CHAPTER 5
SOIL NUTRIENT DYNAMICS

Objective III: Study on variations of soil properties with respect to vegetation

5.1 Introduction

The tropical semi-evergreen forests, characterized by high species diversity and resource availability, are among the indispensable ecosystems of the Himalayan region [1]. The forest soil plays a crucial role in determining the forest's composition, along with ground cover, growth rate of trees, and other silvicultural aspects [2, 3]. However, the interactions between the plants and soil are multidirectional rather than being unidirectional. Different types of plants have above-ground and below-ground biomasses. These biomasses have a significant effect on the physical and chemical properties of soil through various processes like litter falls, root proliferation, and decomposition rates [4, 5, 6]. According to Thakur et al. [7], the mean infiltration of grassland soil tends to be higher than that of forest soil, thereby signifying the impact of root systems on the physical characteristics of soil. There is a difference between these two types of soil because the soil developed under broad-leaf species tends to be more compact and has a finer texture than loamy fine sand [7, 8, 9,]. Additionally, the chemical properties of soil are deriving from the interactions between parent materials and factors that form soil. Then the addition of organic matter and their subsequent decomposition play a key role in determining the pH, electrical conductivity (EC), soil organic carbon (SOC) and nutrients present in the soil [4, 10, 11]. The impact of vegetation cover is more prominent in the topsoil layer as the tree roots extract nutrients from the deeper layers of soil which are released them back through the decomposition of litter and windfall leading to higher accumulation of SOC and nutrients in the topsoil [4, 12, 13]. Koppad and Tikhile [14] reported that the sequestration of SOC increases with an increase in forest cover. Several studies have also reported a lower pH and higher EC are associated with dense tree cover [15, 16, 17, 18]. Furthermore, the presence of dense tree cover can significantly influence the availability of macronutrients such as nitrogen, phosphorus and potassium in the topsoil due to the addition of organic matter [18, 19, 20, 21]. Apart from the vegetation cover, the seasonal variations in temperature, precipitation and other climatic conditions also influence the nutrient dynamics of the topsoil layer [6]. According to Kumar et al. [22], the nutrients present in the soil function as a sensitive indicator to the forest types as well as changes in the climatic conditions. This sensitivity is often evident through seasonal fluctuations, with nutrient concentrations in the topsoil of forests tend to be highest during the spring, summer, and during the autumn [23, 24, 25]. Therefore, the physicochemical properties of the topsoil are strongly affected by its physiographic position, parent materials and weathering processes. The climate and the heterogeneity of the forests, which have different canopy sizes, also play a significant role in the physicochemical properties of the topsoil [26, 27, 28, 29].

5.2 Methodology

5.2.1 Study site

The study on variations of soil properties with respect to vegetation was carried out in the Sonai Rupai Wildlife Sanctuary (Fig. 1.1), which covers an area of 220 km² and has elevation between 125 m to 480 m. The sanctuary encompasses scrub patches along with the tropical semi-evergreen forest [30, 31]. The tropical semi-evergreen forest and scrub patches were selected for the study to understand the variation in soil physicochemical properties.

5.2.2 Sampling method

Composite soil samples were collected seasonally for four seasons, namely winter, premonsoon, monsoon, and post monsoon, annually from 20 different locations that were randomly selected and marked by Garmin Oregon GPS in both tropical semi-evergreen forest-covered areas and scrub patches for two years (2021-2023). For the preparation of composite samples, four cores of topsoil (0-15cm) were taken from each sampling point, mixed thoroughly and stored in Ziploc bags. Each soil sample was divided into two parts: one part was used to measure the moisture content and the other part was air-dried and then passed through 2mm sieves to remove any unwanted debris and stored in Ziploc bags. After the preparation of composite samples (n=320), 3 replicates for each sample were prepared for the analysis of physicochemical properties.

