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PROPERTIES OF SOIL IN RELATION TO ALTITUDE

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INTRODUCTION

Altitude is the major factor affecting the properties of the soil ecosystem. Soils are complex systems where soil organisms and mineral particles interact to produce species richness and complexity (Havlicek and Mitchell, 2014). As we go up or when altitude increases, temperature falls. The rate of decrease of temperature is 6.5^{0}C for each 1000 m altitude change. The physicochemical properties and the biodiversity of soil ecosystems are highly influenced by altitude (Kumar *et al.* 2019). There is a diverse variation of physicochemical properties among different regions of the world. With the increase in altitude, pH, base saturation, bulk density, exchangeable sodium percent, and fine silt-sized particles decrease significantly, while organic matter, soil aggregate stability, water repellency and coarse sand-sized particles increase significantly (Badia *et al.* 2016). The key nutrients C, N, P and K of soils at higher altitude differ significantly from those that are present on plains. There is a steady increase in soil organic carbon and the microbial biomass N also increases (Jeyakumar *et al.*, 2020).

Climate and parent material profoundly influence soil characteristics (Schinner, 1982; Yang *et al.* 2008). The variation in altitude changes the climate which in turn influences the pedogenic processes and soil properties by affecting types and rates of chemical, physical, and biological processes, and also the type and composition of vegetation species (Hutchins *et al.* 1976). High altitude environment is characterized by high solar radiation, low temperature, rapid temperature changes, and low partial pressure of the air (Streb *et al.*1998). Low altitude environment is characterized by higher temperature and different atmospheric humidity.

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Impact of altitude on soil properties

The properties and the biodiversity of the soil ecosystems are highly influenced by variations in altitude (Kumar *et al.* 2019).

There is a diverse variation of physicochemical properties among different altitudinal regions of the world. The physical properties of the soil like soil texture, soil structure, soil density, soil porosity, etc. vary with altitude. It has been reported that the moisture content and water holding capacity of soil increase with increasing altitudes while the bulk density (BD) reduced with increasing altitude. The higher proportion of soil texture is contributed of sand > clay > silt with increase in altitude.

Altitude has a great impact on the properties of soil i.e., physical, chemical and biological.

The physical properties of the soil like soil texture, soil structure, soil weight, soil density, soil porosity, etc. and the chemical properties like pH, EC, organic carbon content, nutrient content quite vary with altitude (Table 1).

Table 1: Properties of soil with increase in altitude

Physicochemical property	**Trend with altitude**
Soil texture	Sandy loam
Soil porosity	High
Water holding capacity	Low
pH	Decreases
EC	Remains constant
Soil organic and biomass Carbon	Decreases
Soil nutrients	Decreases
Microbial and enzyme activity	Decreases
Mineral nutrients(Ca, Co, Ni, B, Mg, Na, K, Fe and Cu)	Decreases

Source: Jeyakumar *et al.*, 2020

1. Impact on physical characteristics

Climate and parent material profoundly influence soil characteristics (Schinner, 1982; Yang *et al.*). The soil textural class shows clear difference with the differences in altitude. As we go up there is a significant increase in the proportion of sand. The soils of high altitude fall under the textural class sandy loam (Yuksek *et al.*, 2013). There is a significant increase in the proportion of sand as we go up the altitude. The high altitude soils are immature and are originated from weathered rocks and therefore have relative proportions of sand, gravel and stones. The presence of coarse grain soil particles indicates the slow process of soil formation. As the altitude decreases, there is an increase in the silt proportion and decrease in sand (Ley *et al.*, 2000). Higher silt but lower sand proportion at lower altitude indicates the presence of quartz, feldspars, micas, etc. in soil (Ley *et al.*, 2000). Therefore, slow process of soil formation along the altitude results in very low content of clay particles which may cause low content of available nutrients in soil (Brady and Weil, 1999). The soil in these ecosystems is coarse textured, deserted and poor in nutrients.

The bulk density of soil decreases with increase in altitude. This is because of increase in organic matter content with increasing altitude. The bulk density of soil depends on soil structure and texture, organic matter, freezing and thawing process (Unger, 1991; Chen *et al.*, 1998).

Studies conducted by Kumar *et al.*, 2010, reported that among the physical properties, the lowest amount of moisture was in lowest attitude which increased with increasing altitudes but bulk density has shown a reverse trend with moisture which reduced with increasing altitude. The water holding capacity also increased with increasing altitudes (Fig. 1). The soil texture was contributed by the highest proportion of sand followed by clay and silt in each altitude (Fig. 2).

