

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

Abstract :

*Forest trees have an appreciable demand for nutrients as they have longer rotation than agricultural 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 of Chakrata 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 were rich in nutrients, where, the maximum mean standard deviation values of pH (6.85), soil organic carbon (5.9 %), available nitrogen (0.04 %) reported in Oak forest of Chakrata and available phosphorus were almost 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, forest needs good management practices, especially in community forests areas to avoid illegal felling, impact of fire, over-exploitation of fuel and fodder. The good management practices would be helpful in mitigating the impact of climate change and sustainable outcome of the resources for the community benefits.*

Keywords: Soil physico-chemical 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, 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). Physico-chemical characteristics of forest soils vary in space and time because of variation 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, Pant D et al., 2019). Oak (*QuercusLeucotrichophora*) 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 (*ShoreaRobusta* Gaertn. f.) belongs to 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 is directly proportional to the living components of the soil. Bacteria cause a number of 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 (proteins ammonia), nitrification (ammonia-nitrites-nitrates), denitrification (release of free elemental nitrogen), biological stabilisation of atmospheric nitrogen (symbiotic and non-symbiotic), oxidation and reduction of sulfur and iron. All these processes play a significant role in plant nutrition (Sahu et al., 2013), and one microorganism that produces thermo-stable lipase was isolated from soil collected from the Himalayan region. 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, TN, and TP stock influenced by vegetation types and soil depths in mountainous areas in the central Himalaya 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 Thano and Chakrata area of Dehradun district in the state of Uttarakhand, India. The *Shorea robusta* (Sal) is the dominant species of Thano region and is deciduous in nature. Similarly temperate forest sites of Chakrata comprise of *Quercus leucotrichophora* (Oak).

Study Areas

The main aim of this study is to hypothesize the impact of specific forest species on depth wise distribution of soil properties and to interpret the correlation among them. Study was carried out in Thano region of Dehradun district of Uttarakhand state, India lies between latitude 30.2373248 and longitude 78.2098735. Nearest state capital from Thano is Dehradun (39.8 KM away). The soils of this region vary according to aspect, altitude and climate, and are generally young and thin. In Garhwal Himalayan, vegetation and soils vary with the aspect, altitude and climate. The hilly region has dense forested slopes and usually contained of clayey to sandy loams sedimentary soil with podzolization (Sheikh *et al.*, 2020). The study area falls in temperate climate zone with cold especially in winter and pleasant in summer. Here temperature ranges -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 are 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 Yamuna rivers, at an elevation of 7000–7250 feet, 98 km from state capital, Dehradun. It is situated in Dehradun district in Garhwal Himalayas between $30^{\circ} 31'$ to $31^{\circ} 3'$ N latitudes and $77^{\circ} 42'$ to $78^{\circ} 5'$ E longitudes, covering an area of approximately 1,999.50 km². The soils of Chakrata are formed as a result of long continued leaching under 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).

Collection of soil samples:-

Selected one forest stand for each species. Demarcated stands into three plots, each 0.5m x 0.5m. Removed litter, dug a pit (30cm wide, 30cm deep, 50cm length) at each plot. Collected soil samples at 0-30cm, 30-60cm, and 60-90cm depths using a trowel. 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 air-dried, ground, and sieved through a 100-mesh sieve.

Physical-chemical analysis of soil

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

Bacteriological analysis

For the isolation of bacteria, serial dilution method given by Johnson and Curl 1972 was followed using Nutrient Agar medium. Nutrient agar media was poured in each sterilized petri-dishes. 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 glass spreader. Then the petri-dishes were incubated at 37°C for 48 hours in inverted position inside Incubator. After incubation colonies were counted on the colony counter.

Statistical analysis

Data were summarized as mean \pm SD (standard deviation). Pearson correlation analysis was done to assess associations between the variables. A two tailed values less than ($p < 0.05$) was 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 sulphur content decreased from higher elevation to lower elevation while pH, potassium and boron showed 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 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, boasting a substantial 5.9%. Delving deeper, we encounter a notable decline, with the middle layer (30-60 cm) harboring a diminished 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 upper layers as compared to 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 Sal forest, mean values of Available N% at all three depths viz. 0-30, 30-60 and 60-90 are found 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 nitrogen value of 0.34% for Garhwal region, and 0.17 to 0.30% in Kumaun Himalaya for *Q. leucotrichophora* forests. Kumar *et al.*, 2004 observed nitrogen values ranging from 0.10 to 0.20% in Tehri Garhwal 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 (*Quercus leucotrichophora* and *Pinus roxburghii*) in Uttarakhand were analyzed by Tewari *et 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.

