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Comparative studies on labile carbon fractions under different land use systems in Nagaland

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Abstract
The present investigation was carried out to assess the soil carbon fractions including organic carbon, labile carbon *viz.* permanganate oxidizable carbon and microbial biomass carbon in natural forest, horticulture and agriculture land use systems in Nagaland. Results revealed that soils of natural forest contained maximum amount of organic carbon, permanganate oxidizable and microbial biomass carbon in surface layer followed by horticulture and agriculture land use systems. Significant variation in these fractions was recorded in different seasons. Permanganate oxidizable carbon constituted 2.6%, 2.4% and 2.0% of organic carbon content in natural forest, horticulture and agriculture land use systems, respectively; while microbial biomass carbon constituted 2.5%, 1.9% and 2.3% of organic carbon in natural forest, horticulture and agriculture land use systems, respectively. The results of present study indicated the need for periodical analysis of above parameters for effective soil management to achieve sustainable production of any land use system.

Keywords: Labile carbon, land use systems, seasons, Nagaland

1. Introduction
Soil organic matter is the central indicator of soil quality. The effects of various land use systems on soil health are mainly due to accumulation of soil organic matter and organic carbon content. Soil organic carbon (SOC) is considered as the most complex and least understood component of soil; influencing the productive capacity of soil with its beneficial effects on soil physico- chemical and biological properties (Verma *et al*., 2013; Wang *et al*., 2017) [22, 24]. Soil physical and chemical properties are directly or indirectly related with soil organic carbon and therefore any agronomic practice that add organic matter in the soil has direct bearing on soil bulk density, porosity and water holding capacity (Bamboriya *et al*., 2022) [2]. SOC is simultaneously a source and sink for nutrients and plays a vital role in soil fertility maintenance. Thus, it becomes imperative to increase SOC density for improvement in quality soil for sustainable crop productivity (Sahoo *et al*., 2022) [17].
There are several fractions of SOC with varying degrees of decomposition and stability, which may be useful in the study of influences of land use practices on soil quality (Ramesh *et al*., 2019) [15]. Both labile and stabilized forms of SOC constitute total organic carbon; of which, labile fractions are quickly changed and restored. The labile fractions of soil carbon are important to study as these fractions fuel the soils food web and therefore greatly influence nutrient cycles, soil fertility and many biologically related soil properties. Several studies have reported that labile fractions, such as the light fraction organic carbon (LFOC) (Six *et al.*, 2002) [18], particulate organic carbon (POC) (Cambardella and Elliot, 1992) [4], permanganate oxidized carbon (Blair *et al.*, 1995) [3] are quickly changed and restored. Hence, labile SOC fractions can serve as sensitive indicators to study the effect of land use change and management practices on soil quality in the short-term compared to total organic carbon. Soil organic carbon oxidized by 0.333M $KMnO_4$ has been considered as useful index of labile soil carbon that is more sensitive to changes in cultivation or management practices (Verma *et al*. 2013) [22]. Soil microbial biomass carbon (SMBC), which mainly consisted of bacteria and fungi is also considered by several researchers as an index of liability of SOC (Haynes, 2005) [7]. This fraction is highly sensitive to management practices and environmental condition (Verma *et al*., 2013) [22]. Seasonal changes in organic matter as well as fractions of organic carbon in soil are visible under different land use systems owing to the differential temperature in different seasons. Soil depth also influences contents of total as well as labile soil organic carbon fractions. Jamala and Oke (2013) [9] reported highest total organic carbon (TOC) content in surface soils (0–15cm) of natural forest and lowest in the crop land.

The present investigation aimed to study the spatial and temporal variation of labile fractions of soil organic carbon under common land use systems in Nagaland.

2. Materials and Methods

The study was conducted in SASRD, Nagaland in 2018-19. Soil samples were collected from the site that lies between 25.69347°N to 25.76559°N latitude and 93.82366°E to 93.88039°E longitudes. The average rainfall in the study site varies from 1500mm to 2500mm. Maximum amount of rainfall received during summer followed by spring season. Winter season received minimum amount of rainfall during the experimental period. Three prevalent land use systems (LUS) *viz.* natural forest (with mixed forest species), horticulture (pineapple) and agriculture (lowland paddy) were selected for the study. The selected LUS existed there in place for past 15-20 years. Geo referenced composite soil samples were collected during spring, summer and winter season from surface (0-0.25m) and sub-surface (0.25-0.50m) soil layers.

Organic carbon (OC) in soil was determined by wet oxidation method (Walkley and Black, 1934) [23]. Potassium dichromate ($K_2Cr_2O_7$) and concentrated H_2SO_4 were used to oxidize organic matter in soil. The excess of $K_2Cr_2O_7$ not reduced during oxidation was determined by back titration with standard ferrous ammonium sulphate in presence of diphenylamine indicator.

