Depth-wise distribution of Soil Chemical properties, Micro-nutrients status, and bacterial population under *QuercusLeucotrichophora* and *ShoreaRobusta*forestof Chakrata and Thano region of Uttarakhand

Abstract :

Forest trees have an appreciable demand for nutrients as they have longer rotation than crops and this is easily replenished by the constant release of nutrients resulting from weathering under favorable conditions in the soils developed from parent material rich in nutrient-bearing minerals. A study was undertaken to assess the chemical properties, micro-nutrient status, and bacterial population; two sites were taken for the collection of soil samples: the oak forest ofChakrata and the Sal forest of Thano. Soils were drawn at three depths viz. 0-30 cm, 30-60 cm, 60-90 cm. All soil parameters examined at three depths viz. 0-30 cm, 30-60 cm, 60-90 cm. Oak (QuercusLeucotrichophora) forests have higher microbial activity than Sal forests. The soil in both the studied areas was rich in nutrients, where, the maximummean standard deviation values of pH (6.85), soil organic carbon (5.9 %),available nitrogen (0.04 %) reported in the Oak forest of Chakrata, and available phosphorus werealmost similar in both forest regions. Oak forests have higher organic carbon, water-holding capacity, and nutrient availability compared to Sal forests.However, it is concluded that, for better conditions of these forests for soil and carbon-storing potential, the forest needs good management practices, especially in community forest areas to avoid illegal felling, impact of fire, and over-exploitation of fuel and fodder. Good management practices would help mitigate the impact of climate change and sustainable outcomes of the resources for the community'sbenefit.

Keywords: Soil physicochemical characterization, Oak, Sal, Over-exploitation, Sustainable outcome, Climate change, Community Benefits

Introduction

Garhwal Himalaya has a vast variation in climate, topography, and soil conditions; forming a very complex ecosystem. The distribution of nutrients in the soil is essential for plant growth. Plants take up nutrients from the topsoil as well as the subsoil. According to our theory, the plant cycle is more important than leaching, weathering, and atmospheric deposition in determining vertical nutrient distribution. "Plant production depends on the dispersion of nutrients according to depth. Nutrient levels are balanced by the physical, chemical, and biological effects of the litter layer on the soil. Compared to crops, forest trees require weathering to restore their nutrients because of their longer rotations. Himalayan ecosystems cover a range of vegetation and soil types that differ significantly in biogeochemical characteristics" (Gairola, et al., 2012, Bargali, et al., 2019)."The studies on the physicochemical properties of the soils of Garhwal Himalaya have been carried out by several workers"(Bhandari, et al., 2000; Gairola, et al., 2010 Sharma et al., 2009)."Physico-chemical characteristics of forest soils vary in space and time because of variations in climate, topography, weathering processes, vegetation cover, and several other biotic and abiotic factors" (Paudel and Sah, 2003; Sheikh and Kumar, 2010)."Altitude plays a significant role in changing the climatic characteristics, soil properties, and land use patterns" (Deb, et al. 2019).

"The Himalayan soils contain a high diversity of bacteria that produce carbonic anhydrase, which is an important candidate for investigations related to carbon sequestration" (Giri A., et al., 2019). "Oak (*Quercus Leucotrichophora*) is a deep-rooted and moderate-sized evergreen tree that occurs in the moist and cool aspects in the lower Western Himalayan temperate forest between altitudes 1000 to 2300 m" (Singh and Singh, 1987; Joshi and Negi, 2015). "Sal (*ShorearobustaGaertn.*

*f.)*belongs to the Dipterocarpaceae family and is one of the most important timber trees in India" (Deka et al., 2012; Sapkota et al., 2009). "Sal forests are widely distributed in tropical India and cover approximately 13.30 percent of the total forest area of the country" (Satya and Nayaka 2005). According to Champion and Seth (1968), "it is one of the dominant tree species in tropical moist as well as dry deciduous forests in India"."The availability and uptake of nutrients are directly proportional to the living components of the soil. Bacteria cause several changes and biochemical transformations in the soil, thereby directly or indirectly contributing to the nutrition of higher plants growing in the soil. The important transformations and processes in which soil bacteria play a vital role include the decomposition of cellulose and other carbohydrates, ammonification (ammonia fromproteins), nitrification (ammonia to nitritesto nitrates), denitrification (release of free elemental nitrogen), biological stabilization of atmospheric nitrogen (symbiotic and non-symbiotic), oxidation and reduction of sulfur and iron. All these processes play a significant role in plant nutrition, and one microorganism that produces thermo-stable lipase was isolated from soil collected from the Himalayan region".(Sahu et al., 2013) "Abandoning agricultural land in Central Himalaya has become a trend in the past few decades due to the rural–urban migration in the region for gainful employment and livelihood opportunities" (Joshi et al., 2023). "Much research has been conducted in the current context of vegetation types to compare the influence of vegetation on SOC and nutrients, microbial biomass, and soil respiration" (Bargali et al., 2019, Joshi and Garkoti, 2020, Kumar et al., 2021). Nevertheless, little research has especially focused on evaluating whether soil depth and vegetation-type variables influence soil characteristics in this area. Thus, a comprehensive understanding of soil biogeochemical characteristics and C: N: P stoichiometry and SOC, TotalN, and Total P stock influenced by vegetation types and soil depths in mountainous areas in the central Himalayas is important to fill the knowledge gap in C, N and P cycling.

Material and methods

Two dominant forest species (Oak and Sal) were selected in the Thano and Chakrata areas of the Dehradun district in the state of Uttarakhand, India. The ***Shorearobusta*** **(Sal)** is the dominant species of the Thano region and is deciduous in nature. Similarly, temperate forest sites of Chakrata comprise ***QuercusLeucotrichophora*** **(Oak).**

Study Areas

The main aim of this study is to hypothesize the impact of specific forest species on the depth-wise distribution of soil properties and to interpret the correlation among them. The study was carried out in the Thano region of the Dehradun district of Uttarakhand state, India lies between latitude 30.2373248 and longitude 78.2098735. The nearest state capital from Thano is Dehradun (39.8 km away). The soils of this region vary according to feature, altitude, and climate, and are generally young and thin.The hilly region has densely forested slopes and usually contains clayey to sandy loam sedentary soil with podzolization (Sheikh *et al.,* 2020). The study area falls ina temperate climate zone with cold, especially in winter, and pleasant in summer. Here temperature ranges from −2 °C to 20 °C in January and 24 °C to 36 °C in June and July (Kumari*et al.,* 2018, Sheikh *et al.,* 2020) with rainfall of 2180 mm and these soils developed from different parent materials in equilibrium with geogenic factors. All pedogenic processes are active in the study area. The soils are generally acidic in nature with pH increasing with depth.Chakrata is a cantonment town in Dehradun district in the state of Uttarakhand, India. It is between the Tons and Yamunarivers, at an elevation of 7000–7250 feet, 98 km from the state capital, Dehradun. It is situated in Dehradun district in Garhwal Himalayas between 30 º 31' to 31 º 3' N latitudes and 77 º 42' to 78 º 5' E longitudes, covering an area of approximately 1,999.50 km^2. The soils of Chakrata are formed as a result of long-continued leaching under a moist temperate climate and consist of clayey and sandy loam on the hills, and sandy and pebbly loam in the valleys and the entire area has moderately deep, non-calcareous, and heavy textured soils. They are characterized by high water-holding capacity, moderate to high nutrient-retaining capacity, and high content of organic matter, nitrogen, and manganese (J.S.P. Yadav 1963).