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

Available K% in Oak forest area of Chakrata were examined at different depths, viz. 0-30, 30-60 and 60-90 and found their mean values 0.009, 0.0082 and 0.0080 % respectively (Fig.1). In 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 amount than any other mineral element except nitrogen and in some cases, calcium Sharma *et al* 2013. Saha, *et al* 2018 reported Potassium content between 102.29 and 206.22 kg ha⁻¹ under Himalayan temperate forest of Garhwal region.

Soil microbial activity differ between Oak and Sal forests, Depth-wise (0-30, 30-60 and 60-90) distribution of microbial activity in Oak forest are 101.3, 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 Sal forest are 106.7, 44.83 and 40.33 colony/gram respectively (Fig. 4(b)).

The sand, silt and clay content in 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 Sal forest of Thano region of Dehradun district, sand content ranged from 68.06 to 69.28%, silt content 12.67 to 13.67% and clay content ranges from 18 to 18.61 % (Fig.4c).Semwal (2006) in a study in *Quercusleucotrichophora* 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.InChakrata oak forest, Usmanet al 2000 reportedthe sand, silt and clay particles values 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 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 increased gradually 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 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 10-20cmdepth. However, clay particles were highest in 20-30 cm and lowest in 10-20 cm depth. In lower altitude the sand particles reduced with increasing soil depth. However, silt particles have shown 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.

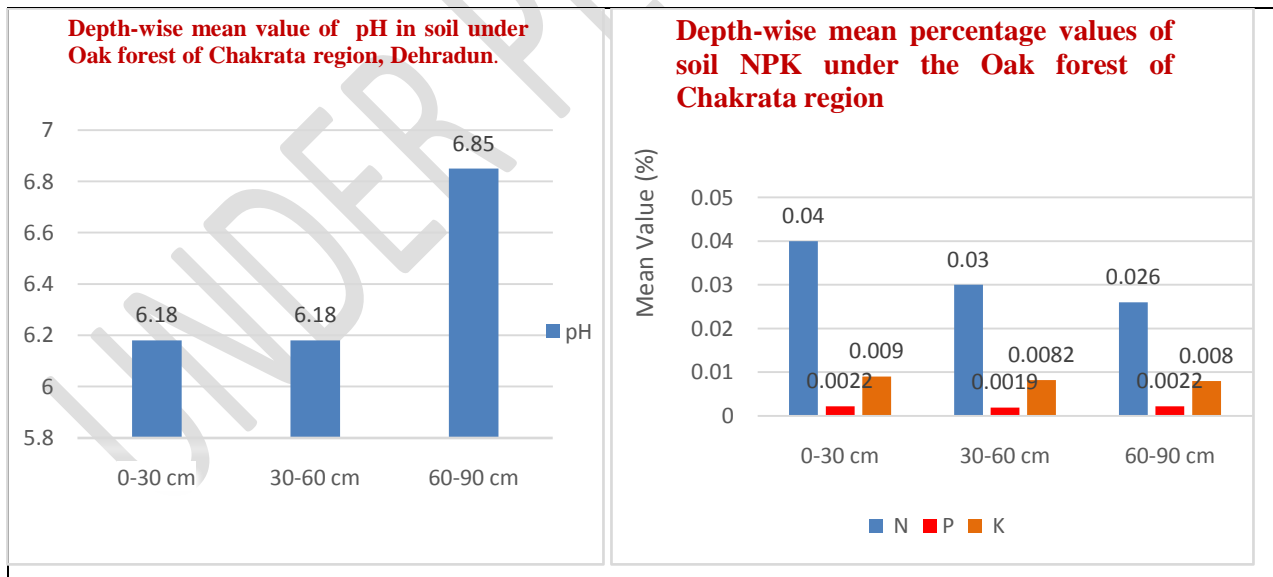


Fig:-1 Graphical representation of depth-wise mean percentage values of Soil N-P-K and pH properties under Oak forest of Chakrata region, Dehradun

