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Soil physico-chemical characteristics of bryophytic vegetation residing Kedarnath Wildlife Sanctuary (KWLS), Garhwal Himalaya, Uttarakhand, India

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Abstract

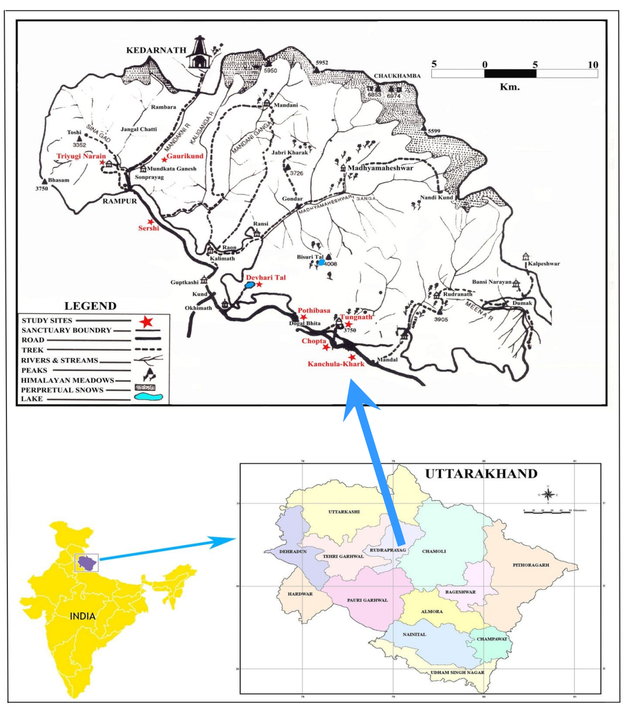
The present study was undertaken at eight different sites of Kedarnath Wildlife Sanctuary (KWLS) of Garhwal Himalaya, India to understand the physico-chemical properties of soils and influence of bryophytic communities on the status of nutrient availability. In the bryophytes dominated sites the values of organic carbon (0.21%) and nitrogen (0.04%) were found to be low as compared to values for forest soils dominated by higher plants which suggests that bryophytes prefer to occupy the barren sites with low organic matter. Mean available phosphorus content in soil of various sites varied between 13.02 Kgha^{-1} and 16.28 Kgha^{-1} with estimated mean exchangeable potassium content ranged between 145.60 Kgha^{-1} and 216.16 Kgha^{-1}. A significant negative correlation between soil temperature and moisture content was observed, whereas organic carbon and available phosphorus exhibited significantly positive correlation. Besides the characteristics of soil underneath the bryophytic vegetation, the study also highlights the kind of bryophytes communities found along altitudinal variation and soil types.

Keywords: Liverworts, Hornworts, Mosses, Potassium, Phosphorus, Nitrogen, Carbon, Nutrient availability.

Introduction

Bryophytes form a significant component of vegetation especially in the temperate biome. They are able to grow on variety of habitats on the upper part of the ground containing humus under the forest, on soil, on rocks, in crevices, on tree barks, dead logs and on the branches of trees. They are adapted to survive on such surfaces, which have least amount of humus. The bryophytes play an important role in the ecosystem, as they fill the gaps and maintain the moisture (Bahuguna *et al*., 2012). Bryophytes play an important role in soil conservation in the tropics by covering soil to protect soil erosion and leaching of minerals.

Fig. 1. Map of the study area.



The growth of vegetation depends upon the nutrient supplying capability of the soil (Jha *et al*., 1984). The state of temperature and humidity along with climatic factors exert a special influence on the distribution of vegetation and the development of the soils. Moisture in the soil promotes the movement of nutrient in the soil and helps to the growing roots and rhizoids. Although numerous studies related to physico-chemical properties of soils of Garhwal Himalaya in relation to growth and distribution of higher plants are available (Semwal *et al*., 2009; Bhandari *et al*., 2000; Gairola, 2010; Sharma *et al*., 2009, 2010a,b,c, 2011), but there is paucity of information about soil properties of bryophytic vegetation. Keeping the aforesaid facts in view the present study was undertaken in Kedarnath Wildlife Sanctuary (KWLS) of Garhwal Himalaya, India to understand the physico-chemical properties of soils in relation to bryophytic vegetation.

