Comparative studies on effect of conventional practices on soil quality parameters and carbon stock in common land uses in Namthang block, South Sikkim

ABSTRACT

Landuse is the prime management intervention that results to significant changes in the physicochemical properties. Two (2) Land use systems (Maize- broadbean and ginger) were selected for study. A total of sixty (60) soil samples were collected from five (5) different villages of Namthang Block from two different depths *viz.* 0-0.20m and 0.20-0.40m. The samples were analysed for the soil physicochemical properties, soil carbon, carbon stock, fertility status and biological properties. It was observed that the soils were moderately acidic to slightly acidic in reaction, high in organic carbon. Bulk density and particle density ranged from 1.02-1.30 g cm^{-3} and 2.45-2.69 g cm^{-3} at the surface soil in the maize-broadbean LUS and the densities increased with depth. The soils were found to be medium in N, P, K and S. The exchangeable calcium and magnesium ranged from 0.54-1.18 [Cmol (P$^+$) kg^{-1}] and 0.51-1.06 [Cmol (P$^+$) kg^{-1}] at the surface soil in the maize-broadbean LUS. The Soil microbial biomass carbon and dehydrogenase activity was found to be decreasing with increasing soil depth. The organic carbon stock ranged from 24.51-32.00 (Mg ha^{-1}) at the surface soil in the maize-broadbean LUS and found to be decreasing with increasing soil depth. Substantial amount of SOC stock indicated fairly healthy soil of Namthang block. Maize-broadbean LUS found to be superior over ginger LUS owing to enhanced soil fertility as well as biological parameters.

Keywords: Namthang, South Sikkim, LUS, physicochemical properties, soil fertility, biological properties, carbon stock

1 INTRODUCTION

Soil quality is "the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation'' (Karlen *et al*., 2003). The magnitude of variation in SOC content and stock (increase/decrease) depends on the type of land-use, degree of land-use change and post-conversion land management (Post and Kwon, 2000). Good farming practices have the potential to make such soil net sink for carbon thereby reducing CO_2 emission to atmosphere and improving soil fertility productivity (Lal, 2004). However, SOC is greatly influenced by vegetation through organic matter input and therefore land use change is one of the most important factors which influence SOC stock build up (Kenye *et al*. 2019). The landuse pattern has been found to be directly correlated with the fertility of the soil and the dynamism of its nutrients (Venkatesh *et al*., 2003). Organic systems had 32% to 84% greater microbial biomass carbon, microbial biomass nitrogen, total phospholipid fatty-acids, and dehydrogenase, urease and protease activities than conventional systems (Lori *et al.*, 2017).

Sikkim lies in the North-Eastern region of the country bordered by Bhutan, China and Nepal. Namthang is located at 24 km distance from Namchi, the district headquarter of South Sikkim. It is located 61 km away from the capital city of the state of Sikkim, Gangtok. The major crops grown in the area are maize, broad-bean, ginger,turmeric, dalle chilli and broom cultivation. The land use systems followed mainly are maize-broad bean and ginger.

People of South Sikkim district have adopted the conventional crop management practices including soil management by application of organic sources of nutrients. Two traditionally practiced land uses in the Namthang block are ‘maize-broad bean’ land use and ‘ginger’ land use systems. Although limited information on the effects of organic soil management practices on the selected soil quality parameters are available for the soils of Sikkim; information on the soil fertility status including soil carbon content under continuous cultivation of nutrient exhaustive crops like maize and ginger only with the application of organic manures like FYM is scarce. Hence, the present study aimed to study the organic carbon content, total carbon content and carbon stock under different land uses and also the physico-chemical and the biological properties of soils under selected land uses.

2 MATERIALS AND METHODS

2.1 Experimental sites

The total geographical area of the South Sikkim district is around 750 sq.km, it is located at 27°10'00'' N latitude and 88°29'0'' E longitude with elevation of 1,246 m. Five (5) different villages under Namthang Block of South Sikkim were selected as the study site based on the proposed land use systems. Two (2) land use systems (**LUS 1:** maize-broadbean and **LUS 2:** ginger) selected for the study are the most common land uses in the Namthang Block. The common manure used in cultivating crops under these two land uses is cow dung manures. The manure is generally applied before sowing of the crop. The crops are grown mostly on sloppy lands as the terrain of the block is sloppy. The monthly average rainfall is 1503 mm. The average relative humidity is 65% and the temperature varies between 14.0 to 23.1°C.