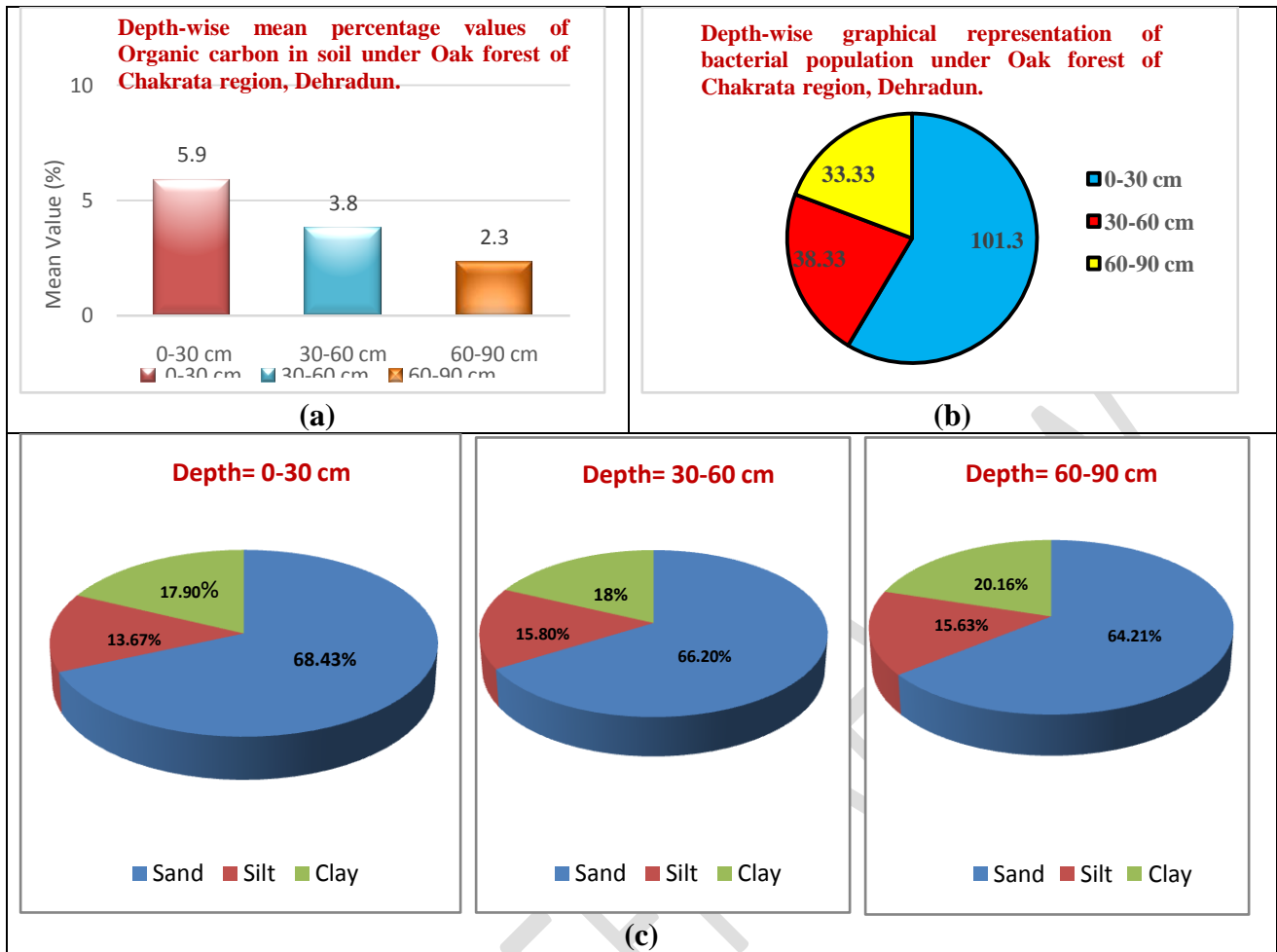


Fig.2: Graphical representations of depth-wise mean percentage values of Soil Organic carbon (a), bacterial populations (b) and Soil texture properties (c) under Oak forest of Chakrata.