(a) Sal forest (Thano, Dehradun)

(b) Oak forest (Chakrata, Dehradun)

Plate.1: Forest areas: (a) Sal forest (Thano, Dehradun) and (b) Oak forest (Chakrata, Dehradun)

<u>Collection of soil samples:-</u>

Selected one forest stand for each species. Demarcated stands into three plots, each 0.5m x 0.5m. Removed litter, and dug a pit (30x30x50cm) at each plot. Collected soil samples at 0-30cm, 30-60cm, and 60-90cm depths using a trowel (Plate.2). Packed samples in labeled plastic zipper bags and transported to the lab. In the lab, divided samples: one part for microbiological parameters (stored at 4°C) and one for physico-chemical parameters. Physico-chemical samples are air-dried, ground, and sieved through a 100-mesh sieve.

Plate.2: Soil samples collection from Forest sites

Physical-chemical analysis of soil

Soil pH was determined by using a calomel electrode with 1:2.5 soil water ratios. Soil organic carbon (SOC) was determined by (Walkley and Black Method, 1934).Soil texture was analyzed by Hydrometer method (Bouyoucous, 1962). Soil available nitrogen was analyzed by the method given by (Subbiah and Asija (1956). Potassium (Hanway and Heidel, 1952), Determination of available phosphorus is by the Olsen method (Olsen, *et al.*, 1954). Micronutrients like zinc, copper, iron, and magnesium, were estimated with the help of an Atomic Absorption Spectrophotometer or AAS (Lindsay and Norvell, 1978).

Bacteriological analysis

For the isolation of bacteria, the serial dilution method given by Johnson and Curl 1972 was followed using a Nutrient agar medium. Nutrient agar media was poured into each sterilized petri dish. For each dilution, two petri dishes were used. 1 mL of 10^{-5} dilution was spread on the petri dish having nutrient agar media with the help of a glass spreader. Then the Petri dishes were incubated at $37^{o}C$ for 48 hours in an inverted position inside the Incubator. After incubation colonies were counted on the colony counter.

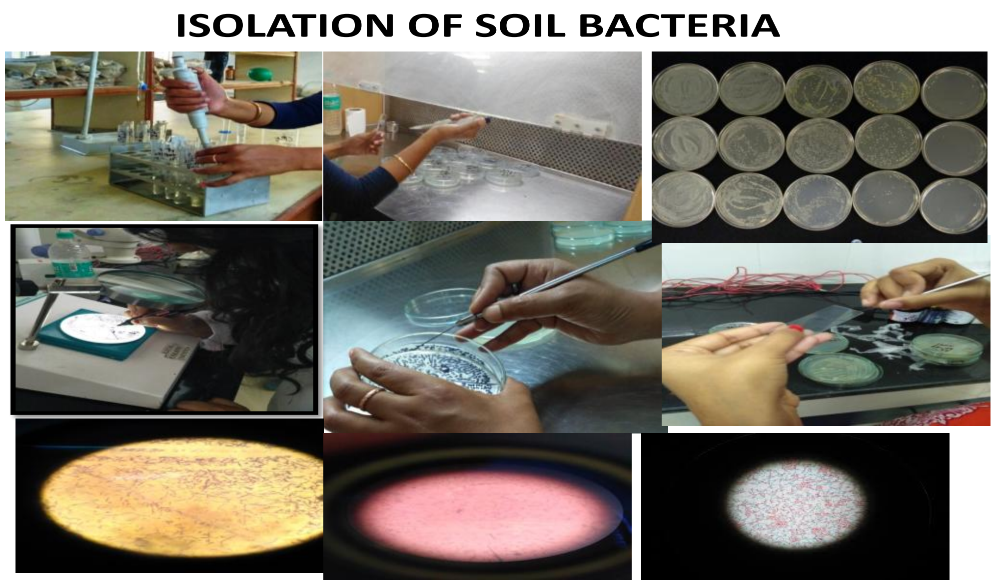


Plate.3: Isolation of bacteria by serial dilution method.

Statistical analysis

Data were summarized as mean ± SD (standard deviation).Pearson correlation analysis was done to assess associations between the variables. A two-tailed values less than ($p<0.05$) were considered statistically significant. Analysis was performed using SPSS software (version 16.0).

Results and Discussion

Analysis of soil Physical, chemical, and bacterial properties

In general, all the soil parameters, viz., organic carbon, available nitrogen, phosphorus potassium heavy metals including copper, zinc, iron, manganese, and most probable number of bacteria were analyzed and found that they decreased significantly with increasing soil depth in both the forests.Mishra et al., 2015 also reported that soil organic carbon, nitrogen, phosphorus, and sulfur content decreased from higher elevation to lower elevation while pH, potassium, and boron showed a reverse trend. However, pH did not show any trend with soil depth in the present study. In Oak Forest mean values of pH at all three depths viz. 0-30, 30-60, and 60-90 are found at 6.18, 6.18, and 6.85(Fig.1) while in the Sal forest mean values of pH at all three depths viz. 0-30, 30-60, and 60-90 are found 6.09, 5.93, and 6.23 respectively (Fig.3).

Soil organic carbon (SOC) content across distinct soil depths within the Oak forest of the Chakrata region, SOC exhibits a pronounced vertical gradient, demonstrating a remarkable decrease with increasing depth. The uppermost layer (0-30 cm) reigns supreme with the highest SOC concentration, with has substantial 5.9%. Delving deeper, we encounter a notable decline, with the middle layer (30-60 cm) having diminished by 3.8% of SOC. Finally, the 60-90 cm soil horizon exhibits a significant decline in organic carbon (SOC) content, dropping from 5.9% in the uppermost layer to a meager 2.3% (Fig.2). This intriguing pattern underscores the pivotal role of surface litter fall and vigorous plant root activity in enriching the topsoil horizons with organic matter, highlighting the diminishing influence of these biological inputs deeper within the soil profile. The soil under the Sal forest in Thano, Dehradun, has the most organic carbon in the top 30 cm, at 5%. This amount gradually decreases to 2.8% at the 60-90 cm depth. Even at deeper depths, there is still a significant amount of organic carbon, which is important for soil health and storing carbon (Fig.4).

The values of total N in the study area were higher in the upper layers as compared to the lower layers. In Oak Forest, mean values of Available N% at all three depths viz. 0-30, 30-60, and 60-90 are found 0.04, 0.03, and 0.026 respectively (Fig.1). In the Sal forest, mean values of Available N% at all three depths viz. 0-30, 30-60, and 60-90cm are found at 0.02, 0.02, and 0.016% respectively (Fig.3). This could be attributed to heavy litter and humus contents in the upper layers of the studied forest types. The available nitrogen is comparatively higher in the surface horizons of all the soil profiles, which is because of the higher amount of organic carbon in those horizons as reported by Jobbagy Jackson 2001.Thadani and Ashton 1995 also reported a nitrogen value of 0.34% for the Garhwal region and 0.17 to 0.30% in Kumaun Himalaya for *Q. leucotrichophora* forests. Kumar *etal.*, 2004observed nitrogen values ranging from 0.10 to 0.20% in TehriGarhwal for *Q. leucotrichophora* forests. Sharma *et al.2010* also reported nitrogen values between 0.14 to 0.19% in Pauri Garhwal for *Q. floribunda*and 0.19 to 0.22% for *Q. semecarpifolia* forests.Physico-chemical properties of soils from different land use systems viz. agriculture, olericulture, and two dominant forest types (*Quercusleucotrichophora* and *Pinusroxburghii*) in Uttarakhand were analyzed by Tewariet al, 2016 and it was found that the physicochemical parameters such as water holding capacity, cation exchange capacity, available nitrogen, and potassium were found significantly higher for oak forests compared to pine forests.

