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Changes in Soil Physico-Chemical Properties in different Land Use Systems of Manipur, Northeast India

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Abstract: The current study examined the soil physico-chemical properties of five different land uses (e.g. Mixed pine forest, MPF; Pine plantation, PP; *Lithocarpus* forest, LF; *Quercus* forest, QF; and *Dipterocarpus* forest, DF) in Manipur, India. Replicated soil samples from three soil depths (i.e., 0-10 cm, 10-20 cm, and 20-30 cm) were collected from each land use type and analyzed for soil physical and chemical properties. Sand percentage was highest in DF and lowest in QF. The soil pH varied between 4.3 and 5.3 in different land uses. The highest water holding capacity (84.86%) was in PP and lowest (55.46%) in LF. The bulk density was highest in LF and QF (1.04 g/cm^3) and lowest in DF (0.85 g/cm^3). The highest soil organic carbon and organic matter were in PP (30.6 and 59.5 Mg/ha) and lowest in MPF (6.6 and 11.2 Mg/ha). The stocks of nitrogen, phosphorus and potassium in different systems ranged 250.5-438.7 kg/ha, 12.7-54.8 kg/ha and 102-236.20 kg/ha, respectively. Higher accumulation of soil organic carbon and nutrients in PP within a short period of time (40 years) compared to others are because slow decomposition of pine needle.

Keywords: Land use, Soil physico-chemical properties, Mixed pine forest, Pine plantation, Northeast India

Land use change is among the major global change processes responsible for affecting the structure and functioning of natural and modified ecosystems (Tripathi et al 2008, Wapongnungsang et al 2018). Soil physico-chemical properties are important determinants of the structure and functioning of different land uses, which are strongly influenced by the biota through recycling of organic matter and nutrients (Singha et al, 2020, Manpoong et al 2020). Soil contains organic matter, minerals, water, air and micro-organisms that determine the physico-chemical characters and provide a natural environment for the growth of terrestrial plants and animals (Velayutham and Bhattacharyya 2000, Singh et al 2020a, Singh et al 2021a, b). Soil and micro-fauna provide several environmental services such as soil erosion control, pest control, depletion of greenhouse gases, pollutants, improve soil composition and help retain nutrient (Kibblewhite et al 2008, Baer and Birgé 2018) thus keep nature in balance. However, vegetation has also affected soil compaction and cycling via litter fall, organic matter, nutrient recycling, weathering process, erosion, etc. (Binkley et al 1992, Nkongolo and Plassmeyer 2010, Singh and Tripathi 2020a, b). Decomposition of litter and presents of organic matter affects soil formation and fertility by adding humus and nutrients to the soil (Singh et al 2022).

Plants are major source of organic matter and are essential elements for a healthy forest environment. In addition, plant species composition has contributed to forest ecosystems to maintain soil organic matter and to support the biogeochemical cycle which in turn disrupts soil structures through rooting, nutrient uptake, and root growth (Marcet et al 2006, Akintola et al 2020). Tropical forest has the potential to sequester 1.1 to 1.8 Gt C per year in 50 years (Makundi et al 1998). However, carbon sequestration potential of these forests is strongly influenced by deforestation for commercialization, conversion to plantation and other land use types, development activities and climate change (Foley et al 2005, Yang et al 2009).

Degradation of the forest ecosystem as a result of anthropogenic activities has been well reported in several studies (Devi and Yadava 2015, Tripathi et al 2016, 2017, Singh et al 2020a, b). This has led to increase in soil erosion, nutrient loss, decreased soil microbes which are responsible for soil structure and quality (Slam and Weil 2000, Chen et al 2001, Singh and Tripathi 2020b). The varying soil structures due to changing vegetation and a strong relationship between vegetation and soil in the forest. Therefore, the physico-chemical properties of soils are important in determining soil production and the quality of the forest site that provide sustainable forest and ecological services. The main aim of the present study was to analyze the physico-chemical soil properties of different land use types and to understand the potential of different land use soils in sequestering carbon and nutrients in Manipur.