5.2.3 Physicochemical analysis

Nine physicochemical parameters soil moisture content, bulk density, pH, electrical conductivity (EC), total organic carbon, available N, available K, available P and available S were analysed seasonally for the collected soil samples. For the physical properties, soil moisture content and bulk density were determined using the gravimetric method and disturb method, respectively [32]. The soil pH was measured using a soil solution prepared with distilled water at a ratio of 1:2.5 [33]. The EC of the soil sample was measured using a soil solution prepared by mixing soil and distilled water at a ratio of 1:5 [34]. Soil organic carbon present in the soil was determined using the standard Walkley-Black wet oxidation method [35]. The available N of the samples was determined using Kjheldahl's method [36]. Available K was measured by a photometric method using a Systronic flame photometer [37]. Bray's No.1 and 0.15% $CaCl_2.2H_2O$ solutions were used to estimate available P and S, [38, 39]. Then the concentration of available P and S was determined by the spectrophotometric method using Systronic visible spectrophotometer 106.

5.2.4 Data analysis

In this study, the null hypothesis (H_0) was that the physicochemical properties of soil (forest and scrub) do not vary across seasons. The alternative hypothesis (H_1) was that the physicochemical properties of soil (forest and scrub) vary across seasons. Kruskal-Wallis test was performed on the forest and scrub soil samples at $\alpha = 0.05$ using IMB SPSS statistics version 26. Multiple factor analysis was performed using the two types of vegetation cover as groups in R using the FactomineR and factoextra packages [40, 41, 42]. The data sets of variables are visualized using a circular correlation plot and multiple factor analysis factor map using R.

5.3 Results

5.3.1 Soil parameters of tropical semi-evergreen forest

Among the physical parameters, the mean bulk density of forest soil samples was not uniform across different seasons (Table 5.1). The lowest bulk density (0.96 g cm^{-3}) was recorded during the premonsoon season (Fig.. 5.1, Table 5.1). However, the distribution of soil moisture remained the same across different seasons ($\alpha = 0.09$) (Table 5.1). The soil moisture content was maximum during the premonsoon at 20.19 ± 8.16 and minimum in the Postmonsoon with 17.56 ± 4.30. Kruskal-Wallis tests revealed that chemical parameters varied across different seasons (Table 5.2). The pH of forest soil was observed to be highest in the post monsoon (4.85 ± 0.52) and lowest in the winter (4.22 ± 0.37) (Fig. 5.1, Table 5.1). Highest value of EC was recorded in the pre-monsoon (132.31 ± 68.85 µS) and lowest in the monsoon (80.03 ± 44.69 µS) (Fig. 5.1, Table 5.1). The soil organic carbon of forest soil was highest during the premonsoon (1.65 ± 0.49 %) and lowest in the winter (1.13 ± 0.53 %) (Fig.. 5.2, Table 5.1). The concentration of available N, P, K and S in the topsoil reached its peaked during the monsoon (284.96 ± 52.00 kg ha^{-1}), post monsoon (274.71 ±

109.21 mg kg^{-1}), pre-monsoon (105.94 ± 48.17 mg kg^{-1}), and winter (18.23 ± 11.90 mg kg^{-1}) (Fig. 5.2 Table 5.1).

5.3.2 Soil parameters of scrub patches

Bulk density of scrub soil samples remained the same throughout different seasons (α = 0.18) (Table 5.1). However, the soil moisture varied across seasons, with the highest recorded during the post monsoon (16.75 ± 2.79 %) and lowest during the monsoon (13.22 ± 4.85 %) (Fig. 5.1, Table 5.1). Both pH and EC in scrub soil varied across different seasons (Table 5.1). The post-monsoon had the highest pH (4.91 ± 0.49) and the premonsoon had the highest EC (116.58 ± 40.64 µS) (Fig. 5.1, Table 5.1). The soil organic carbon of the scrub soil samples peaked in the premonsoon (1.31 ± 0.58 %) and was lowest in the postmonsoon (0.84 ± 0.62 %) (Fig. 5.2, Table 5.1). The Kruskal-Wallis test showed that available N did not vary across different seasons (α = 0.75) (Table 5.2). Available N concentration varies from 191.30 ± 64.02 in monsoon to 210.74 ± 81.40 in post monsoon (Fig. 5.2). However, the concentration of available P, K and S in the scrub soil peaked during the winter (Fig. 5.2, Table 5.1). Table 5.1 provides detailed information on the seasonal variations in the physicochemical parameters of soil of both forest and scrub.