Availablephosphorus was also found higher in the lower horizons of the studied forest types, which may be due to increasedpH in lower depths as the pH value in lower depths was more toward neutral and P is available at near neutral pH.In oak forest mean values of available P% from higher to lower depths are 0.0022, 0.0019, and 0.002 (Fig. 1) Similarly in Sal Forest, the mean value of available P% from higher to lower depths are 0.002, 0.02 and 0.016 (Fig.3).

Available K% in the Oak forest area of Chakratawere examined at different depths, viz. 0-30, 30-60, and 60-90 cmand found their mean % values 0.009, 0.0082, and 0.0080 % respectively (Fig.1). In the Sal forest area of Thano available K% were examined at different depths, viz. 0-30, 30-60, and 60-90 cm and found their mean % values 0.002, 0.002, and 0.0019 % respectively (Fig.3). Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen and some cases, calcium Sharma *et al* 2013. Saha,et al, 2018reported potassium content between 102.29 and 206.22 kg ha^{-1}inthe Himalayan temperate forestof the Garhwal region.

Soil microbial activity differs between Oak and Sal forests, depth-wise (0-30, 30-60, and 60-90 cm) distribution of microbial activity in Oak forestsis101.3, 38.3, and 33.33 colony/gram respectively (Fig.2b). But in Sal forest, microbial activity is higher in the upper soil layers than Oak. Depth-wise (0-30, 30-60, and 60-90) distribution of microbial activity in the Sal forestis106.7, 44.83, and 40.33 colony/gram respectively (Fig. 4(b).

The sand, silt, and clay content in the Oak forest of Chakrata ranged from 64.21 to 68.43%, 13.67 to 15.8 %, and 17.9 to 20.16 % respectively (Fig.2 (c)). In the Sal forest of the Thano region of the Dehradun district, sand content ranged from 68.06 to 69.28%, silt content from 12.67 to 13.67%, and clay content ranged from 18 to 18.61% (Fig.4c).Semwal (2006) in a study of*Quercus leucotrichophora* forest in PauriGarhwal reported that the values of sand, silt and clay particles ranged from 24.10 to 42.10%, 3.80 to 16.80% and 51.70 to 72.10% respectively.In the Chakrata oak forest, Usmanet al, 2000 reportedsand, silt, and clay particle values of 56.10, 25.00, and 18.60%respectively in *Quercusleucotrichophora*forest of Kumaun Himalaya.Kheraet al., 2001 observed the range values of sand between 90.90 to91.30%, silt (3.80 to 4.30%), and clay (1.00 to 1.20%). In the Thano Sal forest general, and the top soils were relatively coarse-textured, being sandy loam, compared to the sub-soils, which were loamy sand, clay contents graduallyincreased with depth, sand particles were reported higher than silt and clay particles. However, silt particles reduced with the increasing soil depth. The clay particles have shown a reversed trend with silt particles, which increased with increasing soil depth. The highest and lowest values of sand particles were reported in 0-30 cm and 30–60 cm depth respectively, while silt particles were highest in 20–30cm depth and lowest in 10–20 cm depth. However, clay particles were highest in 20–30 cm and lowest in 10–20 cm depth. At lower altitudes, the sand particles reduced with increasing soil depth. However, silt particles have shown a reverse trend, which increased with increasing depth. The maximum and minimum values of clay particles were reported in the depths of 10–20 cm and 0–10 cm respectively.

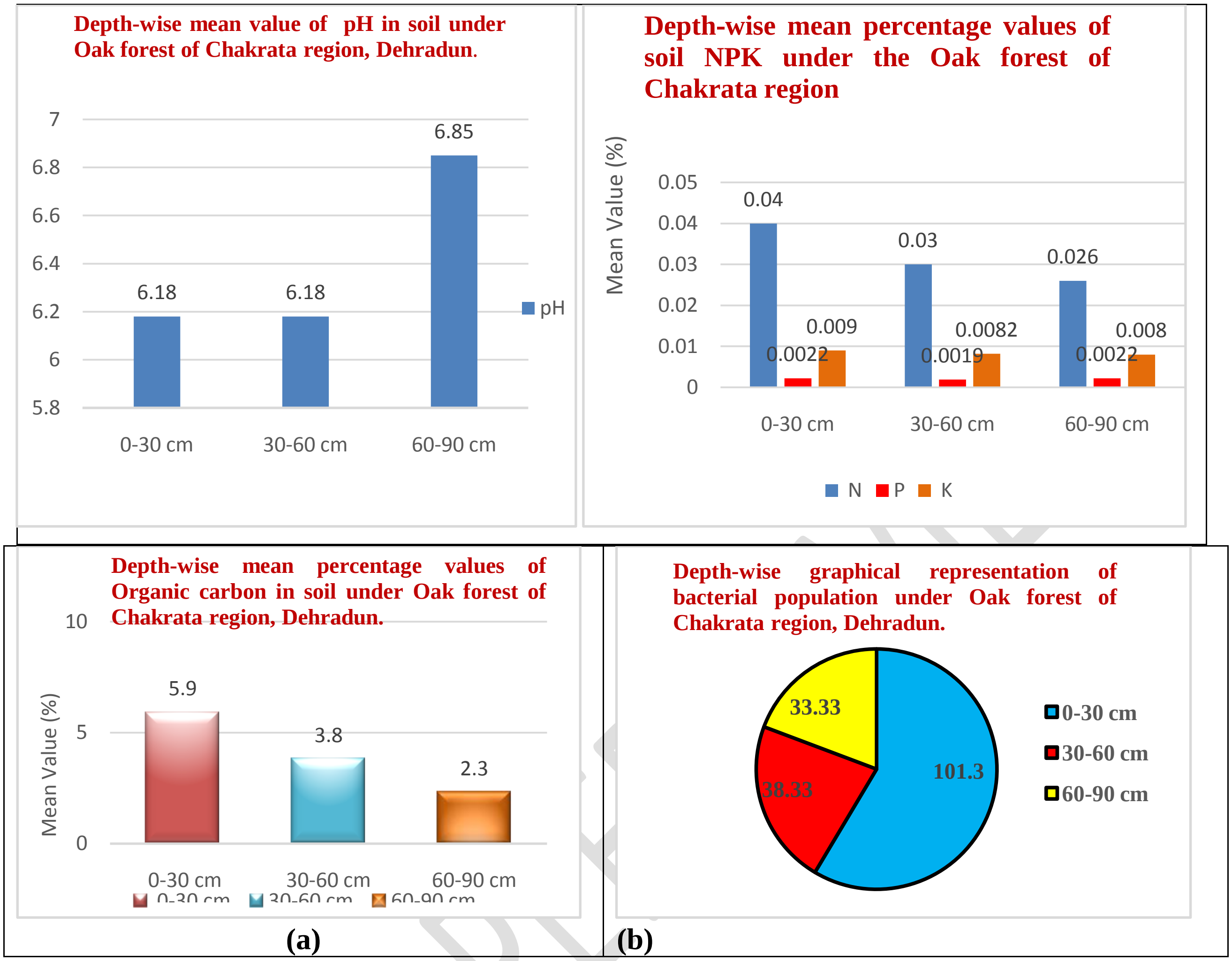


Fig:-1 Graphical representation of depth-wise mean percentage values of Soil N-P-K and pH properties under Oak forest of Chakrataregion, Dehradun