Study area

The study was conducted in KWLS of Garhwal Himalaya, India (Fig.1). Eight sites in the KWLS were selected for the study *viz*., Chopta (CH), Devharital (DT), Kanchula-khark (KK), Pothivasha (PV) and Tungnath (TN) in the southern region and Gaurikund (GK), Sershi (SH) and Triyuginarayan (TNR) in the northern region of the KWLS (Table 1). Kedarnath Wildlife Sanctuary is one of the largest protected areas in the Western Himalaya, covering an area of 975 km^2 between latitude 30°25' - 30°45' N and longitude 78°55' - 79°36' E. The sanctuary harbours rich diversity of flora and fauna and associated

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Table 1. Characteristics and meteorological details of the study sites

Study sites	Altitude (m asl)	Forest type	Mean daily temperature (°C)		Annual rainfall (mm)
			Minimum	Maximum	
Sershi	1760	Oak mixed broad leaf	6.0 (Jan) to 20.0 (Jul)	13.0 (Dec) to 28.0 (Aug)	3120.00
Gaurikund	2125	Oak mixed broad leaf	4.3 (Dec) to 10.1 (Jun)	15.6 (Dec) to 26.4 (Jun)	2895.00
Pothivasha	2235	Oak-*Rhododendron* mixed broad leaf	4.3 (Jan) to 10.7 (Jun)	16.3 (Jan) to 27.7 (Jun)	3032.87
Devharital	2260	Oak-*Rhododendron* mixed broad leaf	4.5 (Jan) to 10.3 (Jun)	16.4 (Dec) to 26.4 (Jun)	3387.74
Triyuginarayan	2340	Oak mixed broad leaf	5.2 (Jan) to 10.3 (Aug)	12.2 (Dec) to 28.6 (Jun)	3195.34
Kanchula-khark	2685	Oak-*Rhododendron* mixed broad leaf	2.7 (Jan) to 9.3 (Jun)	7.5 (Jan) to 18.7 (Jun)	1735.04
Chopta	2757	*Rhododendron* - Oak mixed broad leaf	3.8 (Jan) to 10.5 (Jun)	9.3 (Dec) to 21.4 (Jun)	2665.50
Tungnath	3662	Alpine meadow	6.1 (Oct) to 10.4 (Jul)	18.5 (Oct) to 20.1 (Jun)	3927.60

great cultural heritage. The study area is characterized by undulating topography with gentle slopes on north, north-east and north-west faces and somewhat steep slopes on south and south-west directions. 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 sanctuary 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 (Agrawala, 1973).

The diversity of vegetation in the KWLS reflects the complex and varied interaction of the climate, geology and the topography. About 44.4% to 48.8% area of the sanctuary is forest covered, 7.7% area is enveloped with alpine meadows and scrubs, 42.1% area is rocky or under permanent snow and 1.5% represents formerly forested areas that have been degraded (Agrawala, 1973). The forest vegetation in KWLS is comprised of many broadleaved and conifer tree species *viz*., *Abies pindrow*, *Abies spectabilis*, *Acer pictum*, *Aesculus indica*, *Alnus nepalensis*, *Betula utilis*, *Cedrus deodara*, *Cupressus torulosa*, *Juglans regia*, *Juniperus communis*, *Myrica esculenta*, *Pinus roxburghii*, *P. wallichiana*, *Quercus leucotrichophora*, *Q. floribunda*, *Q. semecarpifolia*, *Rhododendron arboreum*, *Taxus baccata*, etc., growing between 1200m asl and 3200m asl. Dominating shrubs of the study area are *Artemisia roxburghiana*, *Berberis asiatica*, *Cotoneaster acuminatus*, *Ephedra gerardiana*, *Eupatorium adenophorum*, *Inula cappa*, *Juniperus communis*, *Rhododendron anthopogon*, *Rhododendron lepidotum* (in alpine pastures), etc. Further, TN region harbours more than 250 vascular plant species (Semwal & Gaur, 1981) and 177 species of mosses (Negi & Gadgil, 1997). Recently Bahuguna (2009) has recorded 115 species of mosses belonging to 65 genera, 25 families and 11 orders from the study area and Gairola *et al*. (2010) have recorded 338 species of vascular plants from the southern region of KWLS.