UNDER REVIEW

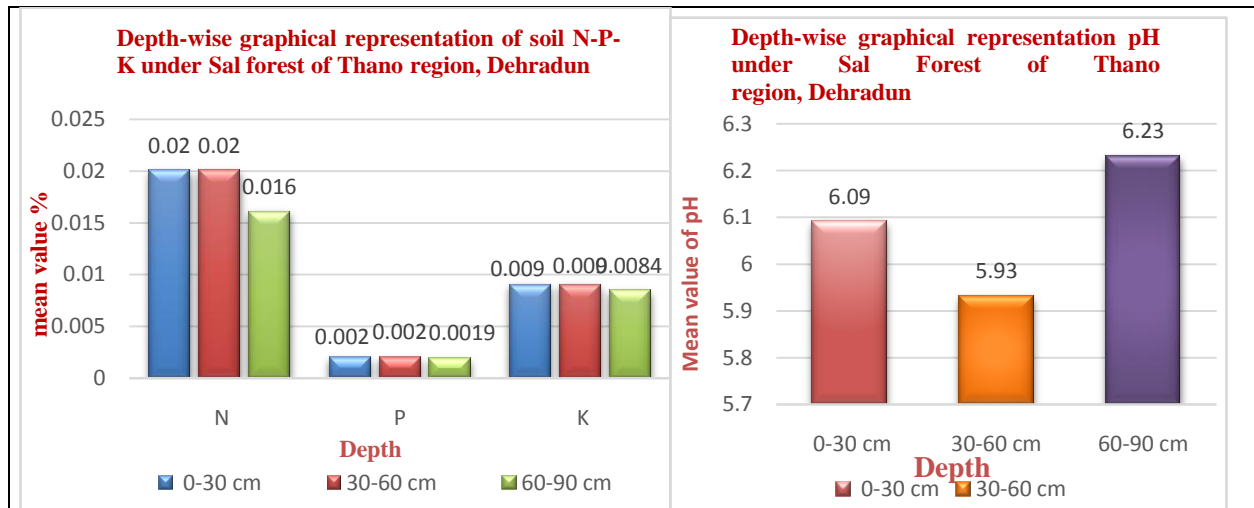
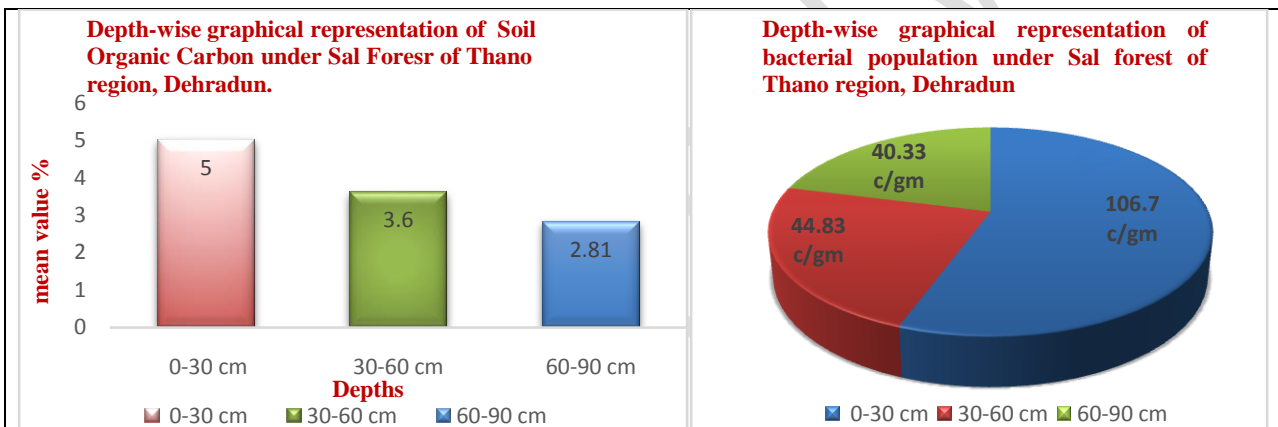
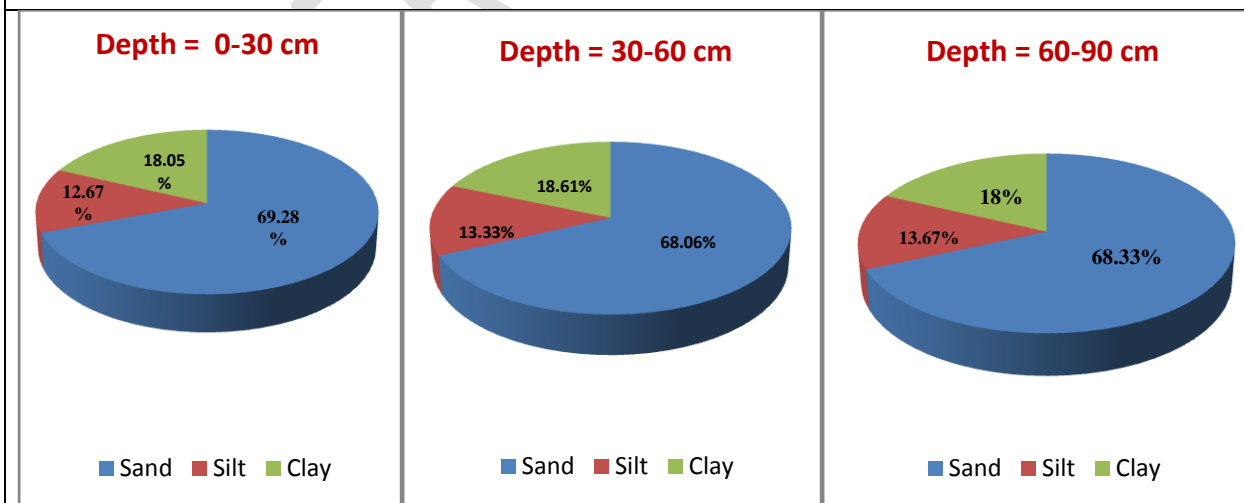