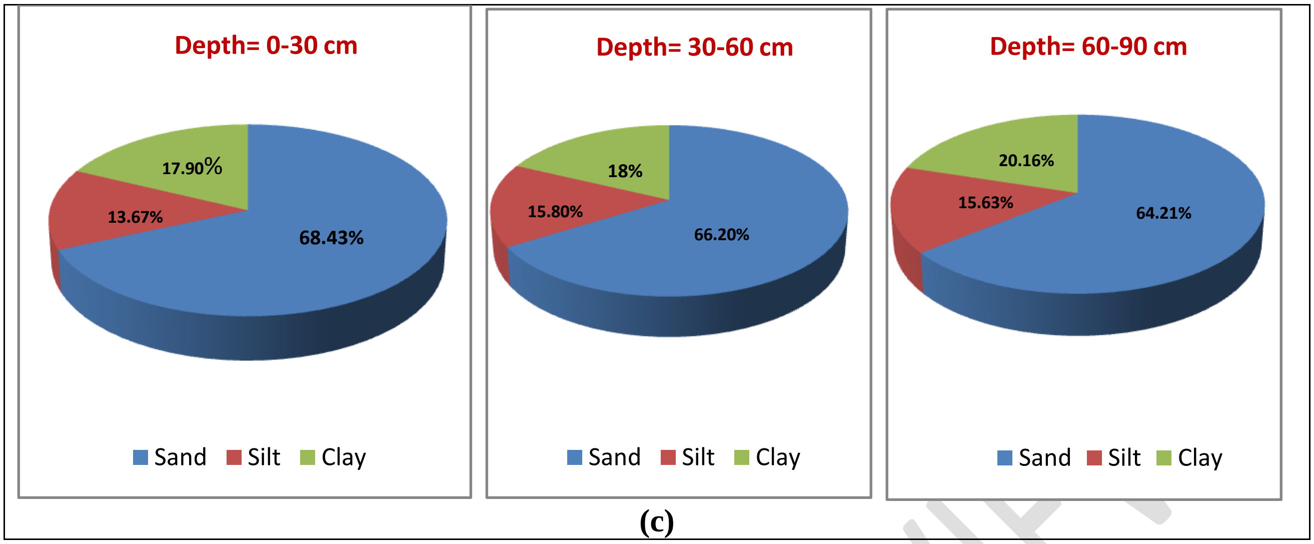


Fig.2: Graphical representations of depth-wise mean percentage values of Soil Organic Carbon (a), bacterial populations (b),and Soil texture properties (c) under the Oak forest of Chakrata.

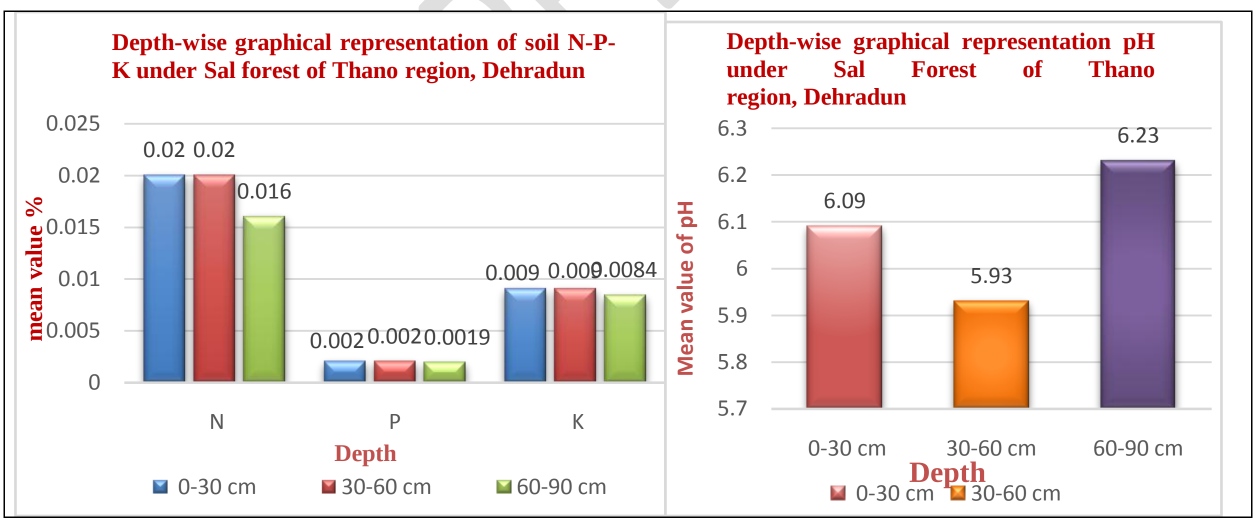
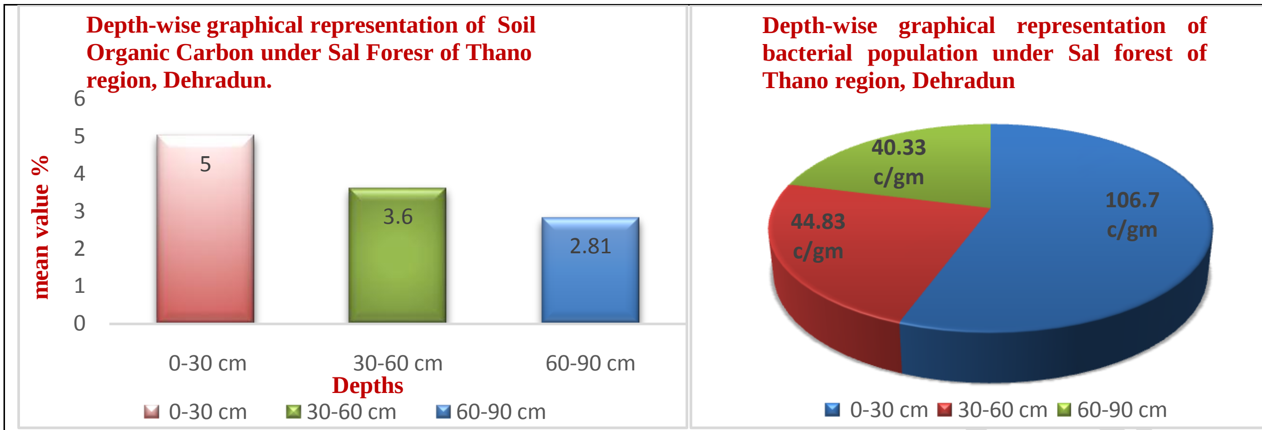
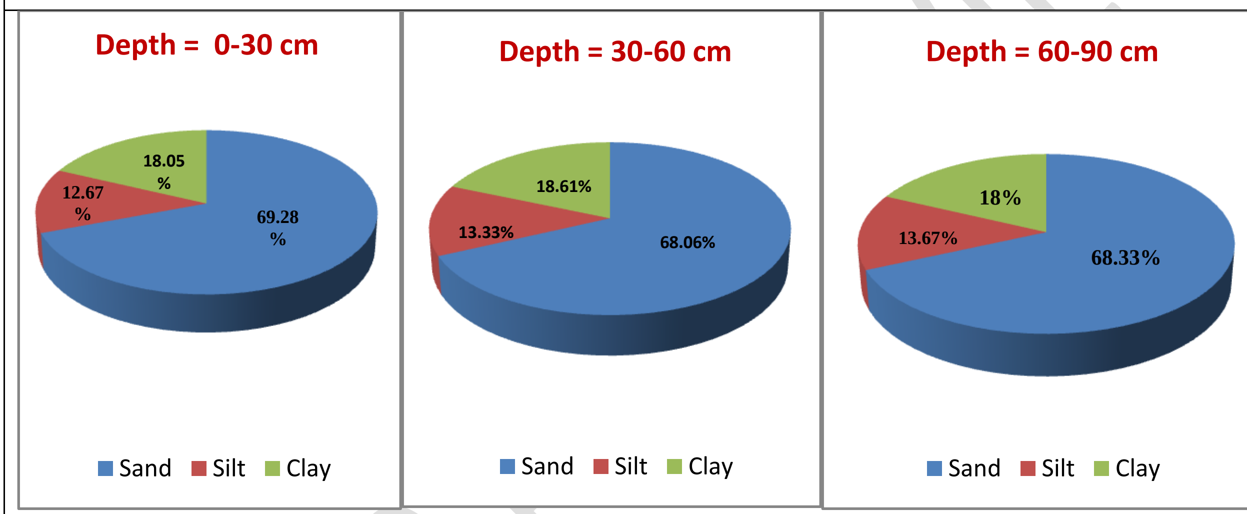