Table 5.1: Seasonal variations in physicochemical properties of soil samples

Physicochemical parameters	Forest				Scrub			
	Postmonsoon	Winter	Premonsoon	Monsoon	Post monsoon	Winter	Premonsoon	Monsoon
Bulk density (g cm^{-3})	1.06 ± 0.09	1.06 ± 0.08	0.96 ± 0.09	1.01 ± 0.11	1.13 ± 0.09	1.14 ± 0.11	1.08 ± 0.14	1.12 ± 0.14
Moisture (%)	17.56 ± 4.30	20.02 ± 8.16	20.19 ± 8.16	17.66 ± 4.56	16.75 ± 2.79	15.19 ± 3.70	15.45 ± 6.42	13.22 ± 4.85
pH	4.85 ± 0.52	4.22 ± 0.37	4.74 ± 0.60	4.52 ± 0.40	4.91 ± 0.49	4.81 ± 0.69	4.26 ± 0.36	4.63 ± 0.52
EC (µS)	93.62 ± 54.43	106.92 ± 72.47	132.31 ± 68.85	80.03 ± 44.69	81.41 ± 59.58	81.07 ± 61.67	116.58 ± 40.64	55.59 ± 33.81
SOC (%)	1.59 ± 0.43	1.13 ± 0.53	1.65 ± 0.49	1.60 ± 0.59	0.84 ± 0.62	1.15 ± 0.49	1.31 ± 0.58	1.09 ± 0.44
Available N (kg ha^{-1})	270.32 ± 35.36	278.79 ± 44.33	234.57 ± 42.63	284.96 ± 52.00	210.74 ± 81.40	201.02 ± 60.36	200.70 ± 56.88	191.30 ± 64.02
Available P (kg ha^{-1})	12.31 ± 4.89	6.76 ± 4.10	5.97 ± 4.42	10.82 ± 6.99	10.97 ± 7.64	5.38 ± 4.09	7.25 ± 4.02	8.32 ± 6.17
Available K (mg kg^{-1})	79.97 ± 30.41	78.24 ± 34.30	105.94 ± 48.17	87.35 ± 50.44	65.96 ± 36.99	90.16 ± 47.16	76.79 ± 31.48	37.65 ± 14.91
Available S (mg kg^{-1})	11.51 ± 5.56	18.23 ± 11.90	8.35 ± 6.36	11.75 ± 9.18	9.75 ± 9.16	22.10 ± 10.58	5.76 ± 3.94	12.59 ± 9.02

Table 5.2: Hypothesis test summary of forest soil samples with significance level (α) of Kruskal-Wallis test is 0.05

Soil sample	Null Hypothesis	Significance (α)	Decision
	The distribution of bulk density is the same across different seasons.	0.00	Rejected
	The distribution of soil moisture is the same across different seasons.	0.09	Retained
	The distribution of pH is the same across different seasons.	0.00	Rejected
	The distribution of EC is the same across different seasons.	0.00	Rejected
Forest soil	The distribution of SOC is the same across different seasons.	0.00	Rejected
	The distribution of available N is the same across different seasons.	0.00	Rejected
	The distribution of available P is the same across different seasons.	0.00	Rejected
	The distribution of available K is the same across different seasons.	0.05	Rejected
	The distribution of available S is the same across different seasons.	0.00	Rejected
	The distribution of bulk density is the same across different seasons.	0.18	Retained
	The distribution of soil moisture is the same across different seasons.	0.01	Rejected
	The distribution of pH is the same across different seasons.	0.00	Rejected
	The distribution of EC is the same across different seasons.	0.00	Rejected
Scrub soil	The distribution of SOC is the same across different seasons.	0.00	Rejected
	The distribution of available N is the same across different seasons.	0.75	Retained
	The distribution of available P is the same across different seasons.	0.01	Rejected.
	The distribution of available K is the same across different seasons.	0.00	Rejected
	The distribution of available S is the same across different seasons.	0.00	Rejected