Material and methods

Soil samples were collected during the rainy season when growth of bryophytes is at its peak. Soil samples were collected just below the carpet of bryophytic vegetation at a depth of 0-10 cm layer from three different locations of a single site; the three samples were mixed at each location so as to obtain a representative composite soil sample from a particular location. The samples were tightly packed in plastic bags with field details (site and depth) and brought to the laboratory. The samples were air dried for analyzing chemical parameters and oven dried for physical parameters.

The soil colour was worked out directly with the help of Munsell Soil Colour Chart (Munsell Colour Division, Kollmorgen Corporation, U.S.A.) and was defined in terms of Hue, Value and Chroma characteristics. The study of soil texture was carried out by using sieves of different pore sizes. Textural classes *viz*., pebble, gravel, sand, silt and clay were expressed in percentage of total dry weight of the samples on account of the standard sizes as described in the Sand Shaker Mechanical Sieve Field Analysis Kit (Geotech Environmental Equipment, Inc, Colorado) and textural classes were determined using Triangular Diagram as per U.S.D.A system. Soil temperature (ST) was measured at 5 cm depth on each sampling site by soil thermometer (Soil analysis field kit, Forestry Supplier Inc.). The soil moisture percentage was calculated on the basis of fresh soil weight. About 100 g of soil beneath bryophytes at 0-10 cm depth was oven dried (at 80°C until a constant weight was observed) and dry weight was recorded. Moisture content (MC) was calculated as per Donahue *et al.* (1987). Water holding capacity (WHC) was measured as per Goel & Trivedi (1992). For estimating soil pH, 5 ml of double distilled water was added to 1g of fresh soil sample (1:5 soil suspensions) and well stirred for 15 minutes on the magnetic stirrer. The contents were then allowed to settle down for 30 minutes and the clear solution was used to measure pH with the help of digital pH meter (Control Dynamics, Model - AP X 175 E/C). The organic carbon (OC) content was estimated as per Okalebo *et al.* (1993). Soil organic matter (SOM) was calculated as per the method given by Walkley & Black (1934). The standard procedure as given by Allen (1974) was followed for the estimation of total nitrogen (N). Available phosphorus (AP) ($Kgha^{-1}$) was estimated using standard procedure as described by Olsen *et al.* (1954). Exchangeable potassium (EK) ($Kgha^{-1}$) was estimated as per Jackson (1958). A two-tailed Pearson correlation coefficient was calculated between various soil parameters using SPSS version 16 software. The collected specimens were numbered, labeled and kept in polythene bags.

The liverworts and hornworts specimens were examined morphologically and anatomically. Identification was done with the help of Botanical monograph of

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Table 2. Variation in soil texture (%) and soil colour at different study sites of KWLS

Study Sites	Soil Separates (%)					Texture type	Hue/ Value/ Chroma	Colour type
	Pebble	Gravel	Coarse sand	Very fine sand	Mixed ratio of silt and clay			
Chopta	14.20±0.04	8.70±0.01	30.57±0.03	40.22±0.01	6.17±0.01	Sandy	5Y/7/4	Pale yellow
Devharital	21.33±0.00	2.80±0.01	22.07±0.01	42.15±0.01	5.64±0.00	Sandy	10Y/5/2	Grayish brown
Gaurikund	39.19±0.01	5.66±0.02	20.25±0.02	29.53±0.02	4.27±0.02	Sandy	5Y/7/4	Pale yellow
Kanchula-khark	21.77±0.01	2.62±0.02	20.95±0.01	44.11±0.00	4.18±0.02	Sandy	10YR/6/2	Light brownish grey
Pothivasha	18.54±0.02	10.18±0.02	30.16±0.02	37.49±0.02	3.27±0.03	Sandy	2.5Y/7/4	Pale yellow
Sershi	22.55±0.03	7.86±0.02	21.16±0.03	44.25±0.02	3.89±0.02	Sandy	5YR/4/1	Dark grey
Triyuginarayan	43.14±0.02	5.16±0.04	16.15±0.03	29.55±0.02	5.23±0.03	Sandy	5Y/6/3	Pale olive
Tungnath	30.44±0.09	5.16±0.01	18.17±0.03	41.23±0.16	3.13±0.02	Sandy	2.5Y/6/2	Light brownish grey