MATERIAL AND METHODS

Study sites: Manipur is in the Northeastern part of India between 23°50' N - 25 ° 42' N lat. and 92°59' E - 94°46' E long. with an area of 22,327 km^2 (ISFR 2019). The state has a tropical climate with moderate temperatures ranging from 14.5 °C to 38 °C and an average annual rainfall of 1200 to 2700 mm (ISFR 2019). There are five major forest types which were further sub-divided into 11 forest types. The present study was conducted in five different land uses under the three districts (Chandel, Senapati and Tengnoupal districts) of Manipur (Fig. 1). Mixed pine forest (MPF) and *Lithocarpus* forests (LF) were in the Chandel district. Pine plantation (PP) and *Quercus* forest (QF) were in the Senapati district and *Dipterocarpus* forest (DF) in the Tengnoupal district (Table 1).

Sampling and analysis of soil: Soils of the selected forests were collected randomly from nine locations and three depths (0-10, 10-20 and 20-30 cm) and three samples were composited to make one and kept in a well labeled zip polybags for analysis of its physico-chemical properties. These soils were sieved through 2 mm mesh and parted into fresh and air-dried soil. Soil texture was assessed through hydrometer method (Bouyoucos 1962) and the result was subsequently classified according to the United States Department of Agriculture (USDA) soil texture classification. Soil moisture content (SMC) was determined following a gravimetric method by oven drying the fresh soil samples at 105°C for 24 hours (Verstraeten et al 2008). Soil pH was measured using a digital pH meter with soil and water ratio of 1: 2.5 (Bandyopadhyay et al 2012). The water holding capacity (WHC) was measured using the Keen Raczkowski box process (Piper 1966). Bulk density (BD) of soil was measured using the stainless-steel tube of known inner as per the method Anderson and Ingram (1993). Soil organic carbon (SOC) was analyzed by Walkley and Black (1947). Soil organic matter (SOM) was estimated following Van Bemmelen factor 1.724. Available nitrogen (N) is estimated using the kjeldahl method (Jackson 1973), available phosphorus (P) was obtained by the Bray and Kurtz method (1945), and exchangeable potassium (K) was estimated using flame photometry method (Jackson 1973).

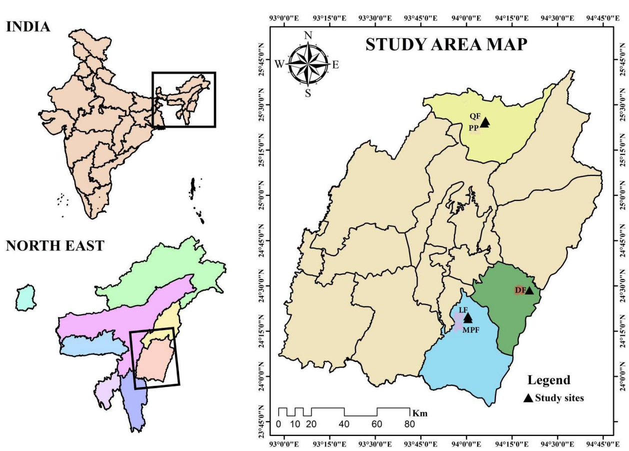

Fig. 1. Location map of the study area

Statistical analysis: Pearson coefficient (r) correlation was performed to assess significant differences among various soil physico-chemical properties. All analyses were conducted using SPSS statistics v18.0 software.

RESULTS AND DISCUSSION

In the present study, soil was sandy with sandy loam and loamy sand in texture (Table 2). In different land uses, the amount of sand, silt and clay ranged from 51.33 - 82.75%, 5.17 - 34.18% and 12.08 - 18.16%, respectively. Highest amount of sand, silt and clay contents were in *Dipterocarpus* forest, *Quercus* forest and *Lithocarpus* forest. The values of sand, silt and clay content of 70.90, 17.90 and 12.01%, respectively reported by Devi and Yadava (2015) in *Dipterocarpus tuberculatus* forest of Manipur were broadly comparable. Niirou et al (2015) also reported sandy soil type in different land use types in Manipur. Soil texture in different land uses is caused by movement and deposition of soil particles (Sand, silt and clay) due to rains and undulating site conditions at altitudinal gradients in forested lands (Saeed et al 2014).