Permanganate oxidizable carbon (POXC) was determined by the procedure as described by Blair *et al.* (1995) [3]. The soil-$KMnO_4$-$CaCl_2$ suspension was initially shaken at 200 rpm and then centrifuged at 3000 rpm and filtered. The bleaching of colour of $KMnO_4$ was measured by spectrophotometer at 550 nm wavelength. POXC were calculated using the formula below:

$$\text{POXC (mg/kg)} = [0.01\text{mol/L} - (a + b \times \text{absorbance})] \times (9000 \text{ mg C/mol}) \times (0.02 \text{ L solution}/0.005 \text{ kg soil})$$

Where, 0.01mol/L is the initial concentration of $KMnO_4$, 'a' is the intercept and 'b' is the slope of the standard curve. The numerical value 0.005 is the amount of soil in kg on oven dry basis. 0.02 L is the volume of $KMnO_4$ reacting with the sample.

Microbial biomass carbon (MBC) was determined by fumigation extraction method as described by Vance *et al.* (1987) [20]. Ethanol free chloroform was used to fumigate the fresh soil samples in vacuum desiccator. 0.5*M* K_2SO_4 was used to extract fumigated as well as non-fumigated soils. The filtered extract was titrated against 0.005 *N* ferrous ammonium sulphate after adding $K_2Cr_2O_7$, concentrated H_2SO_4 and concentrated H_3PO_4 in presence of suitable indicator. MBC was calculated by using the following formula:

$$\text{MBC } (\mu g\ g^{-1}) = E_{CF} - EC_{NF} / K_{EC}$$

Where,

E_{CF} = Total weight of extractable C in fumigated soil sample

EC_{NF} = Total weight of extractable C in non-fumigated soil sample

K_{EC} = Calibration factor ~ 0.38

Pearson's correlation analysis was carried out using SPSS software (version 23.0). One way ANOVA and Duncan's multiple range test (DMRT) for comparison of means with LUS as factor was carried out to assess the significance of difference in studied attributes among LUS.

3. Results and Discussion

Natural forest LUS recorded maximum average content of OC followed by horticulture and agriculture LUS irrespective of seasons and depths. Gradual decline in OC content along the depth was recorded in all the LUS. Significant seasonal variation in OC content among LUS was recorded during three different seasons; maximum content of OC was recorded during winter followed by spring season. Least but significant OC was recorded in summer for all LUS (Table 1). The higher OC under natural forest LUS may be due to abundant and varied plant biomass. Site disturbance and exposure of litter material for decomposition due to tillage and other operations might have resulted less OC content in horticulture and agriculture LUS. High OC content in surface soil may be because of large deposition of organic residues in the surface soil. Decreased rate of residue decomposition due to reduced microbial activity in winter season may be attributed to higher organic carbon values. Higher organic carbon content in natural forest and least in soils of paddy fields was reported by Chase and Singh (2014) [5] under Nagaland condition. Kenye *et al.* (2019) [10] have revealed that forest land use has highest mean SOC concentration and bamboo plantation the lowest in Mizoram. Hoque *et al.* (2020) [8] also reported similar findings related to decreasing organic matter content with increasing depth from a study conducted in Bangladesh. Higher SOC content was recorded in the surface horizon in autumn and winter months, while lower SOC content in spring and summer (Dluzewski *et al.*, 2019) [6]. Omer *et al.* (2018) [14] reported highest SOM in the winter and lowest in the summer from an experiment conducted in three crop management systems including alfalfa, upland cotton and pecan.

The mean permanganate oxidizable carbon (POXC) was found maximum in natural forest LUS followed by horticulture and agriculture LUS. POXC constituted 2.6%, 2.4% and 2.0% of OC content in natural forest, horticulture and agriculture LUS, respectively. Surface soils of all the LUS recorded maximum POXC. Significant seasonal variation was recorded with maximum content during winter followed by spring. Summer season recorded least content of POXC in soils (Table 1). Maximum POXC under natural forest compared to other LUS may be attributed to the abundance of litter materials apart from increased addition of organic substrates directly, which stimulate microbial biomass; and thus contribute to an increase in the labile organic carbon pools. The negative effect on prolonged cultivation practices was evident with low concentration of POXC in agriculture land use system. Accumulation of higher amount of litter materials on the surface soil layer may be the reason for increased POXC content. Lower microbial activity and more accumulation of organic materials might have resulted subsequent increase in POXC content in soil during winter. Similar findings were reported by Badagliacca *et al.* (2020) [1] with higher values under tree crops and natural soil. They have reported greater percentage in the upper soil layer than in the deep one. Omer *et al.* (2018) [14] also reported similar findings with highest POXC in fall and winter.