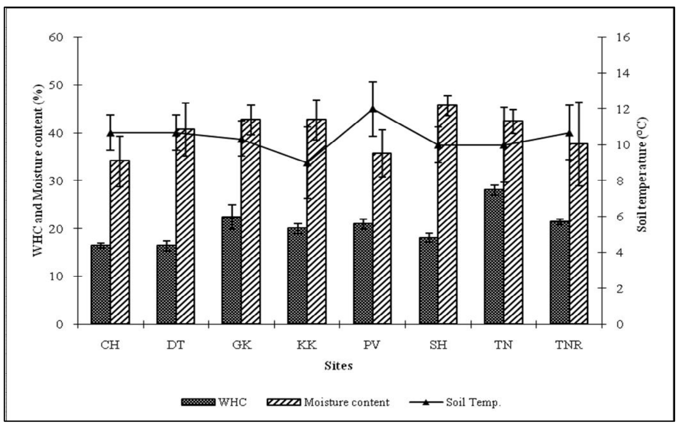
Chopra (1975) and Fascicle of Gangulee (1969-1980) was duly consulted for the identification of mosses and other currently available taxonomic treatise. Samples were submitted in the Herbarium of HNB Garhwal University, Srinagar, Garhwal (GUH).

Results and discussion

Soil physical characteristics

Soils indicated peculiar variations of colours in different sites of the study area at the depth of 0-10 cm. The soil colour in respect to different bryophytic vegetation was light brownish grey at KK and TN dominated by *Bryum*, *Entodon*, *Thuidium* and *Pogonatum*; pale yellow at CH dominated by *Brachymenium*, *Dicranum* and *Brachythecium*; light brown at GK and PV dominated by *Funaria*, *Hypnum*, *Hyophila* and *Philonotis*; greyish brown at DT dominated by *Ditrichum*, *Bryum* and *Plagionium*, pale olive at TNR dominated by *Atrichum*, *Merceya* and *Thudium* and dark grey at SH dominated by *Anoectangium* and *Hymenostylium*. Soils of the study area belonged to the sandy category (Table 2). The temperature of soil was high (maximum) in PV (12.00±1.53°C) and minimum in KK (9.00±2.00°C). Soil at PV was covered by the continuous mat of *Entodon*, *Hypnum* and *Thuidium*. The values of mean soil MC ranged between 34.00±5.29% at CH and 45.67±2.08% at SH. Mean soil WHC varied from a lowest of 16.33±1.53% at DT to a highest of 28.00±1.00% at TN (Fig.2).

Fig. 2. Variation in water holding capacity (%), soil moisture content (%) and soil temperature (°C) at different sites.



Abbreviations in Figures 2 to 4: (CH-Chopta, DT-Devharital, GK-Gaurikund, KK-Kanchula-khark, PV-Pothivasha, SH-Sershi, TN-Tungnath, TNR-Triyuginarayan)

Soil chemical characteristics

Mean AP content varied from a lowest of 13.02±0.00 Kgha^{-1} at TNR to a highest of 16.28±0.00 Kgha^{-1} at SH. Mean EK content ranged from 145.60±0.10 Kgha^{-1} at KK and PV to 216.16±0.01 Kgha^{-1} at CH. Most of the sites of bryophytic vegetation reflected acidic nature, with a pH ranging between 6.57±0.12 (CH) and 7.00±0.10 (KK) (Fig.3). Mean N content ranged between 0.04±0.02% (KK) and 0.11±0.06% (SH). The mean OC was significantly low at all the sites. Mean OC content varied from a lowest of 0.21±0.01% at TNR to a highest of

Fig. 3. Variation in exchangable potassium (Kgha^{-1}), available phosphorus (Kg h^{-1}) and soil pH at different sites.