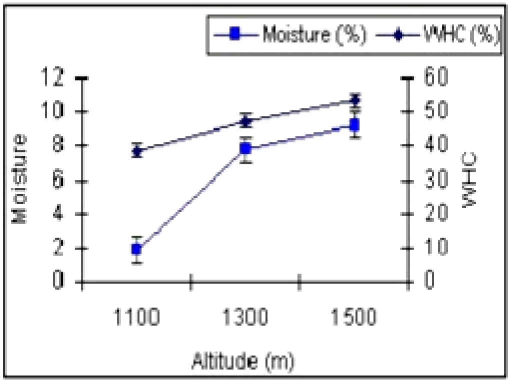

Figure 1: Moisture and water holding capacity at different altitude.

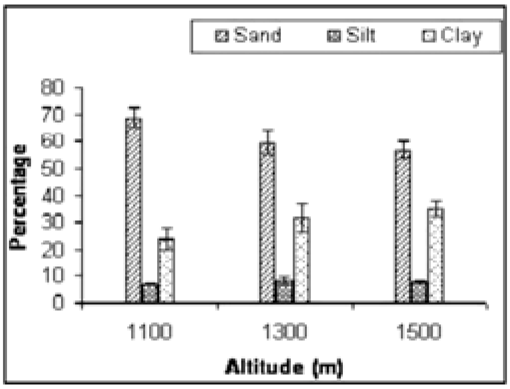

Figure 2: Soil texture at different altitude.

2. Impact on chemical characteristics

Many soil fertility characteristics including organic matter content, pH, CEC, phosphate sorption and phosphorus availability show significant altitudinal variations (Jobbagy and Jackson, 2000).The soil pH decreases and is slightly acidic with increase in altitude. The reduction in pH can be attributed due to accumulation and subsequent slow decomposition of organic matter, which releases acid. Another reason is because of increased precipitation levels at the higher altitudes. High amount of rainfall leaches out the base forming cations like Ca^{2+}, Mg^{2+}, K^+ and increases the ions like Al^{3+} and H^+ (Northcott *et al.*, 2009).The EC of the soils of low and high altitude does not have any significant variation proving that there is cumulative accumulation of salts along the altitude (Charan *et al.*, 2013).Soil organic matter <0.5% is considered poor and >2.0% is considered desirable for agriculture. The soil organic matter increases with the increase in altitude, this is due to decrease in temperature with increase in altitude. Low temperature decreases the microbial and enzymatic activity in high altitude soil; rendering the soil organic matter unaffected by microbial decomposition. Therefore, low temperature with increase in altitude is the major factor determining the high soil organic matter with increase in altitude (Kumar *et al.*, 2019).

The soil organic carbon increases as altitude increases (Sevgi, 2003). Increase in the SOC is due to the change in the temperature with increase in altitude. The soils at high altitude have low nutrient absorption capacity. These nutrients are cycled back to the soil

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which brings about changes in the soil chemical properties (Singh *et al.*, 1986). But there is an increase in soil organic carbon with altitude (Saeed *et al*., 2014). This may owe to the soil texture, constant input of carbon with less loss, decrease in the microbial and enzymatic activity due to the decreasing temperature (Bolstad *et al.*, 2001).The presence of phosphorus is dependent on soil pH, so with the increase in altitude the availability of P increases. Total nitrogen in agriculture soil is generally reported to vary from 0.10% to 0.15%. Increased soil temperature is reported as a primary environmental factor that decrease the N mineralization processes thus influencing the bioavailability of soil nitrogen. Nitrogen associated with SOM is not readily mineralized, thus high total N content of the soil with increase in altitude could be the result of high SOM. Though, the soil OC, N and S content increase with increase in altitude, their bioavailability to the living system is the major factor. Most of the N, P and S remain bound to the SOM, which does not degrade sufficiently under low temperature. The nitrogen mineralization rate, SOM degradation rate and soil P content rate decrease with temperature. Therefore, low nutrient status of soils with increase in altitude is the result of low temperature which induces decrease in mineralization and decomposition. The Calcium, cobalt, nickel, boron, magnesium, molybdenum, sodium, potassium, iron and copper also decrease with increase in altitude. Similar trend in micronutrient dynamics with respect to altitudinal variation was found by Charan *et al.*, 2013.