A wide variation in microbial biomass carbon (MBC) content among different LUS was recorded during the investigation; maximum being recorded in surface soils of natural forest followed by horticulture LUS. Agriculture LUS recorded least

MBC content across the seasons and depths. MBC content in soil started increasing with the pre-monsoon shower in spring season, which attained maximum during summer season and then declined in winter in case of forest and horticulture LUS. Conversely, in case of agriculture LUS, a gradual decline in MBC content was recorded from spring to winter season (Table 1). MBC is often limited by the soil organic carbon as distribution and biological activity of heterotrophic microorganisms depends on substrate availability. The higher MBC content in surface soils of natural forest may be due to high organic carbon and available nitrogen in this LUS. Low MBC in the agriculture LUS might be attributed to different agricultural practices that lead to decrease in organic carbon content and corresponding decrease in MBC. Maximum value of MBC in summer season may be because of appropriate soil moisture content for microbial proliferation. On the other hand, the minimum values in winter season (dry period) may be because many soil microorganisms are intolerant of low water content. Warm and wet weathers during summer or rainy season accelerated litter decomposition; thereby increasing the immobilization of nutrients by the microbes and thus increase in MBC content. Impounding water during summer in lowland paddy might have limited the microbial activity. Lepcha and Devi (2020) [11] have reported highest annual mean microbial biomass carbon in surface soils of forest followed by cardamom agroforestry and paddy cropland with peak value in the rainy season and lowest in the winter season. Similar findings were reported by Xiangmin *et al.* (2014) [25] from a study conducted in Changbai Mountains of Northeast China. Reza *et al.* (2014) [16] have reported significantly greater microbial biomass carbon in the soils of the undisturbed forest than the soils under various land use practices. Soils of natural forest exhibited the maximum MBC whereas the minimum was reported in bamboo forests in Mizoram, North East India (Manpoong and Tripathi, 2019) [13]. Tomar and Baishya (2020) [19] have reported highest MBC in monsoon season and lowest in the winter season.

Table 1: Organic carbon and labile carbon content under different land use systems

Parameters	Land use systems	Spring		Summer		Winter		Mean
		Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	
OC (g kg^{-1})	Natural forest	17.7^{a}	15.3^{a}	17.1^{a}	14.7^{a}	18.7^{a}	16.8^{a}	16.7
	Horticulture	15.0^{b}	13.3^{b}	14.6^{b}	13.0^{b}	15.6^{b}	13.9^{b}	14.2
	Agriculture	11.2^{c}	9.8^{c}	10.7^{c}	9.8^{c}	12.1^{c}	10.7^{c}	10.7
POXC (mg kg^{-1})	Natural forest	467.9^{a}	366.9^{a}	421.4^{a}	338.1^{a}	543.5^{a}	434.1^{a}	428.7
	Horticulture	379.6^{b}	307.5^{b}	332.1^{b}	260.2^{b}	421.9^{b}	328.5^{b}	338.3
	Agriculture	202.2^{c}	148.7^{c}	197.2^{c}	140.2^{c}	340.7^{c}	263.0 ^{c}	215.3
MBC (µg g^{-1})	Natural forest	517.1^{a}	375.2^{a}	549.5^{a}	419.3^{a}	361.6^{a}	330.9^{a}	425.6
	Horticulture	274.4^{b}	246.9^{b}	366.2^{b}	313.5^{b}	252.8^{b}	202.9^{b}	276.1
	Agriculture	403.7^{c}	321.9^{c}	329.5^{bc}	233.2^{c}	136.9^{c}	130.2^{c}	259.2

Values followed by different letters under different land uses are significantly different ($p<0.05$) by the Duncan's multiple range test

Significant positive correlation was obtained between OC and POXC (Table 2); indicating that both OC and POXC are just the fractions of total organic carbon content of soil and increase or decrease of total organic carbon content directly effects the content of its different fractions. Mandal *et al.* (2011) [12] reported the close relationship between POXC and other soil quality parameters like OC, MBC and dehydrogenase enzyme activity. Significant positive correlation was obtained between OC and MBC (Table 2). This indicated that the organic matter is the source of energy for soil organisms and their activities. The availability of substrate materials in the form of organic matter regulated the microorganisms population and hence MBC. A strong positive correlation between OC-MBC was reported by Mandal *et al.* (2011) [12]. Verma *et al.* (2017) [21] reported that organic carbon fraction and soil enzymes were highly correlated ($P = 0.01$) with each other. They have reported significant positive correlation between organic carbon content and soil biological properties including MBC in a study conducted in Meghalaya, India.

Table 2: Correlation among carbon fractions of various land use systems in different seasons (surface)

	Natural forest LUS			Horticulture LUS			Agriculture LUS		
	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer	Winter
OC-POXC	0.94**	0.91**	0.89**	0.94**	0.90**	0.93**	0.81*	0.84**	0.86**
OC-MBC	0.97**	0.92**	0.97**	0.95**	0.95**	0.90**	0.81*	0.85**	0.72*
POXC-MBC	0.87**	0.97**	0.81*	0.96**	0.91**	0.81*	0.85**	0.84**	0.82*

4. Conclusion

Soil organic carbon along with its fractions plays a major role in availability of nutrients and thus determines fertility and health of soil. Labile fractions of soil organic carbon *i.e.* permanganate oxidizable carbon and microbial biomass carbon can serve as the most sensitive indicator for assessing soil health and quality under different land use systems. Hence, periodical and precise analysis of these parameters is required for effective soil management for sustainable production of any land use system.

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