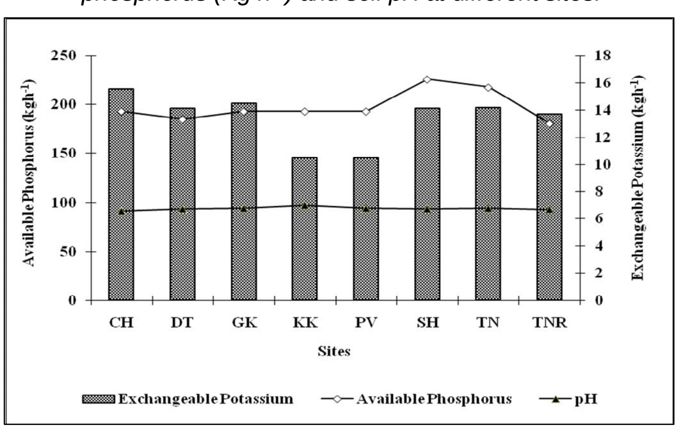
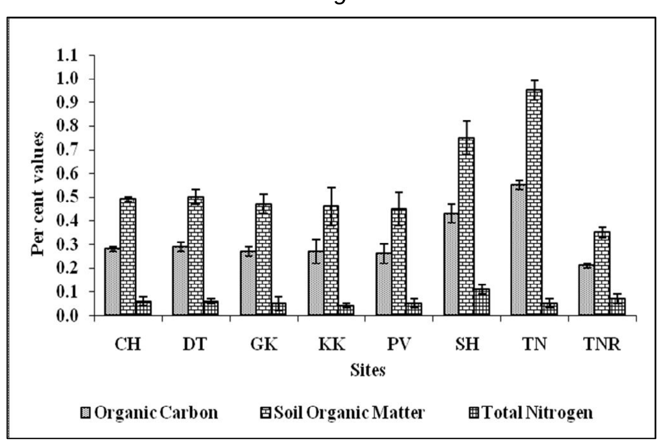


Fig. 4. Percent variation in organic carbon, soil organic matter and total nitrogen at different sites



0.55±0.01% at TN. The values of mean SOM content ranged between 0.35±0.01% at TNR and 0.95±0.01% at TN (Fig.4). The negative correlation (-0.677) between ST and MC was recorded to be significant whereas OC and

AP showed significant positive correlation (0.879). However, a significant negative correlation (-0.797) was recorded for EK and pH (Table 3).

Table 3. Correlation between various physico-chemical parameters of soils of bryophytic vegetation

	WHC	MC	ST	pH	AP	EK	OC
MC	0.235	1.000	-	-	-	-	-
ST	-0.117	-0.677*	1.000	-	-	-	-
pH	0.244	0.465	-0.533	1.000	-	-	-
AP	0.306	0.589	-0.311	0.055	1.000	-	-
EK	-0.112	0.012	-0.037	-0.797**	0.166	1.000	-
OC	0.519	0.518	-0.310	0.048	0.879**	0.262	1.000
N	-0.353	0.327	-0.006	-0.348	0.515	0.379	0.247

* Correlation is significant at the 0.05 level and **at the 0.01 level. Abbreviations: WHC= Water Holding Capacity; MC= Moisture Content; ST= Soil Temperature; AP= Available Phosphorus; AK= Available Potassium; OC= Organic Carbon; N= Total Nitrogen.

The mosses were mostly found growing under forest and on slopes including those of alpine meadows. Liverworts were found abundantly under moist, shady and dense forests, reflecting their shade loving nature. The mosses growing on steep slopes and on high gradient of the alpine area (where almost all the water drains away) were observed to be quite healthy and rich in density. It may be because of their capability to hold large amount of water with the help of their mats, peat and cushion like growth forms. Hornworts were observed to be frequent along streams in shady habitats under dense temperate-subalpine forests. Dominant bryophyte species present at different study sites are given in Table 4. Near Tungnath (3,662m asl), above the timber line, patches of mosses were found on the alpine slopes and liverworts, under shady cleavages of big boulders and in rock crevices. Liverworts and hornworts abundantly were found under dense, humid forest along streams in the study sites as in CH, DT, GK, KK, PV, SH and TNR forests (1700-2800m asl). Some well flourishing species were *Athalamia pinguis*, *Conocephallum conicum*, *Cyathodium tuberosum*, *Dumortiera hirsuta*, *Marchantia polymorpha*, *Pellia endiviiaefolia*, *Plagiochasma appendiculatum*, *Targionia indica* and *Anthoceros punctatus*, etc. The moss species (terrestrial as well as epiphytic) *viz*., *Conocephallum*, *Cyathodium*, *Plagiochasma*, etc., were observed growing abundantly along the roadside from Kund to GK (1000-2200m asl) under rock crevices, at shady places.

