CV, Watanabe FS, and Dean LA. Estimation of available phosphorus in soils by extraction with Sodium bicarbonate. Department of Agriculture Circular, US, 1954; p 939.
39. Pande PK, Negi JDS, and Sharma SC. Plant species diversity and vegetation analysis in moist temperate Himalayan forest. *Indian J For*, 2001; 24(4):456–470.
40. Pande PK, Negi JDS, and Sharma SC. Plant species diversity, composition, gradient analysis and regeneration behaviour of some tree species in a moist temperate western Himalayan forest ecosystem. *Indian For*, 2002; 128(8):869–886.
41. Pandit BR, and Thampan S. Total concentration of P, Ca, Mg, N & C in the soils of reserve forest near Bhavnagar (Gujarat State). *Indian J For,* 1988; 11(2):98–100.
42. Paul EA, and Clark FE. Soil microbiology and biochemistry, 2nd edn. Academic Press, San Diego, 1996.
43. Phillips EA. Methods of vegetation study. Henry Holt, New York, 1959; p 107.
44. Ralhan PK, Saxena AK, and Singh JS. Analysis of forest vegetation at and around Nainital in Kumaun Himalaya. *Proc. Indian National Science Academy*. B, 1982; 48, 121-137.
45. Rawal RS. Woody vegetation analysis along an elevational gradient (1600-3400 m) of upper Sarju catchment, Kumaun Himalaya. PhD Thesis, Kumaun University, Naini Tal, Uttarakhand, India, 1991.
46. Robertson GP, and Vitousek PM. Nitrification in primary and secondary succession. *Ecology*, 1981; 62:376–386.
47. Semwal S. Studies on phytosociology, diversity patterns and competition along an altitudinal gradient in a part of lesser Himalaya in Garhwal, Uttaranchal. D.Phil. Thesis, HNB Garhwal University, Srinagar (Garhwal), Uttarakhand, India, 2006.
48. Sexton WT. Selected forest soil-parent material relationships in the Clearwater and Nez Perce National Forests. Moscow, ID: University of Idaho. *Dissertation*, 1986.
49. Shannon CE, and Weaver W. The mathematical theory of communication. University of Illinois Press, Urbana, 1963; p 117.
50. Sharma CM, and Baduni NP. Effect of aspects on the structure of some natural stands of Abies pindrow in Himalayan moist temperate forest. *Environmentalist*, 2000, 20(4):309–317
51. Sharma CM, Baduni NP, Gairola S, Ghildiyal SK, and Suyal S. Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *For Ecol Manag*, 2010b;260(12):2170–2179.
52. Sharma CM, Baduni NP, Gairola S, Ghildiyal SK, Suyal S. The effect of slope aspects on forest compositions, community structures and soil properties in natural temperate forests in Garhwal Himalaya. *J For Res,* 2010c; 21(3):331–337.
53. Sharma CM, Gairola S, Baduni NP, Ghildiyal SK, Suyal S. Variation in carbon stocks on different slope aspects in seven major forest types of temperate region of Garhwal Himalaya, India. *J Biosci*, 2011; 36(4):701–708.
54. Sharma CM, Gairola S, Ghildiyal SK, Suyal S. Forest dependent livelihood in relation to socio-economic status of the people in temperate villages of Garhwal Himalaya: a case study. *Mt Res Dev*, 2009; 29(4):308–319.
55. Sharma CM, Gairola S, Ghildiyal SK, Suyal S. Physical properties of soils in relation to forest composition in moist temperate valley slopes of the Central Western Himalaya. *J For Sci*, 2010d; 26(2):117–129.
56. Sharma CM, Suyal S, Ghildiyal SK, and Gairola S. Role of Physiographic factors in distribution of Abies pindrow (Silver Fir) along an altitudinal gradient in Himalayan temperate Forests. *Environmentalist*, 2010a ; 30(1):76–84.
57. Sharpe WE, Swistock BR, and Dewalle DR. A greenhouse study of northern red oak seedling growth of two forest soils at different stages of acidification. *Water Air Soil Pollut*, 1992; 66(1–2):121–133.

58. Simpson EH. Measurement of diversity. *Nature,* 1949;163:688.
59. Singh AK, Parsad A, Singh B. Availability of phosphorus and potassium and its relationship with physico-chemical properties of some forest soils of Pali-range (Shahodol, M.P.). *Indian For*, 1986;112(12):1094–1104.
60. Soromessa T, Teketay D, and Demissew S. Ecological study of the vegetation in Gamo Gofa zone, southern Ethiopia. *Trop Ecol*, 2004; 45(2):209–221.
61. Srivastava RK, Khanduri VP, Sharma CM, and Kumar P. Structure, diversity and regeneration potential of oak-dominant conifer mixed forest along an altitudinal gradient in Garhwal Himalaya. *Indian For*, 2005;131(12):1537–1553.
62. Stevenson FJ. Humus chemistry, 2nd edn. Wiley, New York, 1994.
63. Thadani R, and Ashton PMS. Regeneration of Banj oak (Quercus leucotrichophora A. Camus) in the central Himalaya. *For Ecol Manag,* 1995; 78:217–224.
64. Tisdale EW, and Bramble-Brodahl M. Relationships of site characteristics to vegetation in canyon grasslands of west central Idaho and adjacent areas. *Journal of Range Management*, 1983; 36: 775-778.
65. Tomlinson GH, and Tomlinson FL. Effects of acid deposition on the forests of Europe and North America. CRC Press, Boca Raton, FL, 1990; p 281.
66. Ulrich B. The ecological value of soil chemical data. In: Duvigneaud P (ed) Productivity of forest ecosystems. UNESCO, Paris, 1971; pp 101–105.
67. Usman S, Singh SP, Rawat YS, and Bargali SS. Fine root decomposition and nitrogen mineralisation patterns in Quercus leucotrichophora and Pinus roxburghii forests in Central Himalaya. *For Ecol Manag*, 2000; 131:191–199.
68. Walkley A. An estimation of methods for determining organic carbon and nitrogen in soils. *J Agric Sci*, 1947; 25:598–609.
69. Whittaker RH. Communities and Ecosystems (MacMillan, New York,) 1975; pp.385.
70. Wilde SA. Forest soils and forest growth. Publishers Periodical Experts Book Agency,1946.
71. Woodward FI. Climate and plant distribution (Cambridge University Press,) 1987; pp.174.
72. Zarinkafsh M. Applied Pedology. Tehran University, 1987.

9/28/2014