Fig.3: Graphical representation of mean percentage values of Soil pH and NPK properties under Sal Forest of Thano region, Dehradun.



(a)

(b)



(c)

Fig.4: 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.

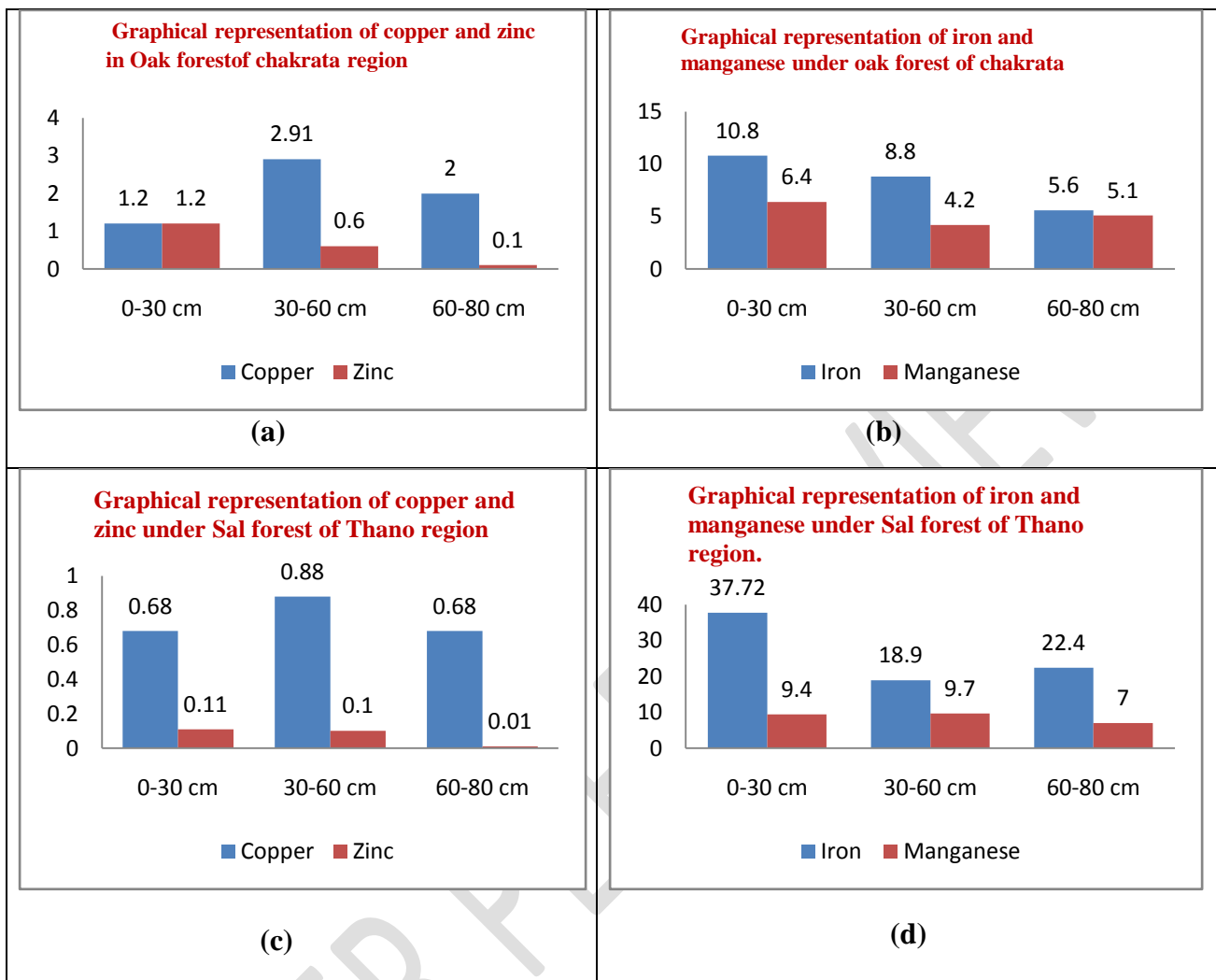


Fig.5: Graphical representation of mean values showing depth wise distribution of soil micro-nutrients [(a) - copper and zinc & (b)- iron and manganese under Oak forest of Chakrata region and (c) – copper and zinc& (d) – iron and manganese under Sal Forest of Thano region, Dehradun

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

Data in 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 discernible 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 ranged 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 