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Effect of Mosses on physical and chemical properties of soil in temperate forests of Garhwal Himalayas

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Research Article

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Abstract

Mosses are one of the most important and dominant plant communities, especially in the temperate biome, and play a significant role in ecosystem function and dynamics. They influence the water, energy and element cycle due to their unique ecology and physiology. The present study was undertaken in three different temperate forest sites in the Garhwal Himalayas, viz., Triyuginarayan (Kedarnath Wildlife Sanctuary (KWLS)), Chakrata, and Kanasar forest range. The study was focused on understanding the influence of mosses on soil physical properties and nutrient availability. Different physico-chemical properties were analysed under two different substrata, that is, with and without moss cover in two different seasons, viz., monsoon and winter. We observed mosses to influence and alter the physical properties and nutrient status of soil in both seasons. All soil physical and chemical properties, except magnesium, showed significant difference within the substrates, among all the sites and across the two seasons. Besides the soil characteristics underneath the moss vegetation, the study also highlights the diversity of mosses found in the area. Mosses appear to create high nutrient microsites via a high rate of organic matter accumulation and retain nutrients for longer periods thus, maintaining ecosystem stability.

Introduction

Soil nutrients are an essential component of the forest ecosystem. Nutrient status of the soil plays a critical role in determining the plant species and the microbial communities in the soil. The knowledge of soil nutrient concentration is an important parameter to understand the productivity and growth pattern in forests (Gairola *et al.* 2012).

Mosses are the most diverse and widespread group of plants and form a major component of boreal, montane and arctic ecosystems (Ayres *et al.* 2006). They form a noticeable component of many ecosystems, from moist tropical mountain systems to arctic tundra (Rieley *et al.* 1979). India is considered a treasure house of mosses. In India, mosses are distributed in the Himalayas, Central India, and South India. In the Himalayas, they are found up to an elevation of 5000 m above sea level (Nath *et al.* 2005, Singh & Srivastava 2013). They play a vital role in regulating ecosystems as they act as a buffer system for other plants. Due to their unique ecology and physiology, mosses influence water, energy, and element cycles differently from the vascular plants (Turetsky 2003). Their poikilohydric nature and high tolerance allow them to survive water stress conditions for a more extended period (Turetsky 2003). Mosses act as very efficient filters and absorb nutrients all over their surface from rainfall, throughfall, dust, and litter decomposing on their surface (Rieley *et al.* 1979, Tamm 1953).

Mosses account for only a few mega-grams of standing biomass per hectare, substantially contributing to the total ecosystem budgets by their rapid turnover of carbon and nutrients (Binkley & Graham 1981). In many habitats, they play an essential role in global nitrogen and carbon cycling, carbon dioxide exchange, nutrient flow, productivity, plant succession, and water balance (Coxson *et al.* 1992, Frahm 1990, O'Neill 2000). In Alaskan black spruce forests, feather mosses (*Pleurozium* sp. and *Hylocomium* sp.) account for 17% of the phosphorus pool; however, they comprise only 6% of the total biomass pool. Forest floors with moss cover have higher nitrogen fixation rates than forests without moss cover (Giddens 1982).

Mosses influence the ecosystem in two significant ways. Firstly, they form a mat that acts as a selective filter to heat transfer. Secondly, they rapidly absorb nutrients from soil and atmosphere and release them slowly when they die and undergo decomposition (Oechel & Cleve 1986). However, in some continuous wetting and drying areas, they release nutrients within the initial minutes of rehydration (During & Tooren 1990). Nutrient cycling in forest ecosystems is associated with litter decomposition and enzymatic transformation of the organic substrates into forms that are accessible by plants. Mosses trap moisture, create a microenvironment more favourable for decomposition, and promote higher microbial activity levels (Wilson & Coxson 1999). As they are present within the boundary layer of the forest floor, variation in the water content and CO_2 partial pressure just near the ground level directly affects the function of mosses. Thus, any change in the moss activity indicates the response of mature forests to rapid climate changes (DeLucia *et al.* 2003, Johnson *et al.* 1996, Oechel *et al.* 1998). The local influence on the ecosystem by mosses includes a decrease in soil temperature (ST), an increase in soil moisture, and a change in the density of soil organic matter (SOM). Thus, mosses influence C and N cycles at both local and global levels (Turetsky 2003). Mosses regulate most essential nutrients at a constant level, but they have a limited capacity to regulate luxury macronutrients such as K, P and Ca (Oechel & Cleve 1986). Ground mosses link above- and below-ground processes and have strong control of soil processes and conditions (Sun *et al.* 2017).

Despite such a vast diversity in abundance and functions, a literature survey reveals only a few studies that explore the effect of mosses on soil nutrients. Mosses are often ignored in large-scale studies of vegetation patterns in forest ecosystems. They are an indispensable part of the forest ecosystem, but detailed information regarding their diversity, distribution and habitat specificity in the Garhwal Himalayas are insufficient (Bahuguna *et al.* 2014). Mosses have various biological features that make them better suited as study organisms in ecological, macro-evolutionary and population genetics research (Shaw & Goffinet 2000). They are also used as promising indicators for tracing sources and migration patterns of heavy metals causing atmospheric pollution (Xiao *et al.* 2021). The present study was undertaken in three temperate forests of the Garhwal Himalaya, Uttarakhand, India, to understand the physico-chemical properties of soil concerning moss vegetation. We hypothesised that mosses affect the physical and chemical properties of soil under different substrates and seasons. This study will highlight the role of lower plants in influencing soil-mediated processes. It may give new insight into considering mosses as a target group for studying climate change and could be further used in devising models, conservation-related strategies and sustainability of ecosystem health.