Fig.3: representation of mean percentage values of Soil pH and NPK properties under Sal Forest of Thano region, Dehradun.

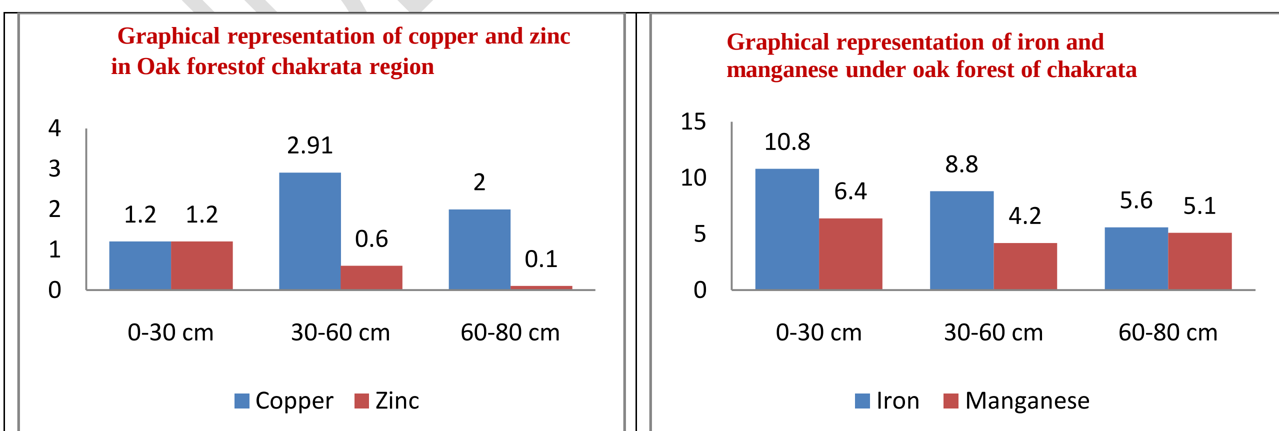


(a) (b)

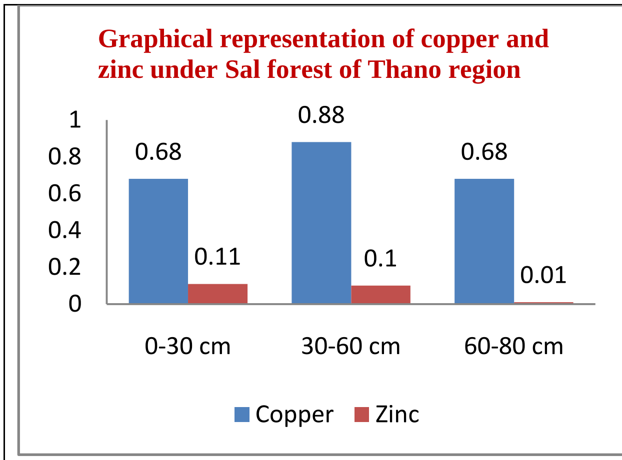


(c)

Fig.4: <u>Graphical representation of mean percentage values of Soil Organiccarbon (a), Bacterial populations (b), and soil texture properties(c) under Sal Forest of Thano region, Dehradun.</u>



(a) (b)



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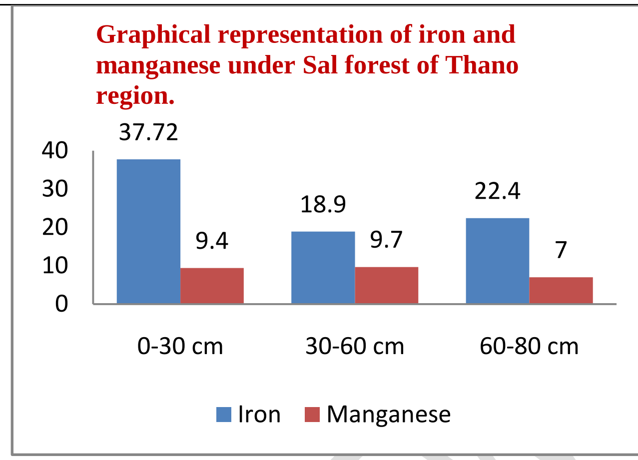

(d)

Fig.5: Graphical representation of mean values showing the depth-wise distribution of soil micro-nutrients [(a) - copper and zinc & (b)- iron and manganese under Oak forest of Chakrata region and (c) – copper and zinc& (d) – iron and manganese under Sal Forest of Thano region, Dehradun

Analyses of depth-wise soil micro-nutrient mean percentage in the Oak forest region of Chakrata, Dehradun, and Sal Forest region of Thano, Dehradun (Fig. 5)

Data reveals the study area in the Oak forest region of Chakrata, Dehradun in which depth-wise soil micro-nutrients were studied. Iron shows the greatest mean percentage value at all depths, culminating in the 0–30 cm layer at 10.8 and progressively decreasing with depth. Zinc shows a similar trend to copper, peaking at 1.2 in the 0–30 cm layer and falling down in concentrations as 0.1 (Fig.5a). Manganese shows mean percentage value 6.4 in the 0–30 cm layer, 4.2 in the 30–60 cm layer, and 5.1 in the deepest layer, which is a more marked decline (Fig.5b). Of the four micro nutrients, zinc has the lowest mean percentage values 1.2 in the 0–30 cm layer, 0.6 in the 30–60 cm layer, and 0.1 in the 60–90 cm layer (Fig.5a). While the study in Sal forest region of Thano, Dehradun revealed iron stands out as the predominant micro-nutrient, demonstrating consistently elevated mean values throughout all soil depths, reaching its zenith at 37.72 within the 0-30 cm range (Fig.5d). In close succession, manganese displays the second-highest concentrations, attaining a peak mean value of 9.7 at the 30-60 cm depth (Fig.5d). Zinc follows a pattern of consistent decline with increasing soil depth, decreasing from 0.11 at 0-30 cm to 0.01 at 60-90 cm(Fig.5c). Copper levels exhibit variations across different depths, with the highest mean value of 0.88 recorded at 30-60 cm (Fig.5c). This thorough analysis underscores the dominance of iron, the successive distribution of zinc, and the distinct patterns in manganese and copper concentrations across diverse soil depths, offering valuable insights into the micro-nutrient dynamics within the scrutinized soil profile.