Soil BD values ranged from 0.85 to 1.04 g/cm^3 in different land uses. Soil BD increase with soil depth (Table 2). In all study sites, the highest value was observed in the bottom soil layer (20-30cm) of *Lithocarpus* forest and *Quercus* forest. Niirou et al (2015) in various land use system in Senapati

Table 1. Location, age, GPS co-ordinates, elevations and districts of the study sites

Land use types	Age (Years)	Co-ordinate	Elevation (m amsl)	District
Mixed pine forest (MPF)	100	24°19`05``N, 94°00`31``E	1019	Chandel
Pine plantation (PP)	40	25°23`51``N, 94°05`52``E	1325	Senapati
Lithocarpus forest (LF)	100	24°19`58``N, 94°00`30``E	960	Chandel
Quercus forest (QF)	100	25°24`43``N, 94°06`15``E	1318	Senapati
Dipterocarpus forest (DF)	100	24°28`31``N, 94°21`04``E	536	Tengnoupal

district of Manipur also observed same trend. The soil BD was lowest in upper soil layer (0-10 cm) and highest in lower depths (20-30 cm). Low BD in upper soil layer is related to the presence of higher organic matter. The lowest BD (0.85 g/cm^3) was in *Dipterocarpus* forest in upper soil layer (0-10 cm). Higher organic matter has been reported lower the soil BD in different forest soils of Japan (Morisada et al 2004). Yinga et al (2020) reported a high amount of BD in the *Emblica* base agroforestry system due to a few crop coverings. In another study, the natural forest had a low amount of BD caused by higher accumulation of vegetation litters and the growth of densely populated roots reduces the soil BD of bamboo forest (Manpoong and Tripathi 2019).

Soil MC, an important regulator of plant growth, affected by the soil texture and organic matter contents. The decrease in soil moisture content with increasing soil depth in the present study is related to decreasing soil organic matter. Zheng et al (2015), reported decreasing soil moisture content with depths during the study period (June to September) in *Larix* spp and *Quercus mongolica* the forest. Authors argued that greater retention of soil moisture in *Q. mongolia* forest was due high soil organic matter and nutrients. The highest (37.25%) soil moisture was recorded in *Dipterocarpus* forest followed by Pine plantation and *Quercus* forest (having 34.95% MC), and the lowest (29.66%) in Mixed pine forest (Table 2). Variation in soil moisture was related to rainfall because precipitation and evapo-transpiration significantly recharged the soils water supply (Zheng et al 2015). Lesser ground vegetation and open canopy in Mixed pine forest may result in lower soil MC. Similar result was reported by Bargali et al (2018) where an open-bed pine chir forest had a lower MC.

WHC ranged from 55.5 to 84.9% with the highest WHC in pine plantation and lowest in *Lithocarpus* forest (Table 2), which may be due to the presence of high soil organic matter and higher content of clay and silt in the site. The higher content of organic carbon and clay contents in the soil have been reported to increase soil water holding capacity (Gupta et al 2010). The study sites were acidic in nature where soil pH ranged from 4.3 to 5.3 (Table 3), which broadly like the range (pH of 4.0 to 5.4) in different forest soils of Manipur (Sahoo et al 2020). The difference in soil pH value between the different land used types may be due to the kind of deposited organic debris (Mishra et al 2018).

In all study sites, the SOM content was very high in the topsoil layer (0-10 cm) which decreased with soil depth. The highest value of SOM (59.5 Mg/ha) was at the topsoil layer (0-10 cm) of pine plantation while the lowest (11.22 Mg/ha) at the bottom layer (20-30 cm) of mixed pine forest (Table 3). The current result is similar to the findings of Oladoye (2015).

Table 2. Depth wise soil physical properties from various forest types

Soil parameters	Depth (cm)	MPF	PP	LF	QF	DF
Sand (%)	0-10	64.67^a	62.03^a	63.33^a	58.33^a	82.75^a
	10-20	61^b	57^b	66^a	61^a	78.25^b
	20-30	59.67^b	62^{ac}	63^a	51.33^b	78.59^b
Silt (%)	0-10	22.84^a	25.57^a	18.51^a	27.34^a	5.17^a
	10-20	23.17^a	26.67^a	19.84^a	25.84^a	8.67^b
	20-30	23.67^a	22.84^a	21.67^a	34.18^b	6.83^{ab}
Clay (%)	0-10	12.49^a	12.50^a	18.16^a	14.33^a	12.08^a
	10-20	15.83^b	16.33^b	14.16^b	13.16^a	13.08^{ab}
	20-30	16.66^b	15.16^b	15.33^b	14.49^a	14.58^b
BD (g/cm^3)	0-10	0.95^a	0.89^a	0.92^a	0.90^a	0.85^a
	10-20	1.02^a	0.98^b	1.02^{ab}	0.95^{ab}	0.95^{ab}
	20-30	1.03^a	1.03^c	1.04^b	1.04^c	1.02^{bc}
MC (%)	0-10	29.66^a	34.95^a	31.61^a	34.95^a	37.25^a
	10-20	29.15^a	32.27^{ab}	26.71^b	33.19^{ab}	31.92^b
	20-30	29.07^a	28.64^c	25.05^{bc}	32.27^b	30.59^b
WHC (%)	0-10	61.26^a	84.86^a	59.33^a	60.47^a	58.08^a
	10-20	64.89^a	74.92^b	55.46^b	66.36^b	60.73^a
	20-30	63.19^a	76.51^b	57.41^a	65.85^b	68.08^b