Study sites

Three sites were selected for study, viz., Triyuginarayan (TYN), Chakrata (CHK) and Kanasar (KAN) in temperate forest zone of the Garhwal Himalayas (Figure 1). All three forest types fall under the moist temperate forest group (group 12) (Champion & Seth 1968). Triyuginarayan is located in Rudraprayag district of Uttarakhand, India, and lies between 30°38'34.36"N to 30° 37'9.28"N and 78°59'55.19"E to 78°57'52.06"E at an average elevation of 2148 m. Triyuginarayan is a part of the core zone of Kedarnath Wildlife Sanctuary (KWLS). The forest type is moist temperate deciduous forest (Class 12/C_Ie) according to Champion & Seth (1968) forest type classification. The forest vegetation in Triyuginarayan is chiefly comprised of broad-leaved tree species viz., *Quercus oblongata* D.Don, *Rhododendron arboreum* Sm., *Neolitsea pallens* (D.Don) Momiy. & H.Hara, *Alnus nepalensis* D.Don and *Aesculus indica* (Wall. ex Cambess.) Hook. Dominant shrubs of the site are *Lindera pulcherrima* (Nees) Benth. ex Hook.f., *Cotoneaster affinis* Lindl., *Sarcococca saligna* (D.Don) Mull. Arg. and *Berberis aristata* DC.

Chakrata and Kanasar are situated in the Dehradun district of Uttarakhand, India. Chakrata lies between 30°43'56.35"N to 30° 41'13.88"N and 77°50'12.43"E to 77°53'20.98"E at an average elevation of 2145 m, while Kanasar lies between 30°47'49.29"N to 30° 45'6.65"N and 77°47'58.21"E to 77°51'8.17"E at an average elevation of 2285 m. The forest type of Chakrata is Ban-Oak forest (Class-12/C_Ia) (Champion & Seth 1968). The forest vegetation in Chakrata comprises broad-leaved tree species with *Q. oblongata* as the climax vegetation. The other major tree species of the area are *Cedrus deodara* (Roxb. Ex D.Don) G.Don, *R. arboreum* and *Pinus wallichiana* A.B.Jacks. Dominant shrubs of the area are *Daphne papyracea* Wall. ex G.Don, *Berberis jaunsarensis* (Ahrendt) Laferr., *B. aristata* and *Hypericum perforatum* L. Kanasar has Moist deodar forests (Class-12/C_Ic) (Champion & Seth 1968). The dominant tree species present in the forest is *C. deodara*. *Picea smithiana* (Wall.) Boiss., *P. wallichiana*, *Q. oblongata* and *Quercus floribunda* Lindl. ex A.Camus are the other tree species present. The major shrub species in the area are *S. saligna*, *Prinsepia utilis* Royle, *Cotoneaster microphyllus* Wall. ex Lindl. and *B. jaunsarensis.*

The climate is divisible into three distinct seasons: Winter (November to February), Summer (April to June) and Rainy (July to September), with short Spring (March) and Autumn (October) (Kaushal & Baishya 2021). The soil colour of the region varies from dark brown to black. Soil type in Triyuginarayan is podzolic. Gravel and large boulders are common in the soil of this region. The region comprises metamorphic rocks, including granites, gneisses and schists known as the central crystalline zone (Agrawala 1973, Bahuguna *et al.* 2012). Chakrata and Kanasar are slightly acidic with a fine texture and are rich in organic matter. The soil has a high cation exchange and water holding capacity (Banerjee & Badola 1980). The rocks of the study area are of the Pre-Cambrian to early Palaeozoic age (Raina *et al.* 1994). The monthly variation in precipitation and temperature during the sampling year for all the three study sites is represented in Figure 2.

Methods

Moss sample collection and identification

Terrestrial mosses were sampled by the systematic sampling method (Bahuguna *et al.* 2016). Ten sample plots of 2 m × 2 m were laid down at each site. Each plot was further divided into quadrats of 0.25 m × 0.25 m and samples were collected from each alternate quadrat. Samples were packed in zip-lock bags and brought to the laboratory for identification. For identification, the collected moss samples were first soaked in water to revive them and then observed under dissecting (Bausch and Lomb) and compound microscopes (Olympus OIC) for characters of leaf cells, branching pattern, capsule, peristome and stem. Moss specimens were identified using flora available for mosses (Mosses of Eastern India and Adjacent Regions (Fascicles 1-8) by H. C. Gangulee and Taxonomy of Indian Mosses by R. S. Chopra).

Soil sampling

Soil samples were collected during the monsoon season when mosses were at the peak of their growth and during the winter season when they undergo desiccation. Two substrata were chosen for soil collection in each of the three study sites: without and with moss cover. Soil samples were randomly collected from 10 different locations for both substrata at a depth of 0–5 cm. The soil samples were mixed and homogenised to make one composite for each substratum. Samples were brought to the laboratory, air-dried, sieved through a 2-mm sieve and tightly packed in air-tight zip-lock bags for chemical analysis.

Physical properties

We determined the physical properties like ST, percentage moisture, bulk density, porosity and soil texture. ST (°C) was