The high altitude forests can be recognized to new soil deposition, high species diversity and extreme species interaction. Buck (1964) has shown that the distribution of forest vegetation is determined by the soil conditions and slope exposure. The soil samples from each site indicated peculiar variations of colours in respect to bryophytic vegetation. The colour of soils is a function of a number of factors *viz*., forest type, weathering of different types of mineral bearing rocks, nature of litter decomposition and by other environmental factors. The colour of soil is a reliable indicator of soil properties. It was observed that soil colour were light brownish grey at KK and TN; pale yellow at CH, GK and PV; grayish brown at DT; pale olive at TNR and dark grey at SH. The structure of soil and its physical constitution like size and shape of soil particles inside the soil classify the nature of soil (Jongmans *et al*., 2001). With reference to soil texture it was observed that bryophytic vegetation of the study area grew on the soils with the sandy texture. The upper layer of soil by the decomposition of litter becomes soft, smooth and mineral rich thus it provides a suitable platform for the growth of bryophytes. 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

Table 4. Dominant bryophyte species present at different study sites

Study sites	Dominant bryophyte species
Sershi	*Bryoerythrophyllum dentatum*, *Bryum badhwari*, *Calymperes calcuttense*, *Funaria hygrometrica*, *Merceya gedeana*, *Philonotis mollis*, *Thuidium cymbifolium*.
Gaurikund	*Anomobryum cymbifolium*, *A. filiforme*, *A. nitidum*, *Brachymenium microstomum*, *B. paradoxum*, *Merceya gedeana*, *Philonotis fontana*.
Pothivasha	*Anomobryum nitidum*, *Brachymenium ochianum*, *Bryum argenteum*, *B. uliginosum*, *Leptodontium viticulosoides*, *Plagiomnium japonicum*, *Thuidium squarrosulum*, *T. talongense*.
Devharital	*Brachymenium nepalense*, *Bryum alpinum*, *Entodon pulchellus*, *Leptodontium viticulosoides*, *Merceya gedeana*, *Plagiomnium rostratum*, *Thuidium squarrosulum*.
Triyuginarayan	*Atrichum aculeatum*, *Bryoerythrophyllum atrorubens*, *Bryum paradoxum*, *Calymperes calcuttense*, *Hyophila involuta*, *Merceya gedeana*, *Pohlia elongata*, *Thuidium haplohymenium*.
Kanchula-khark	*Bryoerythrophyllum atrorubens*, *Entodon chloropus*, *E. prorepens*, *Holomitrium densifolium*, *Mniobryum wahlenbergii*, *Mnium spinosum*, *Plagiomnium rostratum*, *Pohlia ampullacea*, *T. haplohymenium*, *T. squarrosulum*.
Chopta	*Atrichum aculeatum*, *Bartramidula dispersa*, *Pohlia ampullacea*, *Polytrichum alpinum*, *Symblepharis vaginata Thuidium assimile*.
Tungnath	*Bartramidula dispersa*, *Bryum alpinum*, *Dicranum crispifolium*, *D. scoparium*, *Grimmia donniana*, *Plagiomnium rostratum*, *Pogonatum microstomum*, *P. thomsonii, Polytrichum alpinum*.

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away more rapidly. It warms up quickly as well as become cool very soon in comparison to other texture of soil. This character of soil is not suitable for most of the other plant groups, but bryophytes due to their water absorbing nature preferred to grow in sandy soils. Bryophyte species encountered in the study area were *Entodon pulchellus* (mat), *Fissidens grandifrons* (leafy mat), *Marchantia palmata* (thalloid mat), *Marchantia polymorpha* (thalloid mat), *Plagiochila durelii* (leafy mat), *Plagiochila elegans* (leafy mat), *Conocephalum conicum* (thalloid mat), *Dumortiera hirsuta* (thalloid mat), *Lophocolea bidentata* (turf), etc.