All these pedons were found to be sufficient in available Cu as all the values were well above the critical limit of 0.20 mg kg-1 soil as suggested by Lindsay and Norvell (1978) with confidential interval ranging from 1.11 to 1.91 mgkg-1 with a mean value of 1.51mgkg-1. The variation in Cu content with the depth may also be attributed to the positive relation with organic carbon, clay content, and cation exchange capacity of the soils (Yadav and Meena, 2009). The data reveals that all the profiles of the study area were normal in zinc content with a decreasing trend in the sub-surface horizons with the depth with a confidential interval ranging from 1.09 to 1.83 mg kg-1 vertical distribution of Zn exhibited little variation with depth. Considering 0.6 mg kg-1 as a critical level (Lindsay and Norvell 1978) these soils were sufficient in surface horizons. A slight decrease in the content of zinc was noted with the increase in soil depth, which may be attributed to their positive and significant correlation with organic carbon. Similar results were reported by Devi et al., (2015) and Khanday *et al.*, (2017). The distribution of available Fe in all the pedons decreased with the increase in depth. It might be due to the reduction of organic carbon in the sub-surface horizons. Surface horizons had higher concentrations of DTPA-extractable Fe due to relatively higher organic carbon in surface horizons. According to a critical limit of 1.0 mg kg-1 of Lindsay and Norvell (1978), the soils were sufficient in available Mn. The confidential interval ranged from 22.39 to 29.64 mg kg-1 with a mean value of 26.02 mg kg-1 and almost decreased with depth which might be due to higher biological activity and organic carbon in the surface horizons, the higher content of available Mn in surface soils was attributed to the chelating of organic compounds released during the decomposition of organic matter left after harvesting of crop.

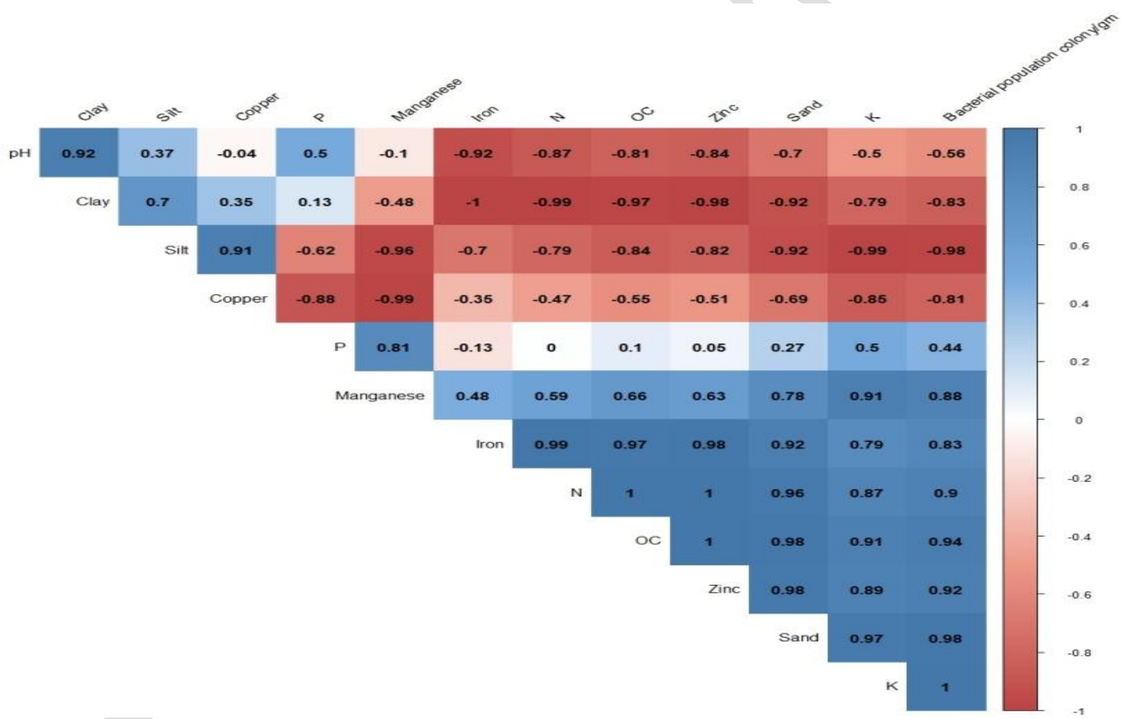

Fig.6: Graphical representation of Pearson's correlation among soil pH, Bacterial populations, N-P-K –OC, micronutrients,andtexture properties under Oak Forest of Chakrata region, Dehradun.

Explanation of Pearson's correlation among pH, Organic Carbon, N-P-K properties, soil texture, and soil micronutrients under the Oak Forest region of Chakrata, Dehradun (Fig. 6).

pH and OC: The correlation coefficient between pH and OC is -0.81. This is a strong negative correlation, meaning that OC decreases as pH increases, and vice versa.
pH and N: The correlation coefficient between pH and N is -0.87. This is another strong negative correlation, suggesting that as pH increases, N decreases, and vice versa.
pH and P: The correlation coefficient between pH and P is 0.5. This is a moderately positive correlation, indicating that as pH increases, P also tends to increase, but this relationship is not as strong as the negative correlations with OC and N.
pH and K: The correlation coefficient between pH and K is -0.5. This is a moderate negative correlation similar to the relationship between pH and P.
pH and Bacterial populations: The correlation coefficient between pH and bacterial populations is 0.-0.56. This is a moderate negative correlation
pH and Silt: The correlation coefficient between pH and silt is 0.37 which is a weak positive between them.
pH and Clay: The correlation coefficient between pH and clay shows a strong positive correlation which means if pH increases; clay contentin soil also increases.
pH and Zn: The correlation coefficient between pH and Zn was -0.84, a very strong negative which means pH decreases with an increase in the Zn content of soil and vice versa.
pH and Cu: The correlation coefficient between pH and Cu was very weak negative -0.04.
pH and Fe: The correlation coefficient between pH and Fe was-0.92, a very strong negative which means pH decreases with an increase in Fe content of soil and vice versa.
pH and Mn: The correlation coefficient between pH and Cu was very weak negative -0.1.
pH and Sand: The correlation coefficient between pH and sand is -0.7 which means if one increases other decreases and vice-versa.
OC and N: The correlation coefficient between OC and N was 0.995. A very strong positive correlation means that OC and N tend to move in the same direction.
OC and P: The correlation coefficient between OC and P was 0.096. This was a very weak positive correlation, indicating almost no relationship between OC and P.
OC and K: The correlation coefficient between OC and K was 0.910. This is a very strong positive correlation similar to OC and N.
OC and Silt: The correlation coefficient between OC and silt is -0.84 strong negative correlations, meaning that OC decreases with silt content increases and vice-versa.
OC and Bacterial populations: There is a very strong positive correlation of 0.94 among OC and bacterial populations, meaning that bacterial populations increase with increasing OC content in the soil.
OC and Clay: There is a very strong negative correlation of -0.97 among OC and Clay which means OC content decreases with increasing clay content in soil and vice versa.
OC and Sand: There is a very strong positive correlation of 0.98between OC and Sand, meaning that Sand increases with increasing OC content in the soil.
OC with micronutrients: The correlation coefficient between OC and Cu was -0.55, a moderately negative correlation. OC and Zn had 1 very strong positive correlation. OC and Fe hada 0.97 very strong positive correlation. OC and Mn hada 0.66 positive correlation.
N and P: The correlation coefficient between N and P is 6.11E-17. This value is essentially 0, indicating no correlation between N and P.
N and K: The correlation coefficient between N and K was 0.866. This is a strong positive correlation similar to the relation between K and N.
N and Bacterial populations: The correlation coefficient between N and bacterial populations was 0.9. This is a strong positive correlation similar to the relation between N and bacterial populations.