confidential interval ranged from 1.09 to 1.83 mgkg⁻¹ vertical distribution of Zn exhibited little variation with depth. Considering 0.6 mg kg⁻¹ as critical level (Lindsay and Norvell 1978) these soils were sufficient in surface horizons. 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 reduction of organic carbon in the sub surface horizons. Surface horizons had higher concentration of DTPA-extractable Fe due to relatively higher organic carbon in surface horizons. According to 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.

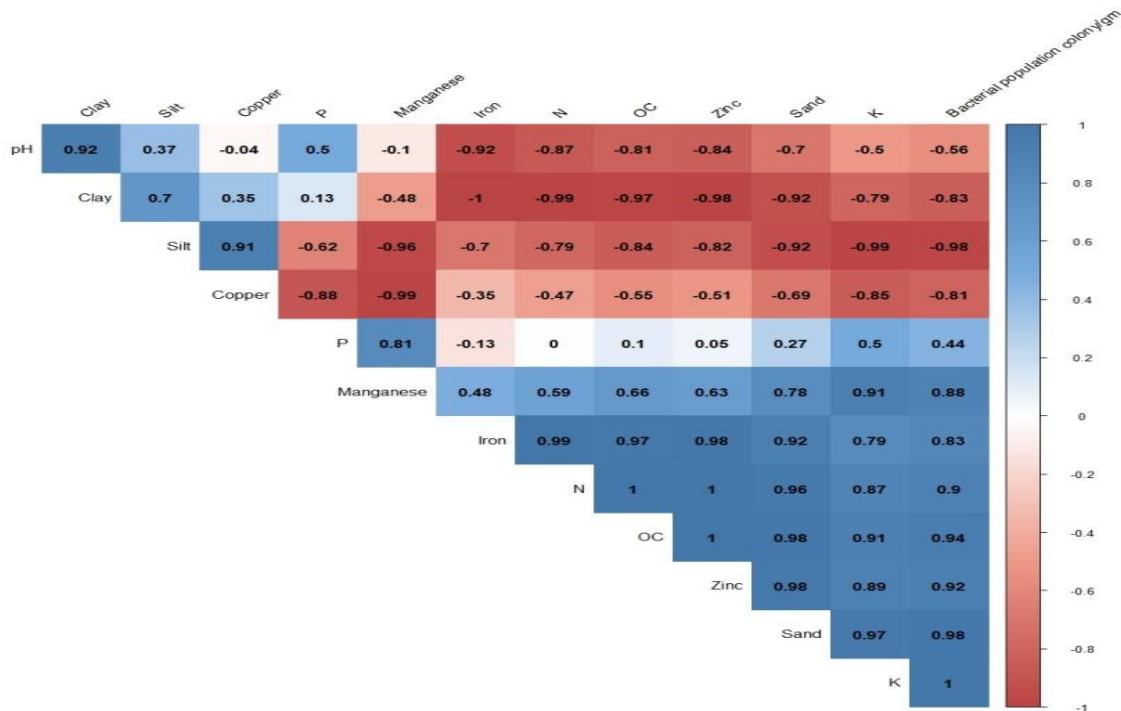


Fig.6: Graphical representation of Pearson’s correlation among soil pH, Bacterial populations, N-P-K –OC, micronutrients and texture properties under Oak Forest of Chakrata region, Dehradun.