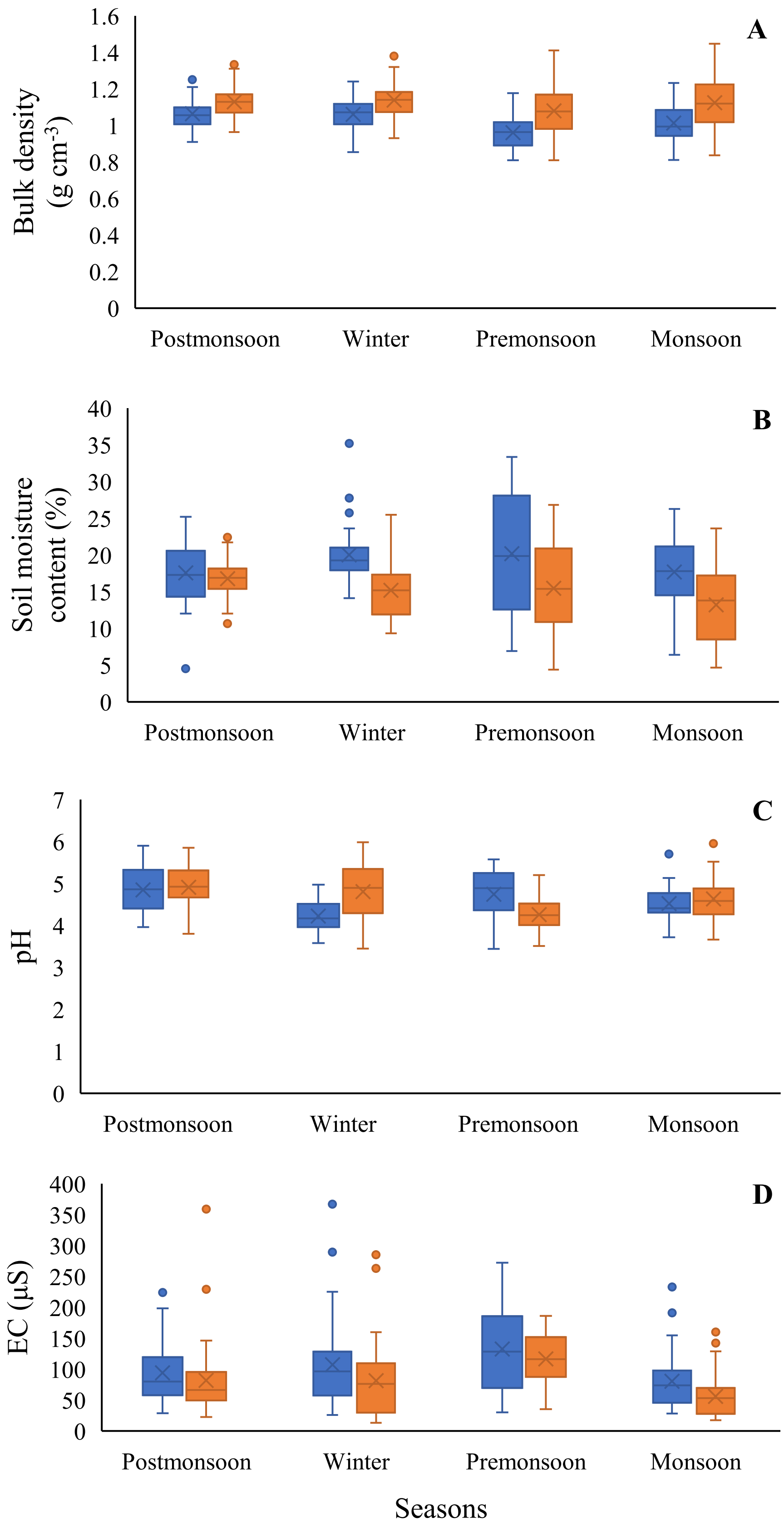

Fig. 5.1: Seasonal variations in bulk density (A), soil moisture content (B), pH (C), and EC (D) in the forest ■ and scrub ■ soil