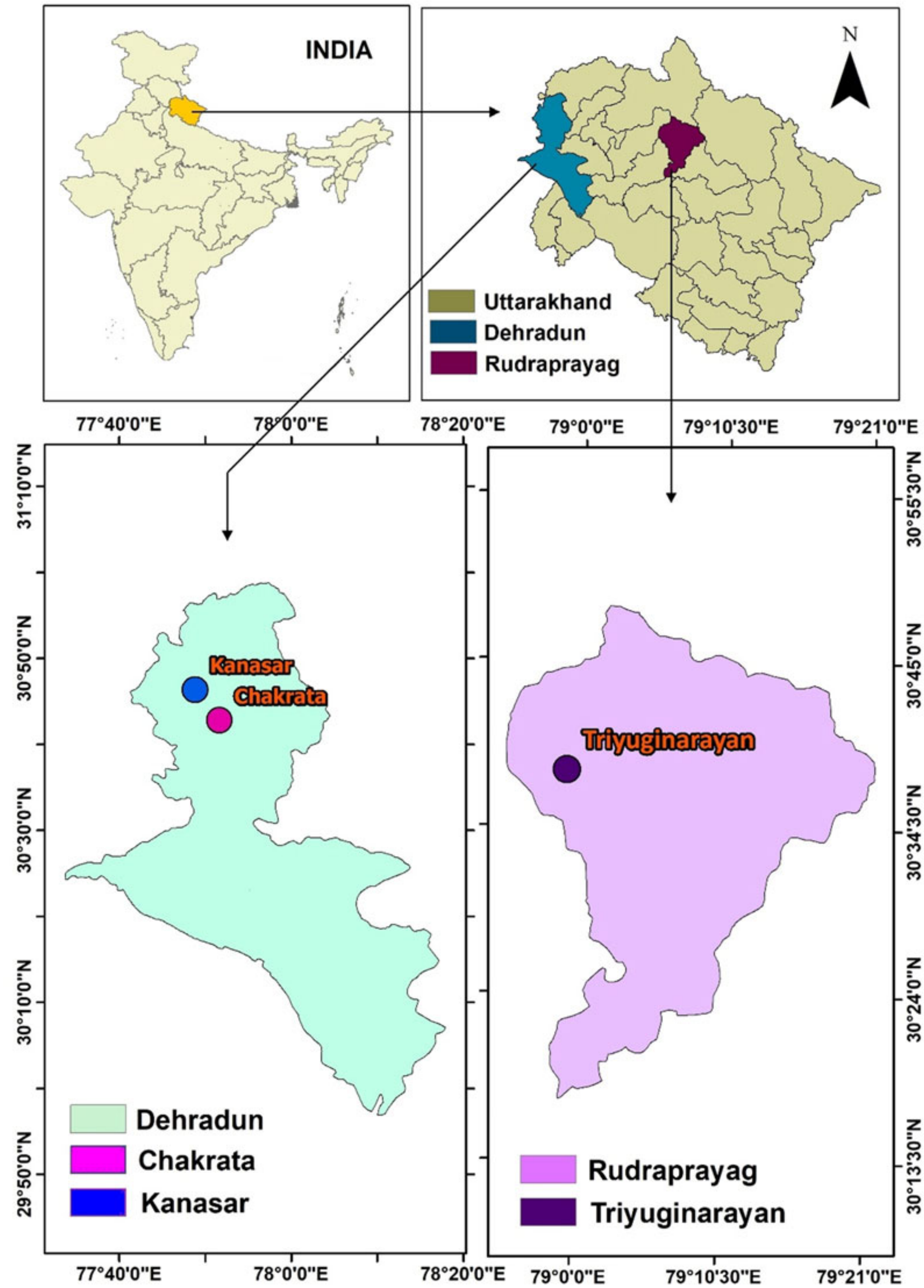

Figure 1. Map showing study sites.

determined using a field soil thermometer (TP 3001 Digital Thermometer) inserted up to a depth of 5 cm in the soil. The percentage soil moisture was determined on a fresh weight basis. Ten grams of soil was oven-dried at 105°C until a constant weight was achieved. The percentage moisture content (MC) was determined as per Allen et al. (1974). For determining soil bulk density and porosity, a steel core of height 5 cm with known weight and volume was inserted into the soil, and the soil sample was collected. Soil obtained from the core was oven-dried at 105°C until a constant weight was achieved. Soil bulk density and porosity were estimated following Anderson & Ingram (1993). Soil texture was determined using the Bouyoucos Hydrometer method (Motsara & Roy 2008). Soil textural class was determined using the USDA Soil Classification Triangle.

Chemical properties

Soil pH was estimated following Allen *et al.* (1974). Soil suspension was prepared using 16 gm of soil and 40 ml of deionised water, that is, 1:2.5 soil to water ratio. Soil was homogenised by stirring it on a magnetic stirrer for 15 minutes. Soil was allowed to settle down to obtain a clear supernatant. pH of the supernatant was taken using a

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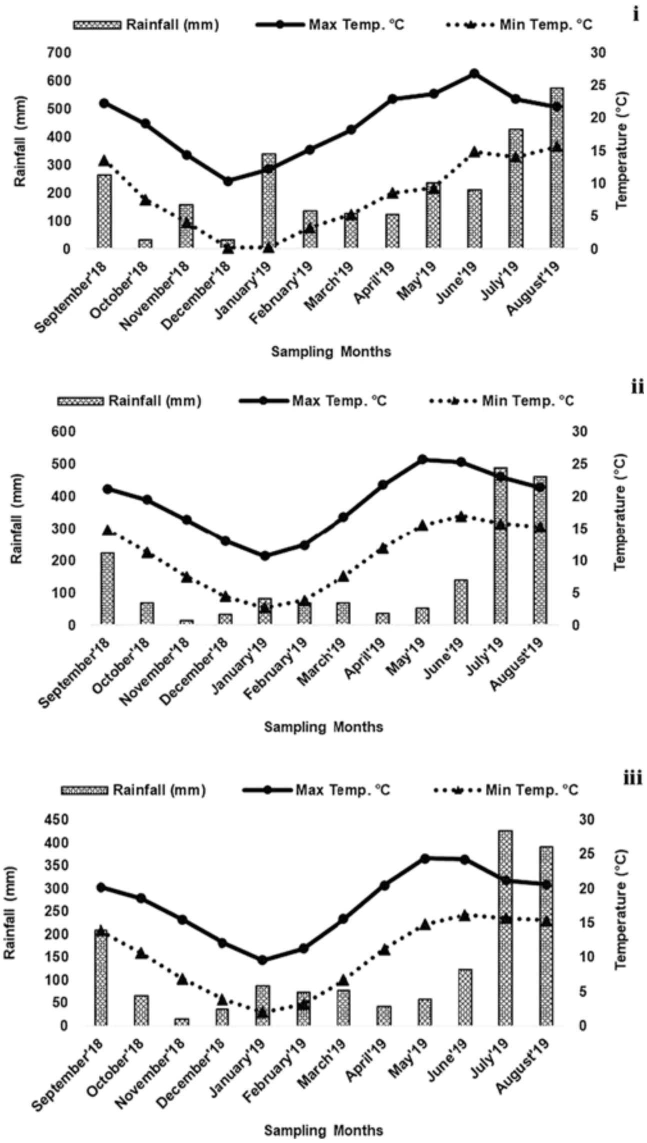

Figure 2. Monthly variation in precipitation and temperature during sampling year (September'2018–August'2019).
i) Triyuginarayan (Source: GBPNIHED, RTC, Triyuginarayan); ii) Chakrata (Source: Climate-Data.org); iii) Kanasar (Source: Climate-Data.org).

pH meter (Hanna Instruments, HI 2211). Soil electrical conductivity (EC) and salinity were measured using a Multiparameter Tester (PCS Tester 35).