Explanation of Pearson’s correlation among pH, Organic Carbon, N-P-K properties, soil texture and soil micronutrients under 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: 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: 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: Correlation coefficient between pH and Bacterial populations is 0.-0.56. This is a moderate negative correlation

pH and Silt:Correlation coefficient between pH and Silt is 0.37 which is weak positive between them.

pH and Clay:Correlation coefficient between pH and Clay shows strong positive correlation which means if pH increases; clay-content among soil also increases.

pH and Zn: Correlation coefficient between pH and Zn was -0.84,very strong negative which means pH decreases with increase in Zn content of soil and vice versa.

pH and Cu: Correlation coefficient between pH and Cu was very weak negative -0.04.

pH and Fe: Correlation coefficient between pH and Fe was-0.92,very strong negative which means pH decreases with increase in Fe content of soil and vice versa.

pH and Mn: Correlation coefficient between pH and Cu was very weak negative -0.1.

pH and Sand: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 very strong positive correlation of 0.94 among OC and Bacterial populations, meaning that Bacterial populations increases with increasing OC content in soil.

OC and Clay:There is 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 very strong positive correlation of 0.98 among OC and Sand, meaning that Sand increases with increasing OC content in soil.

OC with micronutrients: The correlation coefficient between OC and Cu was -0.55, moderately negative correlation. OC and Zn was 1 very strong positive correlation. OC and Fe was 0.97 very strong positive correlation. OC and Mn was 0.66 positive correlation.

N and P: 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:Correlation coefficient between N and Silt was -0.79 strong negative relation between two, meaning that N content decreases with increasing in Silt content

N and Clay:Correlation coefficient between N and Clay was -0.99. A very strong negative relation between two, meaning that N content decreases with increasing in Clay content

N and Sand: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:Correlation coefficient between N and Cu was -0.47 moderately negative correlation. Correlation coefficient between N and Zn was 1, very strong positive correlation. Correlation coefficient between N and Fe was 0.99, very strong positive correlation. Correlation coefficient between N and Mn was 0.63.

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

P and Sand:Correlation coefficient between P and Sand was weakly positive 0.27.

P and Clay: Correlation coefficient between P and Clay was weakly positive 0.13.

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

K and Silt: There is 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 very strong positive correlation of 0.97 among K and Sand, meaning that Sand increases with increasing K content in soil.

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

K and micronutrients: There is 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 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 strong negative correlation of -0.92 among Sand and Silt which means Silt content decreases with increasing Sand content in soil and vice versa.

Sand and Clay: There is strong negative correlation of -0.92 among 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 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 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 strong negative correlation of silt among three out of four micronutrients viz. Mn, Zn, and Fe and the correlation coefficient was found -0.96, -0.82 and -0.7 respectively, which means that Mn, Zn and Fe Content decreases with increase in Silt in soil and vice versa. But correlation coefficient among Silt and Cu was 0.91, a very strong positive correlation.

Clay with micronutrients: There is strong negative correlation of Clay among two out of four micronutrients viz. Zn, and Fe and the correlation coefficient was found -0.98, and -1 respectively and moderately correlation among Clay and Mn was found -0.48, which means that Mn, Zn and Fe Content decreases with increase in Silt in soil and vice versa. The correlation coefficient among Clay and Cu was weakly positive 0.35.

Zn and Fe: There is very strong positive correlation of 0.98 among Zn and Fe, meaning that Fe increases with increasing Zn content in soil.

Zn and Cu: There is negative correlation of -0.51 among Zn and Cu, meaning that Zn increases with decreasing Cu content in soil and vice versa.

Cu and Fe: There is negative correlation of -0.35 among Fe and Cu, meaning that Cu increases with decreasing Cu content in soil and vice versa.