Different superscript letter indicates significant differences ($P < 0.05$) among soil depth. (n-3, Mean ± 1SE. Abbreviation; MC-moisture content, WHC-water holding capacity and BD-bulk density. MPF=Mixed pine forest, PP=Pine plantation, LF=*Lithocarpus* forest, QF=*Quercus* forest, DF=*Dipterocarpus* forest

The decrease in the organic matter was due decline in the amount of litter (leaf and root) inputs in lower soil depths. Similarly, the amount of SOC was estimated to be significantly higher in the upper soil layer (0-10 cm) than the lower soil layers. The reports are in consistent with Niirou et al (2015). The variation in SOC in different land uses were in the order: Pine plantation> *Quercus* forest> *Lithocarpus* forest> *Dipterocarpus* forest> Mixed pine forest. The highest value (30.2 Mg/ha) was observed in the topsoil layer (0-10 cm) of pine plantation while the lowest (6.6 Mg/ha) at bottom layer (20-30 cm) of mixed pine forest (Table 3). The high concentration of SOC in the surface soil is due to the higher inputs of litter biomass which accelerates the amount of SOM and SOC in the soil through the process of decomposition (Wapongnungsang et al 2017, Hauchhum and Tripathi 2017, Shah et al 2021).

In the present study, the concentration of available N ranged from 242.5-440.7 µg/g. The highest amount of N was in *Dipterocarpus* forest followed by *Lithocarpus* forest and *Quercus* forest, and the lowest in mixed pine forest. The availability of P in different land uses ranged from 12.2 - 61.8 µg/g. The available P concentration was highest in the pine plantation followed by *Lithocarpus* forest and mixed pine forest, and least in the *Dipterocarpus* forest. Similarly, the highest exchangeable K concentration ranged from 112.3 - 257.3 µg/g) in different land uses. The highest exchangeable K was in *Lithocarpus* forest (180.7 -257.3 µg/g) in different depths. However, the other land uses had comparable exchangeable K concentrations (112.3 - 144.6 µg/g) (Fig. 2). Singh et al (2014) found 184.1 and 157.3 µg/g concentration of available N, 8.5 and 7.9 µg/g of available P, 159.9 and 136.1 µg/g of exchangeable K in the natural forest land and plantation land which are lower than our reported values in all the land use types except exchangeable K of the plantation which is higher than our values of pine planation. The study on different forests of Kamuan Himalayan had reported available P ranging from 213-267 µg/g in the Banj-oak forest, 93 -167 µg/g in the Chir pine forest and 160 -220 µg/g in the Sal forest which are higher than present study. Similarly, exchangeable K of these study (41 - 54 µg/g in Banj-oak forest; 56 - 62 µg/g chir in pine forest; 25 - 59 µg/g in sal forest) were quite lower than present values.

The N, P and K are the major soil nutrients and their availability in soil play a major role in plant growth and production (Pandey et al 2018). Plants use available form of nitrogen (NO_3-N and NH_4-N) for their growth and development. In the current study, available N varied between different land uses and depth, and ranged from 282.81 to 438.65 kg/ha. The range of available N in the present study is broadly comparable to N availability (219.80