We followed the standard procedures as given by Allen *et al.* (1974) for the estimation of soil available phosphorus (AP), soil exchangeable potassium (EK), sodium (Na), calcium (Ca) and magnesium (Mg). Total Kjeldahl nitrogen (TKN) was estimated by Kjeldahl digestion, distillation and titration (VELP Scientifica – UDK149, Italy). SOM was estimated as per the method given by Hoogsteen *et al.* (2015). Soil organic carbon (SOC) was analysed using Elementar Liqui TOCII (GmbH, Germany).

Statistical analysis

The physical and chemical measurements were analysed using a three-way analysis of variance (ANOVA) with the site, substrate and season as main effects to determine the difference between the means and signify any interaction between the variables. A two-tailed Pearson's correlation analysis was performed between various soil parameters. Multivariate ANOVA, Pearson's correlation analysis and principal component analysis (PCA) were performed using statistical software, IBM SPSS Statistics 21. Diversity indices for moss samples were calculated using PAST software (PAST ver.3.5).

Table 1. List of terrestrial mosses identified from Triyuginarayan, Chakrata and Kanasar in both seasons

Study site	List of moss species present
Triyuginarayan	*Plagiomnium cuspidatum* (Hedw.) T. Cop., *Thuidium recognitum* (Hedw.) Lindb., *Entodon curvatus* (Griff.) A. Jaeger, *Bryum pseudotriquetrum* (Hedw.) P. Gaertn., B. Mey. & Scherb., *Atrichum undulatum* (Hedw.) P. Beauv., *Stereophyllum tavoyense* (Hook. ex Harv.) A. Jaeger, *Plagiothecium cavifolium* (Brid.) Z. Iwats., *Thuidium sparsifolium* (Mitt.) A. Jaeger, *Pseudotaxiphyllum distichaceum* (Mitt.) Z. Iwats., *Pelekium fuscatum* Touw.
Chakrata	*Anacamptodon* spp., *Atrichum undulatum* (Hedw.) P. Beauv., *Brachythecium buchananii* (Hook.) A. Jaeger, *Brachythecium procumbens* (Mitt.) A. Jaeger, *Entodon chloropus* Renauld & Cardot, *Fabronia goughii* Mitt., *Fissidens biformis* Mitt., *Fissidens bryoides* Hedw., *Fissidens geppii* M. Fleisch., *Fissidens xiphioides* M. Fleisch., *Frullania spp.*, *Lescuraea incurvata* (Hedw.) E. Lawton, *Orthomniopsis dilatata* (Wilson ex Mitt.) Nog., *Rhynchostegiella humillima (Mitt.) Broth.*, *Thuidium haplohymenium* (Harv. & Hook. f.) A. Jaeger, *Plagiomnium succulentum* (Mitt.) T.J. Kop.
Kanasar	*Brachythecium buchananii* (Hook.) A. Jaeger, *Dicranoweisia alpnia* (Mitt.) Paris, *Fissidens taxifolius* Hedw., *Pseudosymblepharis pallidens* Dix., *Bryum capillaceum* (Hedw.) With., *Anoectangium bicolor* Renauld & Cardot, *Dicranum crispifolium* Mull. Hal., *Brachythecium rutabulum* (Hedw.) Schimp.

Table 2. Diversity indices of moss species

	Triyuginarayan	Chakrata	Kanasar
Shannon–Wiener index (H')	2.303	2.773	2.079
Simpson's index (D)	0.900	0.937	0.875
Margalef's richness index	3.909	5.41	3.366

Results

Diversity analysis

We observed high diversity of moss species in all of the three study sites. Ten species of terrestrial mosses were identified from Triyuginarayan. *Plagiomnium cuspidatum* and *Thuidium* sp. were commonly occurring in our study area based on the observations made during sampling. In Chakrata, 16 species of terrestrial mosses were identified. *Atrichum undulatum* and *Fissidens* sp. were the commonly occurring species. *Quercus oblongata* and *R. arboreum* tree species harbour most of the moss species in Chakrata. Only eight species of terrestrial mosses were identified from Kanasar. Commonly occurring species in the area were *Brachythecium* sp. and *Bryum capillaceum* (Table 1). Table 2 shows the diversity indices of moss species identified from the three study sites.