N and Silt: The correlation coefficient between N and silt was -0.79 strong negative relation between the two, meaning that N content decreases with increased silt content

N and Clay: The correlation coefficient between N and clay was -0.99. A very strong negative relation between the two, meaning that N content decreases with an increase in clay content

N and Sand: The correlation coefficient between N and sand was 0.96.A very strong positive correlation means that sand and N tend to move in the same direction.

N with micronutrients: The correlation coefficient between N and Cu was -0.47 moderately negative correlation. The correlation coefficient between N and Zn was 1, a very strong positive correlation. The correlation coefficient between N and Fe was 0.99, a very strong positive correlation. The correlation coefficient between N and Mn was 0.63.

P and Silt: The correlation coefficient between P and silt was -0.62 which means if one increases other decreases and vice-versa.

P and Sand: The correlation coefficient between P and sand was weakly positive at 0.27.

P and Clay: The correlation coefficient between P and clay was weakly positive at 0.13.

P with micronutrients: The correlation coefficient between P and Cu was -0.88, a very strong negative correlation which means P decreases with increasing copper in soil. The correlation coefficient between P and Zn was 0.05 very weak positive correlation. The correlation coefficient between P and Fe was -0.13, a very weak negative correlation. The correlation coefficient between P and Mn was 0.81, a strong positive correlation.

K and Silt: There is a very strong negative correlation of -0.99 among K and silt which means K content decreases with increasing silt content in soil and vice versa.

K and Sand: There is a very strong positive correlation of 0.97between K and sand, meaning that Sand increases with increasing K content in the soil.

K and Clay: There is a strong negative correlation of -0.79 between K and clay which means K content decreases with increasing clay content in soil and vice versa.

K and micronutrients: There is a very strong negative correlation of -0.85 among K and Cu which means K content decreases with increasing copper content in soil and vice versa. There is a very strong positive correlation of 0.91 among K and Mn, 0.89 among K and Zn, 0.79 among K and Fe

Sand and Silt: There is a strong negative correlation of -0.92 between sand and silt which means silt content decreases with increasing sand content in soil and vice versa.

Sand and Clay: There is a strong negative correlation of -0.92 between sand and clay which means clay content decreases with increasing sand content in soil and vice versa.

Clay and Silt: The correlation coefficient between clay and silt was 0.7. This is a strong positive correlation similar to the relation between pH and N.

Sand with micronutrients: There is a negative correlation of -0.69 among sand and Cu which means Cu content decreases with increasing sand content in soil and vice versa. There is a very strong positive correlation of 0.98 among sand and Zn, 0.92 among Sand and Fe, and 0.78 among sand and Mn.

Silt with micronutrients: There is a strong negative correlation of silt among three out of four micronutrients viz. Mn, Zn, and Fe, and the correlation coefficient were found -0.96, -0.82, and -0.7 respectively, which means that Mn, Zn, and Fe Content decreases with an increase in silt in soil and vice versa. However,the correlation coefficient among silt and Cu was 0.91, a very strong positive correlation.

Claywith micronutrients: There is a strong negative correlation of clay among two out of four micronutrients viz. Zn, and Fe, and the correlation coefficient were found -0.98, and -1 respectively and a moderate correlation between clay and Mn was found -0.48, which means that Mn, Zn, and Fe content decreases with an increase in silt in soil and vice versa. The correlation coefficient among clay and Cu was weakly positive at 0.35.

Zn and Fe: There is a very strong positive correlation of 0.98betweenZn and Fe, meaning that Fe increases with increasing Zn content in the soil.
Zn and Cu: There is a negative correlation of -0.51 between Zn and Cu, meaning that Zn increases with decreasing Cu content in soil and vice versa.
Cu and Fe: There is a negative correlation of -0.35 between Fe and Cu meaning that Cu increases with decreasing Cu content in soil and vice versa.

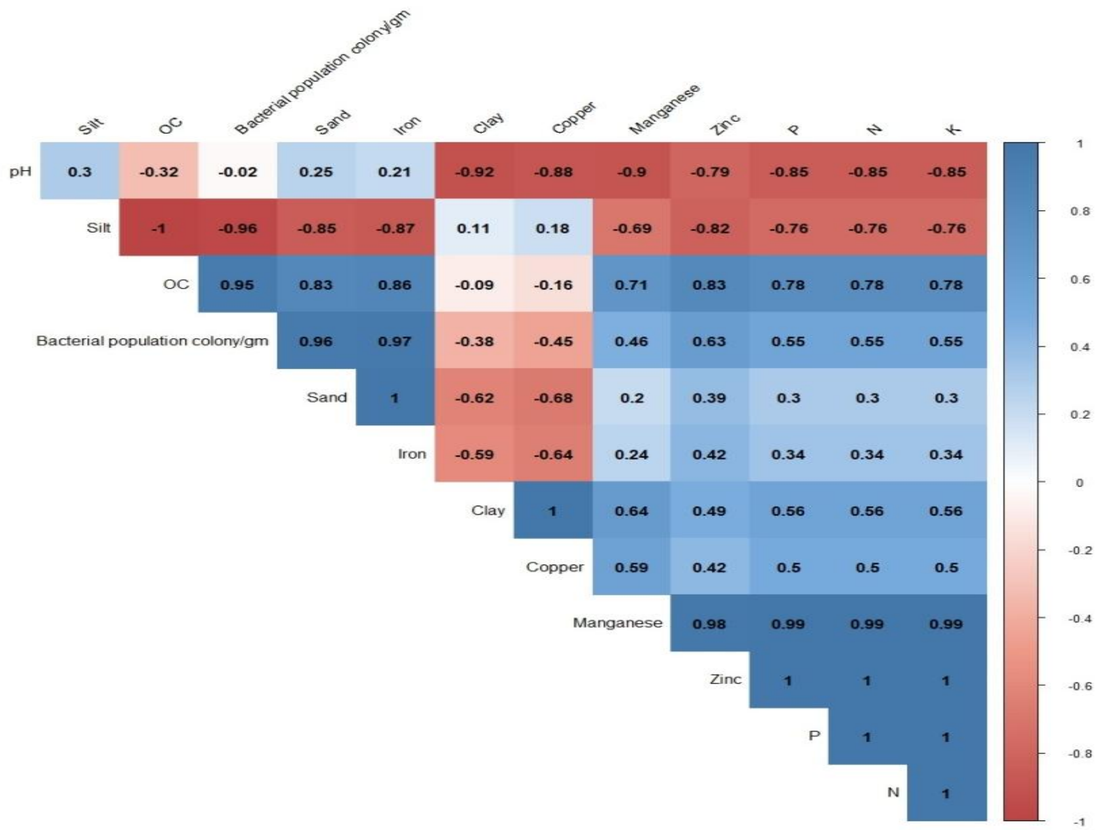

Fig.7: Graphical representation of Pearson's correlation among Soil N-P-K, Organic carbon, and pH under the Sal forest of Thano region, Dehradun.