Low temperature together with high precipitation may decrease the organic matter deposition and N turnover rates. Soil nitrogen (N) available as ammonical, nitrite and nitrate form is taken up and utilized directly by plants. The content of nitrogen significantly promotes productivity, species diversity, community succession and sustainability.Studies conducted by Mishra *et al.*, 2021, on the effect of altitude on soil properties of Mon and Zunheboto district, Nagaland revealed that there was no significant influence of altitude on SOC stocks in soils of both the districts. Available N was found to be significantly affected by the different altitudes in the Mon district and the highest N content (427.99 mg kg^{-1}) was found at lower elevations (1000 m) and were statistically similar to each other (278.48 and 324.59 mg kg^{-1}, respectively). Available P was affected by different altitudes in both the districts. In the Mon district, the lowest (7.07 mg kg^{-1}) value of available P was found at a higher elevation (>1000 m), which was not statistically different compared to intermediate (7.11 mg kg^{-1}) altitudes (500–1000). The highest value of available P was found at lower elevation altitudes (<500m) in both the districts. Significant differences in available K values were found in Zunheboto district only, and maximum and minimum values were recorded at lower (53.66 mg/kg) and intermediate (27.99 mg kg^{-1}) intermediate elevations, respectively.

Table 2: Effect of altitude on different soil parameters in the two districs of Nagaland.

Altitude range(m)	Soil carbon stock (mgC/ha)		Available N (mg/kg)		Available P (mg/kg)		Available K(mg/kg)	
	Mon	Zunheboto	Mon	Zunheboto	Mon	Zunheboto	Mon	Zunheboto
<500[2]	27.31	24.54	427.99	312.72	9.30	8.78	32.49	53.66
500-1000	29.23	27.21	278.48	317.97	7.11	7.39	30.48	27.99
>1000	33.14	29.62	324.59	347.30	7.07	8.58	40.40	43.64

Source: Mishra *et al.*, 2021.

Table3: Descriptive statistics of altitude and soil variables from the two districts.

Variable[1]	Mon District (n = 103)				Zunheboto District (n = 102)			
	Mean	Min	Max	Std. Dev.	Mean	Min	Max	Std. Dev.
Altitude (m)	627a	100	1332	405	1240b	133	1845	409
Clay (%)	22.9	0.4	40.9	8.5	25.5	1.5	57.8	14.6
Sand (%)	50.3	24.0	85.2	12.6	46.0	16.0	94.6	19.7
Silt (%)	26.8	2.6	67.5	9.0	28.5	3.4	73.6	13.4
BD (Mg m^{-3})	0.90b	0.60	1.19	0.14	0.85a	0.62	1.10	0.10
Porosity (%)	65.9a	55.1	77.4	5.4	67.8b	58.5	76.6	4.0
pH	5.22b	3.61	6.69	0.90	4.99a	3.70	6.59	0.74
EC (d sm^{-1})	0.063	0.020	0.280	0.042	0.067	0.010	0.260	0.056
SOC (%)	2.19	0.62	4.57	0.73	2.19	0.70	3.40	0.57
Stock (Mg C ha^{-1})	29.33	9.70	70.61	10.21	27.94	6.82	44.09	7.51
CEC (Cmol+ kg^{-1})	9.71a	4.07	15.52	2.55	10.94b	5.82	20.00	2.71
Ex. Ca (Cmol+ kg^{-1})	1.92	0.59	3.96	0.55	2.03	1.25	3.92	0.51
Ex. Mg (Cmol+ kg^{-1})	1.65a	0.52	4.10	0.63	1.88b	0.75	4.36	0.66
Ca:Mg	1.23	0.37	2.09	0.31	1.16	0.38	2.96	0.35
Ex. Na (Cmol+ kg^{-1})	0.70	0.17	2.34	0.43	0.84	0.17	3.30	0.64
Ex. K (Cmol+ kg^{-1})	1.52a	0.20	4.76	1.02	1.77b	0.43	4.30	0.72
BS (%)	62.00	18.63	92.63	17.68	61.86	29.99	94.85	13.77
Ex. Al (Cmol+ kg^{-1})	3.92	0.30	11.40	2.47	4.41	0.30	14.00	2.42
Av. N (mg kg^{-1})	356.4	67.9	853.3	174.8	336.5	101.2	690.9	134.2
Av. P (mg kg^{-1})	8.08	3.66	16.25	2.48	8.19	5.15	12.04	1.60
Av. K (mg kg^{-1})	33.79	7.73	147.59	25.25	38.72	9.78	157.87	29.13

Source: Mishra *et al.*, 2021

3. Impact on biological characteristics

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Soil comprises the largest pool of terrestrial carbon (C) and, through the soil organic matter (SOM) cycling, it represents either an important sink of C or a possible source of CO_2 (Bispo *et al.*, 2017). SOM includes a wide range of compounds at different stages of decomposition derived from litter, root turnover, and microorganisms and its dynamics are controlled by the quality of the substrate, the activity of the organisms, and the environmental conditions (Dungait *et al.*, 2012). Moreover, soil bacterial communities from high altitude are regarded as among the most complex and diverse assemblages of microorganisms. The C/N decrease consistently with increasing altitude. A possible explaination to the differences in soil chemistry maybe the composition of the litter (Yuksek *et al.*, 2013).