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Table 3. Mean seasonal variation in physical and chemical properties under soil without moss cover and with moss cover during the study period. Values in parentheses represent ±SD of the mean

Seasons	Surface	Parameters	Sites		
			Triyuginarayan	Chakrata	Kanasar
Monsoon	**Without moss cover**	Soil moisture (%)	39.33 (0.38)	25.80 (0.17)	31.40 (0.10)
		Soil pH	5.56 (0.05)	6.30 (0.01)	6.74 (0.03)
		Soil temp. (°C)	18.80 (1.61)	18.05 (1.32)	17.86 (0.72)
		Soil EC (μS/cm)	54.70 (5.42)	57.80 (1.28)	125.60 (2.46)
		Soil salinity (ppm)	31.43 (1.80)	34.43 (0.57)	61.60 (1.01)
	With moss cover	Soil moisture (%)	44.97 (0.25)	33.20 (0.10)	34.63 (0.23)
		Soil pH	5.55 (0.02)	5.81 (0.19)	7.15 (0.01)
		Soil temp. (°C)	17.10 (1.34)	17.05 (0.95)	17.01 (0.38)
		Soil EC (μS/cm)	110.8 (0.78)	76.50 (4.93)	147.03 (2.42)
		Soil salinity (ppm)	56.07 (0.25)	41.27 (2.60)	75.83 (2.40)
Winter	**Without moss cover**	Soil moisture (%)	49.37 (0.31)	21.80 (0.44)	26.47 (0.60)
		Soil pH	5.40 (0.03)	6.29 (0.04)	6.80 (0.03)
		Soil temp. (°C)	09.24 (0.89)	04.68 (0.49)	03.46 (1.17)
		Soil EC (μS/cm)	56.27 (3.73)	151.10 (5.47)	228.00 (2.00)
		Soil salinity (ppm)	32.73 (3.39)	71.10 (2.86)	105.67 (0.58)
	With moss cover	Soil moisture (%)	42.73 (0.06)	20.97 (0.51)	24.43 (0.70)
		Soil pH	5.43 (0.01)	5.71 (0.14)	6.66 (0.20)
		Soil temp. (°C)	10.15 (1.56)	4.28 (0.38)	2.70 (0.77)
		Soil EC (μS/cm)	42.07 (3.50)	40.80 (1.46)	211.67 (7.51)
		Soil salinity (ppm)	27.53 (2.27)	23.67 (0.57)	99.17 (0.77)

Physical properties

Triyuginarayan has sandy clay loam with a bulk density of 0.65 g/cm^3 and a porosity of 75.35%. Chakrata and Kanasar were found to have silty clay loam type of soil with a bulk density of 0.77 g/cm^3 and 0.72 g/cm^3, respectively, with porosity of 71.10% and 73%, respectively. Soil moisture ranged from 20.97% during winter in soil with moss cover at Chakrata to 49.37% during winter without moss cover at Triyuginarayan. The temperature of the soil was highest at Triyuginarayan without moss cover during monsoon season (18.80°C) and lowest at Kanasar with moss cover during winter season (2.70°C) (Table 3).

Chemical properties

Soil pH was acidic at all the study sites, slightly more acidic in winter season (5.40 to 6.80) than monsoon season (5.56 to 7.15). Soil EC ranged from 40.80 μS/cm during winter in soil with moss cover at Chakrata to 228 μS/cm during winter without moss cover at Kanasar. Soil salinity varied from 23.67 ppm during winter in soil with moss cover at Chakrata to 105.67 ppm during winter without moss cover at Kanasar (Table 3). TKN percentage varied from 0.294% during monsoon season under moss cover at Chakrata to 1.077% during winter season in soil without moss cover at Triyuginarayan. AP content under moss cover ranged from 0.00005% at Triyuginarayan during winter to 0.00413% at Kanasar during monsoon season. EK content varied from 0.019% at Triyuginarayan in soil with moss cover during monsoon season to 0.054% at Chakrata in soil without moss cover during winter season. Magnesium percentage varied from 0.06% during winter season under moss cover at Triyuginarayan to 0.143% during winter season in soil without moss cover at Chakrata. Sodium concentration was lowest (0.001%) at Chakrata during winter in soil without moss cover and highest (0.0071%) at Triyuginarayan during monsoon in soil with moss cover. Calcium percentage varied from 0.036% during monsoon in soil without moss cover at Triyuginarayan to 0.497% during winter in soil without moss cover at Kanasar. The SOM ranged from 9.28% at Chakrata during winter in soil with moss cover to 28.23% at Triyuginarayan during winter without moss cover. The SOC percentage in soil with moss cover varied from 3.23% at Chakrata during monsoon to 7.68% at Triyuginarayan during monsoon (Figure 3). A significant difference was observed for all chemical properties except magnesium across the seasons among all the sites and also within the substrates as given in the ANOVA table (Table 4). Correlation analysis between different physical and chemical properties is represented in Tables 5 and 6.

For PCA analysis in soil without moss cover, PCA axis 1 (PC1) with eigenvalue 3.975, PCA axis 2 (PC2) with eigenvalue 2.258 and PCA axis 3 (PC3) with eigenvalue 1.126 together explain 93.119% of the cumulative variation in the data, which is also evident from scree plot (Figure 4(i)). The first two principal components accounted for 77.913% of the data variance. PC1 explained 49.688% of the data variance and PC2 explained 28.225% of the total data variability. MC with a component loading of 0.937 correlates the most with PC1, Mg with a component