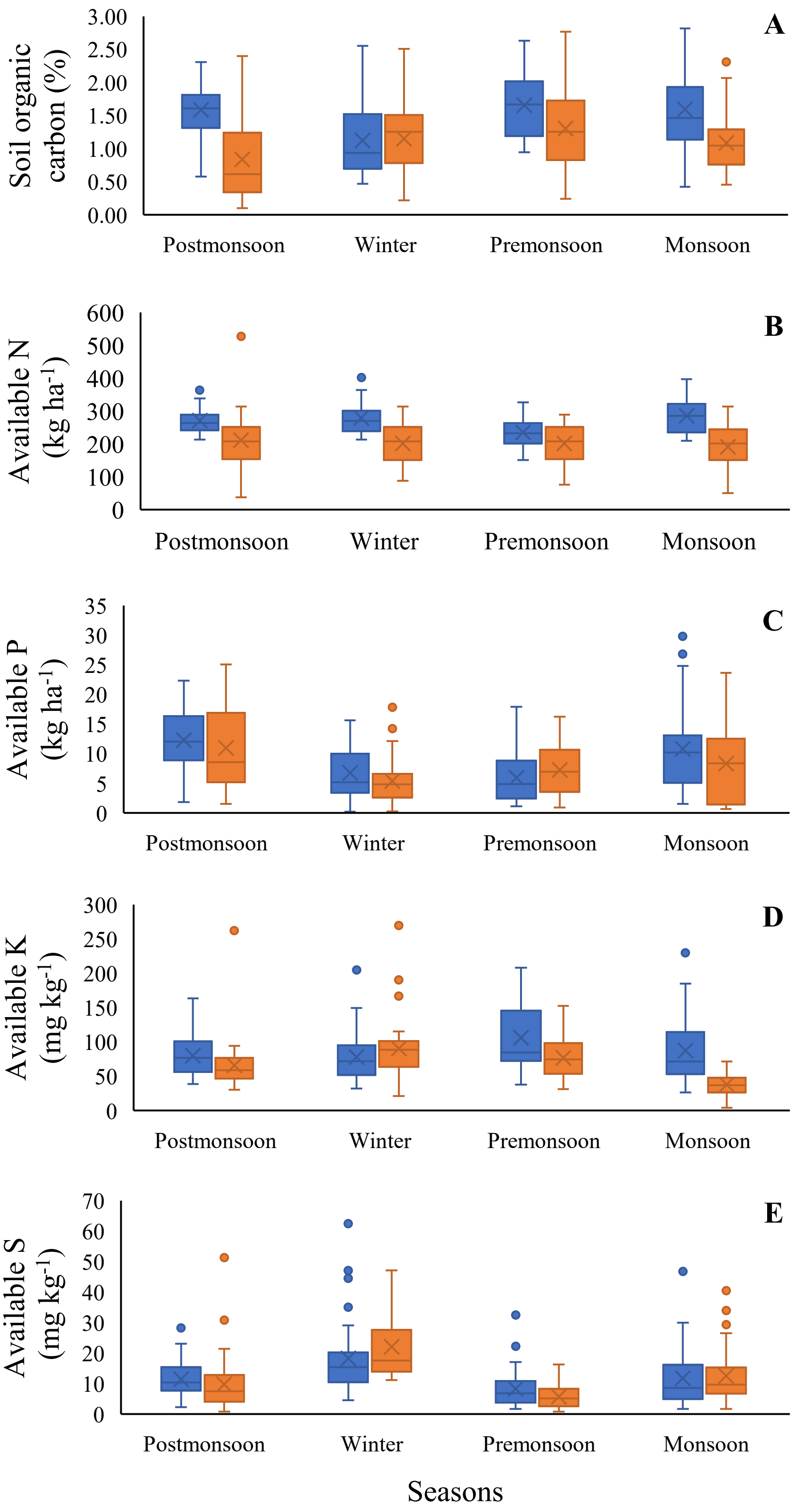

Fig. 5.2: Seasonal variations in soil organic carbon (A), available nitrogen (B), available phosphorus (C), available potassium (D), and available sulphur (E) in the forest ■ and scrub ■ soil.

The correlation circle of variables plot displays the relationship among the 9 selected physicochemical properties of the soil samples and the variances in two dimensions, i.e., Dim1 (19.9%) and Dim2 (15.4%). In the correlation plot, the length of the variable from the center represents the contribution of the variable to the dimension. The relationships between different variables are demonstrated by the angles between them, i.e., the smaller the angle, the higher the correlation between them (Fig.. 5.3) [43]. The variables pointed in the same direction, such as available N and SOC, are positively associated, whereas those pointed in opposite directions, such as SOC and bulk density, are negatively associated. The presence of an angle of 90° between two variables signifies no association between them. Dim1 exhibits the relationships between nutrients, like available N, available K, SOC, etc., and properties of soil like bulk density and electrical conductivity (Fig.. 5.4). Dim2 exhibits the variability caused by variables like pH, and moisture.