The ST refers to the amount of heat entering the soil and diffusion of heat in the soil. The study area is in vicinity of alpine regions and various sites are in the montane zone of KWLS (Garhwal Himalaya). Thus, the ST of the study area mostly ranged between 9°C and 12°C during rainy season. In winters most of the sites are covered with snow thus the ambient and the ST drop down (0°C-5°C) for about five months. Later on the ST increases very slowly in the summers in sub montane zone. Though the radiation is very high in alpine zone even then the ST does not increase because of moist, humid climate, thinning of air and pollution free environment. High soil MC was observed at all the sites. It was observed that the range of soil MC varied between 34.00±5.29% and 45.67±2.08%. The variation in MC in different sites can be attributed to differences in altitude, rainfall, forest cover and slope aspect as well as the WHC of the soil and high water absorbing nature of some tree species (*Quercus leucotrichophora*). Soil moisture promotes the movement of nutrients in the soil by which the bryophytic vegetation grow well, as well as it augments the retention of soil moisture with the help of their rhizoids and compact creeping thallus. The significantly negative correlation (-0.677) between ST and MC was recorded, which infers role of moisture in lowering temperature of the soil.

Water holding capacity of soil is directly governed by the soil texture. The water retention and transmission properties vary according to soil texture (Kumar *et al*., 2002). Most of the sites under investigation have dense forests and therefore possess a thick layer of decomposed litter on the forest floor. This enhanced WHC of the soil, which is highly suitable for the growth of bryophytes and other lower plants. The bryophytes are moisture-loving plants and their rhizoids are able to hold and check the runoff of water. A scan of WHC of various sites has revealed the lowest WHC of 16.33±1.53% (DT) and highest of 28.00±1.00% (TN). Tungnath being an alpine region, dominated by a herbaceous vegetation *viz*., *Geum elatum*, *Plantago depressa*, *Plantago major*, *Potentilla atrosanguinea*, *Potentilla cuneata*, *Potentilla fulgens*, *Potentilla microphylla*, *Primula denticulata*, *Pimpinella diversifolia*, *Ranunculus hirtellus*, *Sassurea taraxifolia*, *Trachydium roylei*, *Viola biflora* etc., which coupled with carpets of mosses like *Atrichum obtusulum*, *Brachythecium cameratum*, *Dicranum himalayanum*, *Pogonatum alpinum*, *Polytrichum alpinum*, etc. retained maximum water in soil. Regular heavy rainfall is also a major factor for high WHC at this site. Whereas in DT, dense tree vegetation is abundant and under storey vegetation is scarce, thus precipitation is not retained by the soil, which may be the main reason for the low WHC at this site.

Few bryophytes grow only in a narrow pH range and thus they may be used as an indicator of soil pH. Serrato Sanchez *et al*. (2000) reported that soil phosphorus and nitrogen contents, clay contents, pH, altitude and slopes are independent variable. In the present study pH ranged between 6.57±0.12 and 7.00±0.10, which infers that the bryophytic vegetation is more frequent in acidic and neutral soils. It may be due to high litter decomposition and remains of previous bryophytic thallus rich in flavonoids, terpenoids, lignins, antibiotics, lipids and sterols, which are suitable to bryophytic growth. Further many inorganic and organic chemical reactions are regulated in the soils, which govern soil pH. Pidwirny (2004) also suggested that soil pH range from 6.0 to 7.2 is suitable for vegetation. The calcareous soil bears high concentration of calcium carbonate thus it exhibit high pH. In such soil some bryophytes like *Fissidens cristatus* grow well, which shows a definite requirement for calcium, but only at relatively low concentrations. The pH is an important factor for the growth and distribution of *Fissidens cristatus* and other calcicole bryophytes.