Explanation of Pearson's correlation among pH, Organic Carbon and N-P-K properties, micronutrients, and Soil texture properties under the Sal Forest region of Thano, Dehradun (Fig. 7).

pH: Organic carbon has a negative correlation with pH (-0.32). This means that as the pH of the soil increases, the organic carbon content decreases, and vice versa. N, P, and K all have negative correlations with pH. It has a correlation of 0.3 with silt and 0.25 with sand (weaker positive), witha strong negative correlation with clay. The correlation coefficient among pH and bacterial population is -0.02 which is a very weak correlation among them.The correlation coefficient among pH and Zn was -0.79, among pH and Cuwas -0.88, and among pH and Mn was -0.9 very strong negative correlation meaning that Zn, Cu, and Mn decrease with an increase in pH of soil and vice versa. The correlation coefficient between pH and Fe has a weakly positive correlation of 0.21.

Organic carbon (OC): N, P, and K all have similar positive correlations with organic carbon 0.78. The correlation coefficient among OC and clay was found -0.09 weaker negative. The correlation coefficient among Organic carbon and silt was very strongly negative -1 which means that OC content decreases with increasing silt content.The correlation coefficient among Organic carbon and sand was 0.83, a strong positive correlation. OC and the bacterial correlation coefficient was very strong positive correlation 0.95.The correlation coefficient among Organic carbon and three out of four micronutrients viz. Fe, Zn, and Mn were 0.86, 0.83, and 0.71 respectively, meaning that a very strong positive correlation. There was a weak correlation coefficient among OC and Cu -0.16.

Nitrogen N: Nitrogen has a positive correlation with organic carbon (0.775), with P and K (1). It has a weak negative correlation with pH (-0.84).The correlation coefficient between N and clay was 0.56, a moderately positive relation. Among N and sand, it was 0.3 a weak positive correlation, and among N and silt, the correlation coefficient was negative -0.76 which means n content decreases with an increase in silt content.The correlation coefficient among N and bacterial population was 0.55, moderately positive.The correlation coefficient among N and all four micro-nutrients viz. Cu, Fe, Zn, and Mn were 0.5, 0.34, 1, and 0.99 respectively. Correlation among N and Zn and N and Mn was very strongly positive.

Phosphorous P: P has a positive correlation with C (0.78) and it has a strong negative correlation with pH (-0.85).The correlation coefficient among P and bacterial population was 0.55, moderately positive. The correlation coefficient among P and silt, P and sand, and P and clay was found -0.76, 0.3, and 0.56 respectively. The correlation coefficient among P and silt has a negative correlation meaning P decreases with an increase in silt content in soil.The correlation coefficient among P and all four micro-nutrients viz. Cu, Fe, Zn, and Mn were was0.5, 0.34, 1, and 0.99 respectively, similar to N with all four micronutrients

K: K has a positive correlation with OC (0.78)and a strong negative correlation with pH (-0.85).The correlation coefficient between K and the bacterial population was 0.55. The correlation coefficient among K and silt, K and sand, and K and clay were found -0.76, 0.3, and 0.56 respectively. The correlation coefficient among K and all four micro-nutrients viz. Cu, Fe, Zn, and Mn were again found similar to that of N and P with all four micronutrients.

Sand and Silt: There wasa strong negative correlation of -0.85 between sand and silt which means silt content decreases with increasing sand content in soil and vice versa.

Sand and Clay: There wasa negative correlation of -0.62 between sand and clay which means clay content decreases with increasing sand content in soil and vice versa.

Clay and Silt: The correlation coefficient between clay and silt was 0.11. This is a weak positive correlation.

Sand with micronutrients: There wasa very strong positive correlation coefficient among sand and Fe was found 1,meaning that Fe increases with an increase in the sand content of the soil. There weak positive correlation among sand–Mn and sand-Znwas found 0.2 and 0.39 respectively. Sand and Cu showa moderately negative correlation among them,the correlation coefficient between sand and Cu was -0.68, which means that Cu decreases with an increase in the sand content of soil and vice versa.

Silt with micronutrients: There wasa strong negative correlation of silt among three out of four micronutrients viz. Mn, Zn, and Fe, and the correlation coefficient werefound -0.69, -0.82, and -0.87 respectively, which means that Mn, Zn, and Fe content decreases with an increase in silt in soil and vice versa. There was a weaker positive correlation between silt and Cu, the correlation coefficient was found 0.18.

Clay with micronutrients: Clay shows a positive correlation with all four micro-nutrients viz. Fe, Cu, Zn, and Mn, and the correlation coefficient among them was 0.59, 1.0, 0.49 and 0.64

respectively. Clay shows the strongest positive correlation with copper and a moderately positive correlation with the remaining three.

Discussion

The study focuses on soil micro-nutrient concentrations in the Oak forest region of Chakrata, Dehradun, and the Sal forest region of Thano, Dehradun. In the Oak forest region, iron exhibits the highest mean percentage value at all depths, peaking at 10.8 in the 0–30 cm layer and decreasing progressively with depth. Zinc follows a similar trend, reaching 1.2 in the 0–30 cm layer and decreasing to 0.1. Manganese shows a marked decline from 6.4 in the 0–30 cm layer to 5.1 in the deepest layer. Zinc has the lowest mean percentage values. In the Sal forest region, iron dominates as the predominant micro-nutrient, with consistently elevated mean values at all depths, peaking at 37.72 in the 0-30 cm range. Manganese follows with the second-highest concentrations, reaching a peak of 9.7 at the 30-60 cm depth. Zinc shows a consistent decline with increasing soil depth; from 0.11 at 0-30 cm to 0.01 at 60-90 cm. Copper levels vary across depths, with the highest mean value of 0.88 at 30-60 cm. This analysis highlights the dominance of iron, the sequential distribution of zinc, and distinct patterns in manganese and copper concentrations across soil depths, providing valuable insights into micro-nutrient dynamics in the studied soil profiles.Soil organic matter, nutrients (N, P, K), and heavy metals decrease with depth in both forests. Oak forests have higher organic carbon, water-holding capacity, and nutrient availability compared to Sal forests. Available N and P are higher in the upper soil layers due to organic matter decomposition. Oak's deep root system gives it an advantage in extracting nutrients from deeper layers. Potassium content is high in both forests, exceeding most other minerals except N. Microbial activity is higher in the upper soil layers and greater in the Sal forest than in Oak. pH remains constant with depth in our study, despite previous reports of increasing pH with depth. Our N values fall within the reported range for Himalayan Oak forests. P availability is higher in lower horizons due to near-neutral pH in those layers. Sand, silt, and clay content differ slightly between the two forests. Both forests show zinc deficiency. Soil properties and microbial activity differ between Oak and Sal forests, with Oak generally showing higher organic matter, water-holding capacity, and nutrient availability. Understanding these differences is crucial for managing and conserving these valuable ecosystems.

Conclusion

It was concluded that considering that SOC (Soil Organic Carbon) stored in the surface layer is more vulnerable and less stable than that in the deeper layers, the disturbance processes in the ecosystems usually increase greenhouse gas emissions (GHGs) and affect the atmospheric gas concentration (Kumar et al., 2019,Kumar et al., 2021).The topsoil of these forests should be protected to minimize the risk of large carbon release. A significant increase in nutrient concentration with increasing soil depth may explain that the zone of accumulation of nutrients is not well established in the forest soils of this mountainous region due to the strong leaching effect.By recognizing the inherent vulnerabilities of SOC and nutrients in mountainous forest soils, we can implement targeted interventions to promote ecological resilience, and carbon sequestration in soil is not advantageous, improving productivity and sustainability. Protecting the fragile surface layer and mitigating leaching losses are crucial steps toward maintaining vital ecosystem functions and fostering sustainable land-use practices in these dynamic landscapes.

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