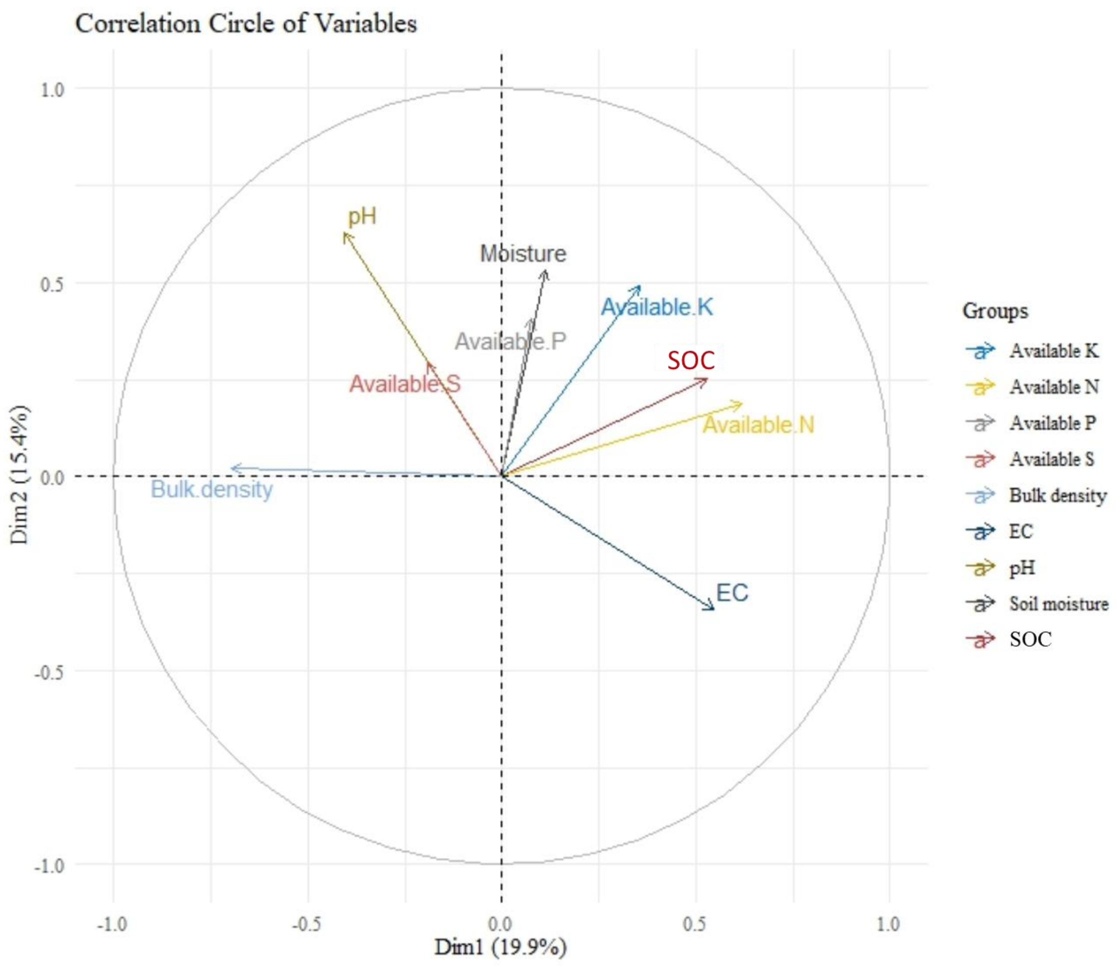

Fig. 5.3: Correlation circle plot of variables displaying nine physicochemical properties of the soil samples