Table 3. Depth wise chemical properties of the soil from various forest types

Soil parameters	Depth (cm)	Land use					LSD (p=0.05)
		MPF	PP	LF	QF	DF	
SOM (Mg/ha)	0-10	29.9[a]	59.5[a]	36.5[a]	38.2[a]	32.3[a]	9.27
	10-20	11.8[b]	42.4[b]	18.2[b]	33.8[ab]	19.3[b]	5.04
	20-30	11.2[bc]	27.4[c]	16.8[bc]	26.7[b]	16.7[bc]	9.52
SOC (Mg/ha)	0-10	16.5[a]	30.6[a]	19.3[a]	19.9[a]	16.2[a]	4.98
	10-20	7[b]	24.3[b]	10.9[b]	18.7[a]	10.6[ab]	3.25
	20-30	6.6[bc]	16.4[c]	10.1[bc]	16.1[b]	10.1[bc]	5.50
N (kg/ha)	0-10	282.8[a]	343.6[a]	376.3[a]	360.5[a]	376.1[a]	152
	10-20	345.4[b]	346.0[ab]	438.7[b]	406.4[b]	344.5[b]	172
	20-30	250.5[c]	376.7[c]	314.1[c]	407.8[b]	282.4[c]	255
P (kg/ha)	0-10	49.2[a]	54.8[a]	52.1[a]	15.1[a]	26.8[a]	2.2
	10-20	42.4[b]	47.6[b]	49.9[b]	13.0[ab]	41.0[b]	1.8
	20-30	29.1[c]	37.6[c]	34.9[c]	12.7[ab]	16.3[b]	1.9
K (kg/ha)	0-10	125.8[a]	109.9[a]	236.2[a]	122.3[a]	120.6[a]	1.3
	10-20	116.4[b]	122.7[b]	195.4[b]	109.2[b]	103.9[b]	1.3
	20-30	113.0[c]	109.5[a]	187.1[c]	115.0[c]	102.3[b]	1.8
pH	0-10	4.4[a]	4.8[a]	4.3[a]	5.1[a]	4.6[a]	0.54
	10-20	4.4[ab]	4.8[ab]	4.5[ab]	5.1[a]	4.8[b]	0.19
	20-30	4.9[b]	5.3[b]	4.8[b]	5.2[b]	4.9[b]	0.13

See Table 2 for details

to 878.1 kg/ha) in different land use types of Manipur (Watham et al 2018, Singh and Athokpham 2018). In contrast to the SOC, the highest soil N content (438.65 kg/ha) was recorded in the middle soil layer (10-20 cm) in *Lithocarpus* forest. This reflects the movement of available N from the upper soil layer to the lower soil layer due to the process of leaching. The low N value (250.45 kg/ha) in mixed pine forest of the bottom layer (20-30 cm) corresponds to the low SOC value in mixed pine forest (Table 3). SOC content has been well correlated with the amount soil available N in different forest soils (Bhuyan and Sharma 2017, Haobijam et al 2020).

Available P helps to promote plant growth through the proliferation of roots and thereby improving the nitrogen fixation process (Watham et al 2018). The available P was the highest in all the soil depths except DF (Table 3). Between sites, high P concentrations were observed at pine plantation (37.64 to 54.75 kg/ha) which may have the effect of litter decay and high concentrations of organic matter. The low P was in *Quercus* forest (12.74 to 15.14 kg/ha), which is in the reported range (11-30 kg/ha) for disturbed mixed oak forest in Manipur (Niirou et al 2015).

Similarly, the exchangeable K is most abundant in the topsoil layer at all sites except Pine plantation which may be due to the leaching effect of the nutrient transfer to the bottom soil layer. The nutrient cycling brings back the nutrient to the surface forest floor through litterfall. Thus, the release of K from the decomposition of organic matter in its high concentration occurred in the topsoil of forest (Kumar et al 1998). In all sites, the highest K values were observed at *Lithocarpus* forest (187.13 to 236.20 kg/ha) which may be due to the input of high amount of leaf litter from very deep trees (Table 3).

The significant interaction was observed at soil depth with pH and BD but negative interactions with MC, SOM, BD, SOC, and P. Soil MC shows a significantly positive interaction with SOM and SOC but a negative interaction with BD. Soil pH had a very good correlation with silt content but significantly negative correlation to P and K. WHC shows positive interaction with sand content but significantly negative interaction with K content, clay and silt. SOM indicates a negative interaction with BD and sand. BD was very well matched with clay and silt. The available P and K also show significantly positive interactions (Table 4).