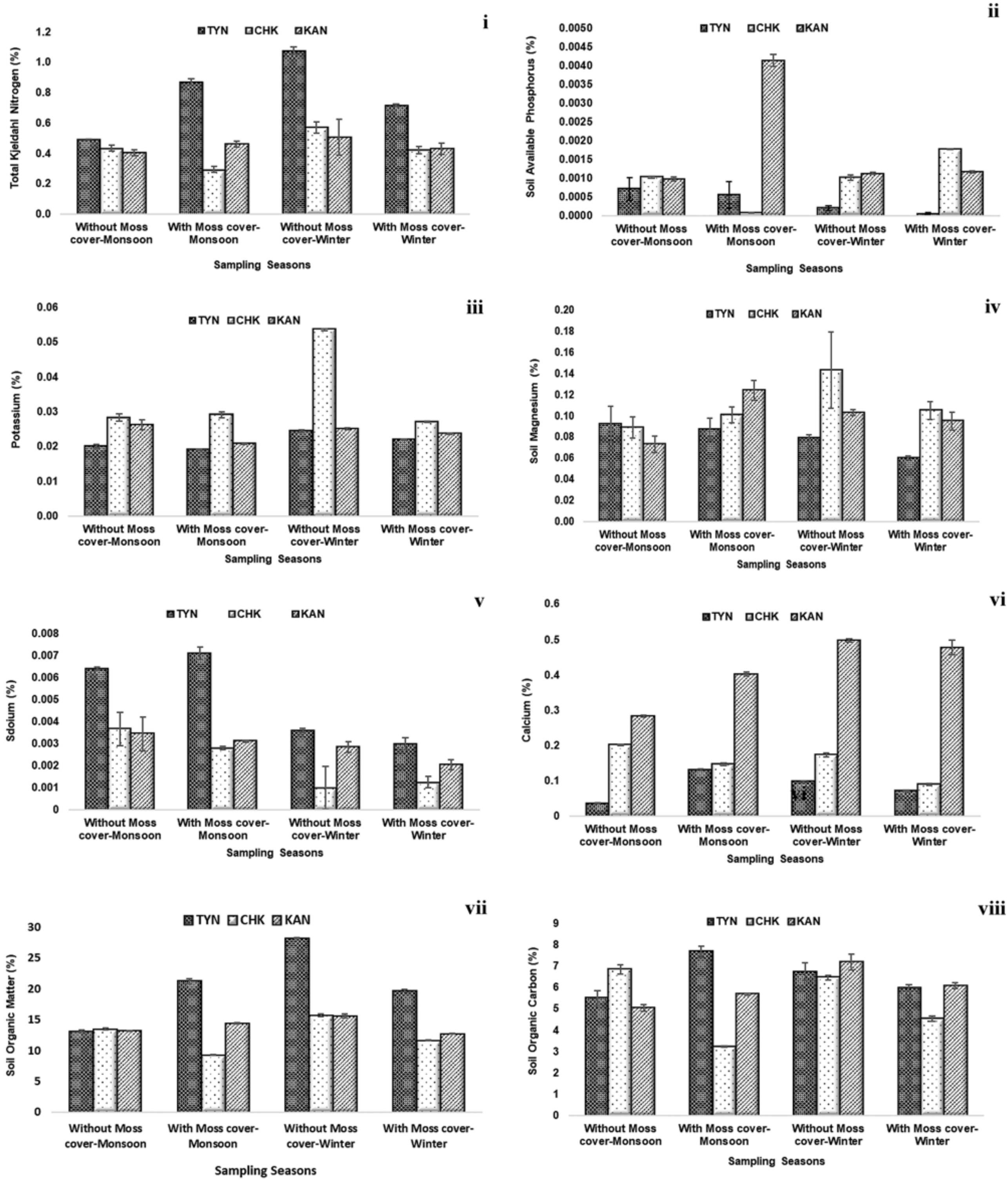

Figure 3. Mean seasonal variation in different chemical properties in soil without moss cover and with moss cover in monsoon and winter season in Triyuginarayan, Chakrata and Kanasar. Bars indicate standard deviation of the mean.
i) Total Kjeldahl nitrogen (%); ii) Total available phosphorus (%); iii) Exchangeable potassium (%); iv) Available magnesium (%); v) Exchangeable sodium (%); vi) Exchangeable calcium (%); vii) Soil organic matter (%), viii) Soil organic carbon (%).

loading of 0.740 correlates the most with PC2 and Ca with a component loading of 0.823 correlates the most with PC3 (Figure 4).

In soil with moss cover, PC1 with eigenvalue 4.028, PC2 with eigenvalue 2.075 and PC3 with eigenvalue 1.238 together explain 91.758% of the cumulative variation in the data. Here, the first two principal components accounted for 76.278% of the data variance. The PC1 explained 50.344% of the data variance and PC2 explained 25.934% of the total data variability. The TKN with a

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Table 4. Three-way ANOVA for all physical and chemical properties.

	Sites	Surface	Seasons	Sites*surface*seasons
df	2	1	1	2
Soil moisture	8158.060***	80.017***	970.581***	64.720***
Soil pH	645.601***	17.518***	18.742***	8.644***
Soil temperature	210.293***	59.153***	5843.265***	2.712*
Soil EC	1799.013***	49.146***	360.730***	107.367***
Soil salinity	1717.898***	10.066***	177.640***	42.644***
TKN	568.963***	24.432***	171.846***	133.303***
Phosphorus	309.497***	87.459***	54.214***	210.825***
Sodium	276.010***	1.737*	420.480***	18.655***
Potassium	1410.595***	773.821***	648.533***	503.856***
Calcium	7871.796***	4.751**	223.694***	55.862***
Magnesium	15.733***	0.096*	0.463*	2.381*
SOM	11244.677***	1369.598***	4504.333***	2924.129***
SOC	4779.376***	789.040***	1891.502***	1028.619***

*p>0.05; **p>0.01; ***p<0.001

Table 5. Pearson's correlation matrix between Na, K, Ca and Mg stocks with pH and EC.

	pH	EC	Na	K	Ca	Mg
Without moss cover						
pH	1	**0.811****	−0.446	0.224	**0.860****	0.127
EC		1	**−0.593****	0.354	**0.882****	0.406
Na			1	**−0.867**	−0.341	**−0.602****
K				1	−0.014	**0.747****
Ca					1	0.058
Mg						1
With moss cover						
pH	1	**0.736****	−0.250	−0.156	**0.912****	**0.652****
EC		1	0.060	−0.355	**0.932****	0.298
Na			1	**−0.692****	−0.177	−0.235
K				1	−0.195	0.192
Ca					1	**0.479***$^{}$
Mg						1

*Correlation is significant at the 0.05 level (two-tailed).
**Correlation is significant at the 0.01 level (two-tailed).Significant correlations are in bold; EC: electrical conductivity; Na: sodium; K: potassium; Ca: calcium; Mg: magnesium.

Table 6. Pearson's correlation matrix between TKN, EK, AP and S stocks with SOC, soil moisture and soil temperature.