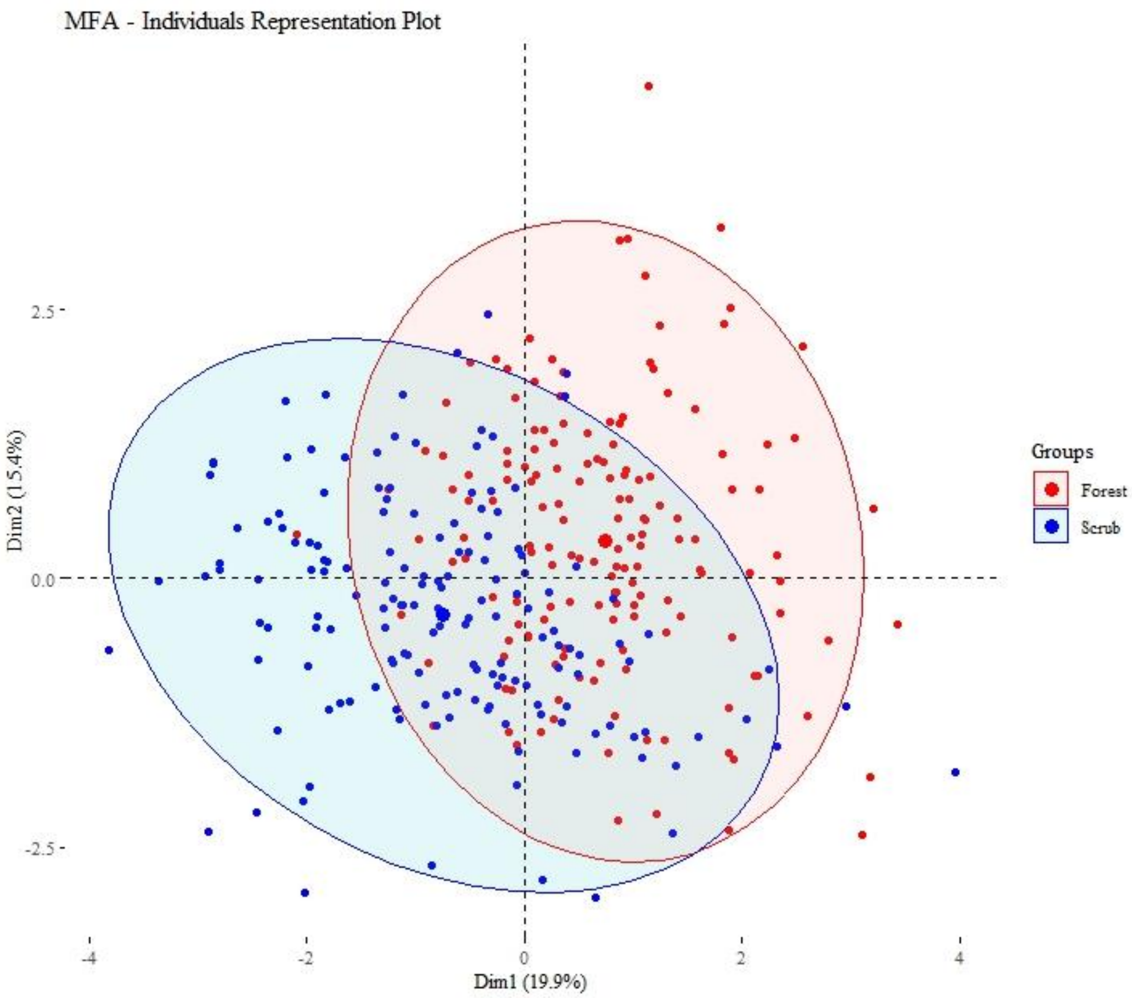

Fig. 5.4: Relationship between variablesand individuals representation plot of multiple factor analysis (MFA)

The MFA individuals representation plot displays the distribution of the samples across the two dimensions: Dim1 (19.9%) and Dim2 (15.4%). The plot reveals that although the samples form distinct clusters, there is overlapping between the two categories (Fig.. 5.4). This illustrates the presence of similarity in physicochemical properties of soil among the two categories as well as the heterogeneity within each category.