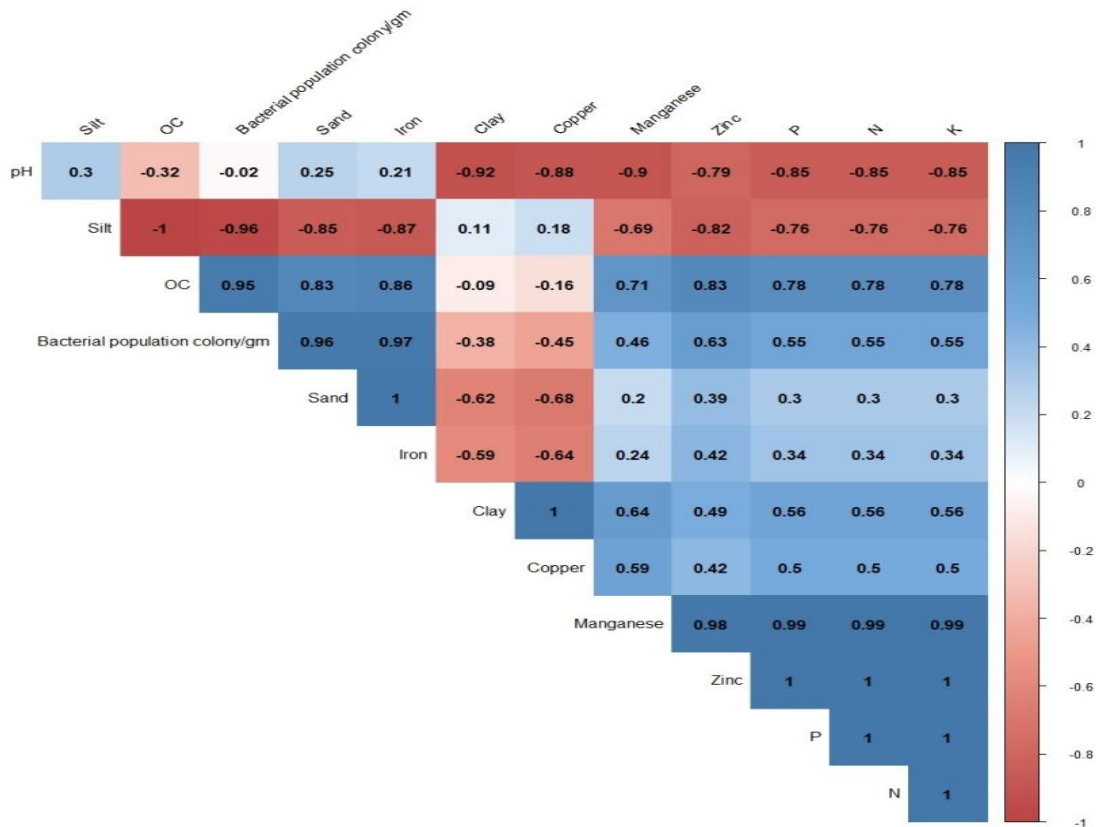


Fig.7: Graphical representation of Pearson’s correlation among Soil N-P-K, Organic carbon and pH under Sal forest of Thano region, Dehradun.

Explanation of Pearson’s correlation among pH, Organic Carbon and N-P-K properties, micronutrients and Soil texture properties under 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 correlation of 0.3 with Silt and 0.25 with Sand (weaker positive), while strong negative correlation with Clay. The correlation coefficient among pH and Bacterial population is -0.02 which is very weaker correlation among them. The correlation coefficient among pH and Zn was -0.79, among pH and Cu was -0.88, among pH and Mn was -0.9 very strong negative correlation meaning that Zn, Cu and Mn decreases with increase in pH of soil and vice versa. The correlation coefficient among pH and Fe has a weakly positive correlation 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 meaning 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 Bacterial correlation coefficient was very strong positive correlation 0.95. The correlation coefficient among Organic carbon and three out of four micro nutrients viz. Fe, Zn and Mn was 0.86, 0.83 and 0.71 respectively, meaning that a very strong positive correlation. There was 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 among N and Clay was 0.56, 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 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 was 0.5, 0.34, 1 and 0.99 respectively. Correlation among N and Zn and N and Mn was very strongly positive.

Phosphorus 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 negative correlation meaning P decreases with increase in Silt content in soil. The correlation coefficient among P and all four micro-nutrients viz. Cu, Fe, Zn and Mn was 0.5, 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 among K and Bacterial population was 0.55. The correlation coefficient among K and Silt, K and Sand and K and Clay was 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 was again found similar to that of N and P with all four micronutrients.

Sand and Silt: There was strong negative correlation of -0.85 among Sand and Silt which means Silt content decreases with increasing Sand content in soil and vice versa.

Sand and Clay: There was negative correlation of -0.62 among 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 was strong positive correlation coefficient among Sand and Fe was found 1, meaning that Fe increases with increase in Sand content of soil. There weak positive correlation among Sand-Mn and Sand-Zn was found 0.2 and 0.39 respectively. Sand and Cu shows moderately negative correlation among them, correlation coefficient among Sand and Cu was -0.68, which means that Cu decreases with increase in Sand content of soil and vice versa.

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

Clay with micronutrients: Clay shows positive correlation with all four micro-nutrients viz. Fe, Cu, Zn and Mn and correlation coefficient among them was 0.59, 1.0, 0.49 and 0.64 respectively. Clay shows Strongest positive correlation with Copper and moderately positive correlation with 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 Thanu, 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 Sal forest than 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.*, 2019,2021). 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 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 net advantageous, improving the 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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