Soil organic matter (SOM) is the most important factor determining the microbial community structure in soil. Low temperature is reported to decrease the microbial and enzymatic activity in high altitude soil, thus rendering the SOM unaffected by microbial decomposition. Majority of the microorganisms in high altitude are Psychrophiles and Psychrotrophs which are equipped with well adaptation to thrive in high altitude associated stresses. Psychrophilic bacterial population has been reported to be increased with altitude Psychrophiles can grow at maximum 20^{0}C (Gounot 1986) and represent all three domains of life (bacteria, archaea and eukarya). These Psychrophilic microbes are distributed extensively across all spheres of earth. Psychrophilic microorganisms are extensively sought for the production of cold active enzymes, cold adapted biofertilizers and metabolites which work best at low temperature.

Such bacteria have been reported to be isolated from Arctic permafrost to marine environment (Dyrset *et al.*, 1984, Mykytczuk *et al.*, 2013). In high altitude soils of Himalaya, *Proteobacteria* like *Pseudomonas* accounts for 73% of bacterial diversity (Margesin and Miteva, 2011). Fungi too are found in high altitude. These *Psychrophilic* fungi have evolved themselves to adapt to the climatic condition of high altitude. Photosynthetic microbes also have a rich diversity in high altitude soils. According to Kumar *et al.*, 2019 the quantitative study of total bacteria and diazotrophs showed that bacterial and diazotrophic counts were significantly influenced by altitudinal differences. At Gangotri soil, high altitude and associated stresses decrease the total bacterial and diazotrophic count. Low available carbon and other soil nutrients at high altitude could negatively affect the growth of heterotrophic

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bacteria thus reducing the total bacterial count (TBC). On the other hand, low available nitrogen could provide selective advantages to the diazotrophs thus enhancing the diazotrophic count to the level which could sustain with other available nutrient resources. Further, high soil nitrate under decreased N mineralization conditions indicated that the high nitrate concentration at high altitude soil could be the functional attribute of the diazotrophs which is further supported by the rich diazotrophic count in Gangotri soil. Considering the high altitude and permanent cold stress, psychrophilic nitrogen fixing bacteria from Gangotri soil were isolated. Molecular characterization of selected psychrophilic diazotrophs identified them as *Pseudomonas helmanticensis, Arthrobacter humicola, Brevibacillus invocatus and Pseudomonas mandelii*. These isolates were reported as cold adapted but not with nitrogen fixing attribute. Further, nitrogen fixation is an enzymatic process and negatively affected by temperature other than the optimal temperature for nitrogenase. However, growth in nitrogen deficient medium at 2°C revealed that the nitrogen fixation machinery in these bacteria was least affected by very low temperature. Altitude strongly affects rhizosphere soil properties. The contents of TN, TOC, and water content, C/N, urease decrease with the increase of altitude. There is no significant correlation between fungal biomass and elevation gradient (Tang *et al*. 2020). Margesin *et al.* also suggested that fungal biomass decreased with altitude. Similarly, soil fungal biomass has been reported to vary along altitudinal gradients. Contrary to fungal biomass, C- and N-cycling gene abundances did not vary along elevation gradients, but there were significant differences in different vegetation types. Different vegetation types with different litter input can lead to difference in the composition of soil organic matter. This indicates that vegetation types drive the spatial distribution of functional gene richness along altitudinal gradients.

CONCLUSION:

The productivity of soil depends on its physical, chemical and biological properties. The changes in altitude have a significant impact on certain properties of soil. Altitude profoundly affects the soil's inherent fertility and runoff-erosion behavior (Mani, 1990; Bowman *et al.*, 2002). The level of rainfall and temperature variation affects organic matter decomposition which in turn affects the accumulation of organic matter with altitude. These changes in microenvironment may affect the properties of soil of the area.

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Therefore, knowledge on the properties of soil in relation to altitude can go a long way in managing resources while working in improving the workability of the soil mass.

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