The carbon pool in soil consists of soil OC and soil inorganic carbon. It is not only critical for the soil to make it productive but also governs the global carbon cycle (Sahrawat, 2003). Soil organic matter is responsible to build a major portion of the soil OC pool, which regulate the soil properties *viz*., physical, chemical and biological (Woomer *et al*., 1994). It has been observed that remains of dead thallus of previous years, which are left under the new bryophytic vegetation in the form of peat, are responsible for increase of OC and SOM. These two components may also increase in places where there is a plain field under forest, as rain water does not washes the organic matter in comparison to sloppy sites. The values of OC ranged between 0.21±0.01% and 0.55±0.01%. The difference in OC between the different sites is little as compared to each other, which infers that all the sites were more or less under the same stages of succession. Organic carbon content was found to be low compared to earlier reported values for forest soils of higher plants which suggest the lesser carbon fixation rate of bryophytes compared to higher plants. Bryophytes are generally early successive species which occupy the barren lands with low organic matter. Invariably at all the sampling sites we observed where bryophytes were growing there was lack of organic matter or litter in soil, which yet again justifies our findings of low OC in soil. This insinuates that bryophytic vegetation prefers to grow in habitats that are deficient in OC.

Nitrogen is most essential element for all growth process in plants. Nitrogen is an important nutrient within a limit, for plant growth, especially in cold regions. Microorganisms play an important role in N cycle. In the absence of N it is observed that mosses produce few protonema and gametophores. Some mosses *viz*., *Bryum* sp., *Funaria* sp., *Sphagnum* sp., hornworts *viz*., *Anthoceros* sp. and liverworts *viz*., *Blasia* sp. and *Calycularia* sp., provide suitable medium for the biological fixation of nitrogen in association with cyanobacteria. The percentage of N ranged from 0.04±0.02% to 0.11±0.06%. Low N at KK as compared to SH can be attributed to the fact that OC is also lower at KK as compared to SH and OC and N are directly proportional to each other.

Available phosphorus is inevitable for the vital growth processes in plants. Richards (1959) reported that when mosses and grasses grow together, the mosses take up most of the phosphate. Bryophytes have the property to gather large amount of phosphate. Hoffman (1966) reported that few protonemata and no gametophores were formed during the deficiency of phosphorus. The response of bryophytes to N input is highly dependent on the availability of other nutrients, especially phosphorus (Heijmans *et al*., 2001; Limpens *et al*., 2003). Soil organic matter has the inorganic form of phosphorus transformed into insoluble form in many soils. The rates of weathering control phosphorus availability to plants. Phosphorus in turn controls the input levels of plants residues (Brown *et al*., 1994). Significantly positive correlation (0.879) between OC and AP was recorded. It is because generally in the surface soils phosphorus is between 20 to 25% of SOM (Stevenson, 1994).

The mineral potassium is an important factor for the growth of vegetation (Gairola *et al*., 2009). Hoffman (1966) reported that potassium deficiency in *Funaria* gives the dark green protonemata and light green gametophores, a response somewhat differ from the higher plants. Available phosphorus content varied from 13.02±0.00 $Kgha^{-1}$ to 16.28±0.00 $Kgha^{-1}$. The anthropogenic activities may be responsible for enhanced amount of soil phosphorus at a particular site. These activities are very high in SH area as compared to TNR so the impact of these activities is significant in influencing the character of soil. Bryophytes growing on phosphorous enriched soils are *Barbula* sp., *Bartramia* sp., *Gymnostomum* sp., *Hypnum* sp., *Isopterygium* sp., *Jungermannia* sp., *Lepicolea* sp., *Philonotis* sp., *Plagiochila* sp., etc. In case of bryophytes a suitable concentration of potassium is 6.71-20.30 ppm, and the optimum concentration is 67.10ppm. Mean EK content varied from 145.60±0.10 $Kgha^{-1}$ to 216.16±0.01 $Kgha^{-1}$. Total soil potassium differs according to different altitudes and the higher content of available potassium is found in surface soil in the form of exchangeable potassium which later converts as the soil solution (Dimri *et al*., 2006). Since EK in soil largely depends upon the composition of parent rock material, no specific reason can be assigned to its differential quantities at different sites. Bryophytes are most important pioneer in colonization of bare areas and trap the soil after colonization. They take the elements directly from atmosphere. After the partial decay of the bryophytic vegetation, minerals are released in soil. Thus bryophytes influence ecosystem by retaining nutrients for long periods in un-decomposed dead organic matter. Therefore, present study is useful in understanding the dynamics of plant succession pattern in relation to soil nutrient availability of the KWLS Garhwal Himalaya. The study also provides a better understanding on the bryophytic harmony with herbaceous species occurring in these areas. It may also give a new insight for considering bryophytes as a target functional group for studying the recent climate change.

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