	MC	ST	SOC	TKN	EK	AP
Without moss cover						
MC	1	−0.006	**0.808****	**0.844****	−0.156	**−0.880****
ST		1	−0.332	−0.287	**−0.526***	−0.139
SOC			1	**0.984****	−0.128	**−0.805****
TKN				1	−0.053	**−0.827****
EK					1	0.300
AP						1
With moss cover						
MC	1	**0.642****	**0.754****	**0.770****	**−0.660****	−0.300
ST		1	0.129	0.194	−0.247	0.089
SOC			1	**0.979****	**−0.879****	−0.169
TKN				1	**−0.815****	−0.259
EK					1	−0.249
AP						1

**Correlation is significant at the 0.01 level (two-tailed).
*Correlation is significant at the 0.05 level (two-tailed).Significant correlations are in bold; MC: moisture content; ST: soil temperature; SOC: soil organic carbon; TKN: total Kjeldahl nitrogen; EK: exchangeable potassium; AP: available phosphorus.

component loading of 0.958 correlates the most with PC1, AP with a component loading of 0.832 correlates the most with PC2 and ST with a component loading of 0.866 correlates the most with PC3 (Figure 5).

Discussion

Triyuginarayan and Chakrata harbour a remarkable diversity of mosses due to frequent alteration of the wet and dry seasons, promoting niche differentiation. The dense canopy of the forest helps maintain an optimum level of atmospheric temperature, ST and soil moisture, influencing their growth. Kanasar being a moist deodar forest had lower moss species diversity than the two other study areas.

A specific seasonal trend was observed in our study for all physical properties, but no clear seasonal trend was observed for chemical properties. All physical parameters and some nutrients were higher under the soil with moss cover during monsoon and under soil without moss cover during winter season. Mosses prefer to grow in moist, cool and humid habitats. They have a great potential for absorbing water from the environment. Our study showed higher MC under moss cover during monsoon

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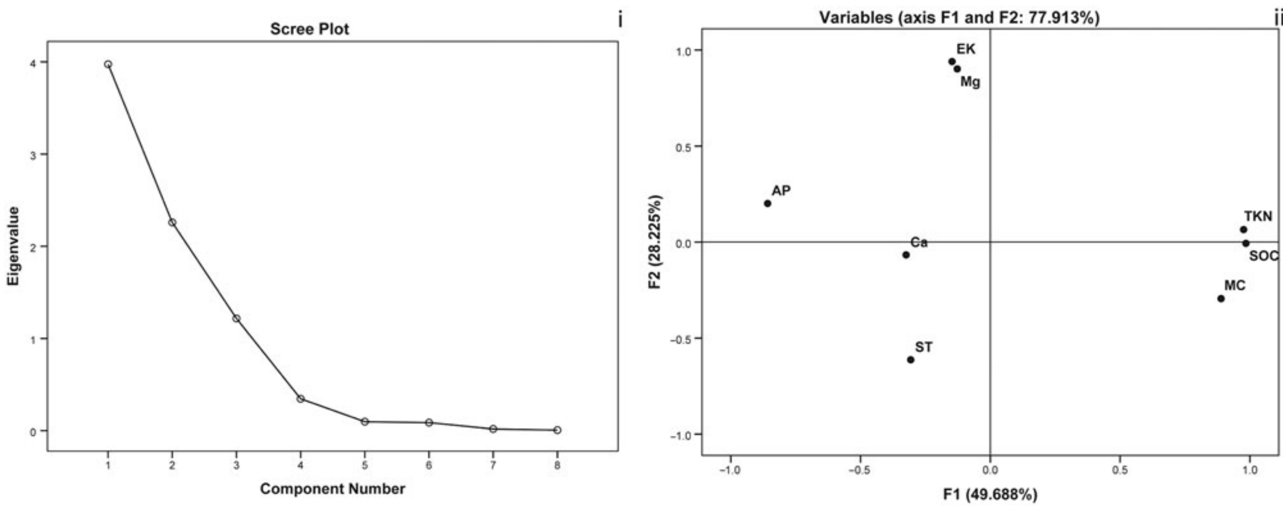

Figure 4. (i). Scree plot of soil moisture, soil temperature and soil chemical properties in soil without moss cover; (ii) biplot of soil moisture, soil temperature and soil chemical properties in soil without moss cover.
MC: moisture content; ST: soil temperature; AP: available phosphorus; TKN: total Kjeldahl nitrogen; EK: exchangeable potassium; Ca: calcium; Mg: magnesium and SOC: soil organic carbon.