5.4 Discussion

The vegetation cover and seasonal variations of climatic conditions of an area are the two key determinants of any seasonal trends in the physicochemical properties of soil [5, 6, 25]. As the vegetative phenophases of trees such as leaf initiation, leafing and leaf fall are species-specific responses to changes in climatic variables, the habits and degree of deciduousness tend to vary species-wise [44]. Consequently, the tree species differ in their impact on the soil properties and fertility due to their variations in physiological and ecological traits [29, 45]. Several studies have also reported that the soil nutrient and organic matter contents fluctuated with the seasonal changes in temperature, precipitation, humidity, etc. [16, 24, 46]. The study observed seasonal variation in most of the physicochemical properties of soil from forest and scrub patches (Table 5.2). The bulk density of the forest soil displayed seasonal variations, but such was not the case for scrub patch soil. On the other hand, the moisture content of the forest soil failed to display any seasonal variations. These variations in the physical properties of soil can be attributed to the differences in vegetation covers that influence the soil through the addition of litter and rooting [47, 48]. Studies have also associated variations in the pH and EC of soil to vegetation and seasons [4, 33]. Both forest and scrub patches exhibit low pH in the soil due to the presence of organic matter and their subsequent degradation. According to Gairola et al. [20], low pH is observed in those soils that have high organic carbon and are subjected to least to no disturbances. Studies have shown that the pH of forest soils commonly ranges from 3.5 to 6.5 [7, 49]. In contrast, higher EC was observed in the forest soil than in scrub patch soil. Saleem et al. [18] reported that the comparatively higher density of trees in the forest-covered area results in higher litterfall and salt accumulation in the soil, thereby higher EC.

The seasonal litter fall and windfall undergo decomposition under suitable climatic conditions, which results in adding organic compounds to the soil [22]. As a result, the soil organic carbon for both forest and scrub soil peaked in the premonsoon. Studies have shown that there is a close association between the concentrations of nutrients in litterfall, litter mass, and topsoil [19, 33]. The changes in vegetation type can lead to alterations in rates of nutrient release during decomposition of litter [47]. The higher concentration of available nitrogen in the topsoil is often attributed to both the quantity and quality of the organic matter present in the surface layer [50]. The present study found that the highest amount of available N was found in the forest soils during the monsoon, indicating an increase in mineralization and nitrification [22]. In contrast, in the case of scrub patches, the amount of available N was lowest during the monsoon. This decrease in the available N in the topsoil of the scrub patches can be attributed to rapid absorption by the herbs and shrubs along with the leaching due to precipitation [18, 22]. In the forest soil, the highest amount of available P and K was during the postmonsoon and premonsoon, respectively, due to the increased mineralization resulting in rapid nutrient release from the decomposition of litter [21]. Whereas, the build-up of available P and K in the scrub soil can be attributed to less precipitation and higher accumulation of the minerals in the topsoil. In contrast with scrub patch soil, the presence of canopy cover over the forest soil facilitates the accumulation of available P [21]. According to Xue et al. [46] and Hou et al. [51], the availability of soil P is influenced by several factors such as soil pH, organic matter, soil moisture content, rainfall, etc. The seasonal fluctuation in the available K of scrub patch is explained by the ability of monocotyledonous species to extract and recycle the K [23, 52]. The concentration of available S in both forest and scrub soil increased during the winter and monsoon which is attributed to the mineralization of S from the organic matter present in the soil [53, 54]. However, the amount of available S in premonsoon was lower in the scrub soil than in forest soil. The decrease in available S content in the soil during the premonsoon is due to the occurrence of leaching when the soil is rewetted due to the occurrence of sporadic localized rainfall [54]. The observed seasonal variations in the properties of soil are a result of the interplays between the soil vegetation and climatic variables of the region.

5.5 Conclusion

The present study reveals the complex interplay between the vegetation types, climatic conditions, and soil within the Sonai Rupai wildlife sanctuary. The impacts of seasonal variations in precipitation, temperature, relative humidity, etc., due to the occurrence of the monsoon are evident from the fluctuations observed in the physicochemical properties of the soil. However, the responses of soil moisture, bulk density, and available nitrogen varied with respect to the vegetation type. Consequently, these differences signify the influence of the vegetation traits along with the ecological processes, on physical properties and nutrient availability of soil. Thus, the findings enhance our understanding of the convoluted soil-vegetation-climate relationship in the foothills of the Eastern Himalaya.

5.6 References

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