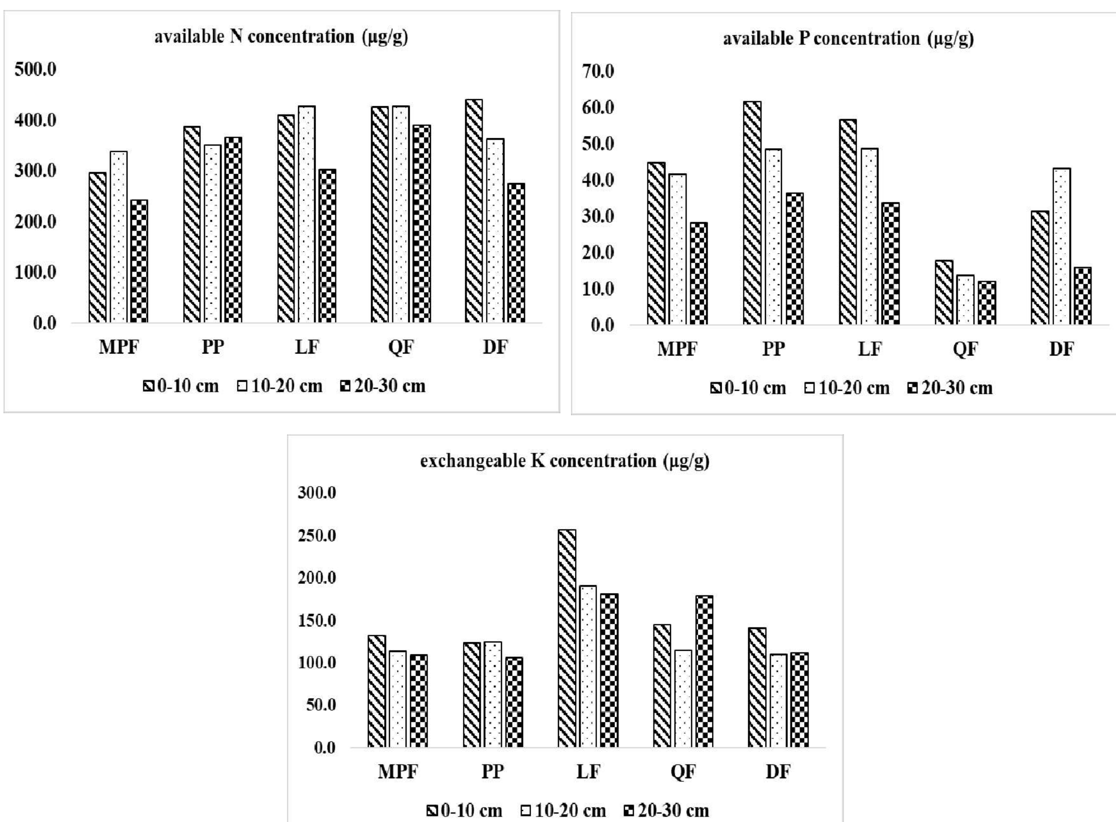

Fig. 2. Spatial changes in the concentration of available NPK (µg/g) in different land-use systems in Manipur. Abbreviation: MPF=Mixed pine forest, PP=Pine plantation, LF=*Lithocarpus* forest, QF=*Quercus* forest, DF=*Dipterocarpus* forest

Table 4. Correlation coefficient (r) of various soil physico-chemical properties in different land use

	Soil depths	MC	pH	WHC	SOM	BD	SOC	N	P	K	Clay	Silt
MC	-.538**											
pH	.489**	-.003										
WHC	.070	.155	-.105									
SOM	-.604**	.562**	.012	-.151								
BD	.730**	-.509**	.199	-.090	-.565**							
SOC	-.527**	.526**	.061	-.181	.988**	-.444**						
N	-.176	.187	.136	-.169	.244	-.126	.262					
P	-.376*	-.199	-.595**	-.144	.217	-.108	.207	-.037				
K	-.186	-.270	-.470**	-.327*	-.039	.012	-.044	.271	.422**			
Clay	.273	-.252	-.100	-.356*	-.190	.298*	-.160	-.130	.189	.442**		
Silt	.224	-.216	.296*	-.588**	.018	.334*	.087	.203	-.179	.053	.296*	
Sand	-.072	.091	-.218	.552**	-.338*	-.179	-.386**	-.139	-.081	-.046	-.348*	-.834**

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)

CONCLUSIONS

The *Lithocarpus* forest and pine plantation having higher soil chemical properties (soil organic carbon, soil organic matter, available NPK) that may be attributed to higher nutrient availability in the region and to the type of the vegetation grown that accumulated higher contain of litter biomass that improve the soil structure. The forests with high soil organic carbon have great potential for mitigating climate change. Therefore, there is a need to promote and conserve such forests.

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