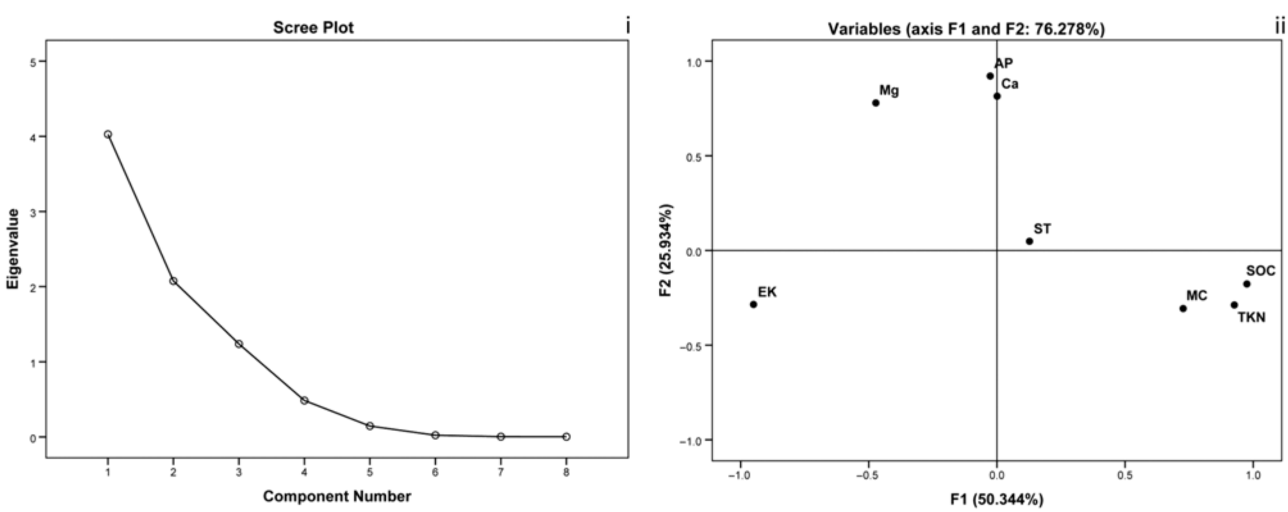

Figure 5. (i). Scree plot of soil moisture, soil temperature and soil chemical properties in soil with moss cover; (ii) biplot of soil moisture, soil temperature and soil chemical properties in soil with moss cover.
MC: moisture content; ST: soil temperature; AP: available phosphorus; TKN: total Kjeldahl nitrogen; EK: exchangeable potassium; Ca: calcium; Mg: magnesium and SOC: soil organic carbon.

season, but MC was higher under soil without moss cover during winter. During winter season, mosses are in the senescence phase of their life cycle, lowering their capacity to trap moisture and nutrients. Also, the sites studied have a thick layer of litter on the ground floor during winter season, enhancing the water holding capacity of soil without moss cover (Bahuguna *et al.* 2012). Higher MC during monsoon season under moss cover also accounts for lower ST underneath moss cover. Soil moisture allows the movement of nutrients in the soil, which promotes the growth of mosses. In our study, soil pH ranged from 5.40 to 7.15, which infers that mosses grow more frequently in acidic soils. It may be due to high litter decomposition and remains of previous moss thallus rich in antibiotics, lipids, flavonoids, terpenoids, lignin and sterols which provide suitable conditions for their growth (Bahuguna *et al.* 2012).

SOM forms a major pool of SOC. SOC governs the global carbon cycle, making the soil productive and regulating the physical, chemical and biological properties of the soil (Sahrawat 2003, Woomer *et al.* 1994). The SOM and SOC showed a similar trend as soil moisture and ST except for Chakrata, where SOM and SOC contents were lower under the soil with moss cover than soil without moss cover in monsoon season. The SOC in our study ranged from 3.23 to 7.68%, which correlates with the data in the study done by Gairola *et al.* (2012), where SOC ranged up to 7.74% in mixed broad-leaf forests. A highly significant positive correlation was observed between soil moisture and SOC. Dead remains of the thallus of previous years left under the moss cover increase SOM and SOC during monsoon season. During winter season, the initiation of litter decomposition adds organic matter to the soil, which increases SOC content in soil without moss cover.

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Nitrogen is the most essential element for the growth of plants. It is also one of the most limiting nutrients available for plant growth. Nitrogen cycling depends on microorganisms that are responsible for the decomposition of SOM. Nitrogen content can be attributed to organic carbon content as both are directly proportional to each other. A significant positive correlation was observed between SOC and TKN both in soil under moss cover (0.979) and without moss cover (0.984). Similar trends for TKN and SOC in all three sites also support the influence of SOM content on nitrogen percentage in soil. Accumulation of both SOC and TKN depends on microbial activity occurring on SOM. A similar positive correlation between TKN and SOC was also observed by Bahuguna *et al.* (2012).

AP showed an entirely different trend in all three sites. AP was observed to be the lowest under moss cover during monsoon season in Triyuginarayan and Chakrata. AP is necessary for plant growth. Mosses are known to accumulate most of the phosphate available when they grow together with grasses (Bahuguna *et al.* 2012). In the above-ground parts of the Alaskan black spruce forest, they account for 75% of annual phosphorus accumulation. *Hylocomium* sp. had about fivefold higher phosphate absorption potential than that of roots of black spruce (Chapin *et al.* 1987). SOM has the organic form of phosphorus transformed into insoluble forms. Mineralisation rates control the amount of these insoluble forms available to plants (Bahuguna *et al.* 2012).

EK showed the same seasonal trend in all the sites. However, the seasonal trend was different from most of the other elements. As EK levels depend mainly on the composition of parent rock material and weathering process, no specific reason could be provided for its differential quantities (Tripler *et al.* 2006).

Calcium and magnesium were higher under moss cover during monsoon season and under soil without moss cover during winter season except for Triyuginarayan and Chakrata, where Mg and Ca, respectively, were higher in soil without moss cover during monsoon season. In comparison, sodium showed no specific trend in seasons or within the sites. Calcium and magnesium showed a significantly positive correlation with EC and salinity. These elements are considered secondary plant nutrients and do not play a much important role in the vital growth processes of plants. Both calcium and magnesium can easily leach from the soils.

Different sites have different vegetation composition, which play a significant role in influencing soil properties. Triyuginarayan and Chakrata are forests with broad-leaf species, whereas Kanasar has coniferous-dominated moist deodar forest. The vegetational and elevational differences have a different effect on soil physical and chemical properties. Environmental factors, including precipitation, temperature, and light, show variations at different elevational gradients, which result in differences in soil properties. The hypothesis proposed by us proved to be correct based on all the observations and results. Mosses were found to influence the physical properties and nutrient status of soil in both seasons in all three study sites.

Conclusion

In this study, we showed that mosses, despite being small in size, alter the physical and chemical properties of soil. It was profoundly influencing various ecosystem processes, including nutrient cycling. The present study helps understand the role of mosses in regulating different aspects of the forest ecosystem. The dynamics of plant succession patterns concerning soil nutrient availability can be understood with the help of the present study. Mosses can be considered as the target functional group to study phytoremediation of heavy metals, biomonitoring purposes and ecological modelling. Mosses are sensitive to temperature fluctuations and can act as a key indicator for climate change. Their contribution towards various ecosystem functions such as nutrient retention and nutrient release is of prime importance.

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Conflict of interest. None

Ethical statement. None

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