2.2 Analysis of soil

Soil samples were collected from five (5) different villages from two different depths *viz.* 0-0.20 m and 0.20-0.40 m. Twelve (12) composite soils samples were collected from three (3) sites of each land use system of each of the selected villages. A total of 60 soil sample were collected and processed for subsequent analysis of soil.

Table 1: Methods of soil analysis

Physical properties	Mechanical Analysis (%)	Piper, 1966
	Bulk Density (g cm^{-3})	Black, 1965
	Particle Density (g cm^{-3})	Black, 1965
Chemical properties	Soil reaction (pH)	Jackson, 1973
	Soil organic carbon (g kg^{-1})	Walkley and Black, 1934
	Total organic carbon (g kg^{-1})	Snyder and Trofymow, 1984
	Available nitrogen (kg ha^{-1})	Subbiah and Asija, 1956
	Available phosphorus (kg ha^{-1})	Bray and Kurtz, 1945
	Available potassium (kg ha^{-1})	Jackson, 1973
	Available sulphur (kg ha^{-1})	Chesnin and Yien, 1951
	Exchangeable calcium [Cmol (P+) kg^{-1}]	Richards, 1954
	Exchangeable magnesium [Cmol (P^{+}) kg^{-1}]	Richards, 1954
Biological properties	Dehydrogenase activity (µg TPF g^{-1} hr^{-1})	Casida, 1977
	Microbial biomass carbon (µg g^{-1} soil)	Vance *et al.*, 1987

Carbon stock (Mg ha^{-1}) = BD (Mg m^{-3}) x C content (g kg^{-1}) x D (m)
Where, BD= Soil bulk density, C= Total carbon content, D= Sampling depth

2.3 Statistical analysis

Statistical analysis was done using correlation coefficient to find out the interrelationship among various soil characteristics using procedures outlined by Panse and Sukhatme (1961).

3 RESULTS AND DISCUSSION

3.1 Physical properties

3.1.1 Mechanical Analysis (%)

The sand, silt and clay content of different soil samples at the surface and sub-surface are given in the table 2. At the surface soil, sand, silt and clay content ranged from 42.54-48.25%, 25.92-31.21% and 20.72-30.32% for maize-broadbean LUS, whereas, for ginger LUS, the sand, silt and clay content ranged from 42.63-48.34%, 26.02-31.59% and 20.07-29.78%. Likewise, at the sub-surface soil, the sand, silt and clay content ranged from 40.59-46.54%, 23.42-29.64% and 24.32-34.34% for maize-broadbean LUS whereas for ginger LUS, the sand, silt and clay content ranged from 40.54-46.25%, 24.89-29.65% and 24.10-33.62%. At the surface soil, for maize-broadbean LUS, the maximum average sand, silt and clay content was observed in Ruchung (48.25%) followed by Nalam (31.21%) and Kolbung (30.32%) and the lowest sand, silt and clay content was observed in Kolbung (42.54%) followed by Bokrong (25.92%) and Ruchung (20.72%). In ginger LUS the highest sand, silt and clay content was observed in Ruchung (48.34%), Ruchung (31.59 %) and Kolbung (29.78%) and the lowest sand, silt and clay content was observed in Kolbung (42.63%), Bokrong (26.02%) and Ruchung (20.07%). The percent sand and silt content was seen to be decreased with depth; while clay content increased with increasing depth (table 2) probably because of leaching and eluviation of clay particles from surface soil and deposition in the sub-surface soil layers. It was observed that the texture of soils of Namthang block under the study belongs to clay loam (3 villages) and loam (2 villages) (table 2)

3.1.2 Bulk Density (g cm^{-3})

The data related to BD of soils of Namthang block at the surface and sub-surface soil are given in table 3. that the BD of the soils at the surface for maize-broadbean LUS ranged from 1.02-1.30 g cm^{-3} with an average value of 1.16 g cm^{-3}, whereas, in ginger LUS, it ranged from 1.01-1.28 g cm^{-3} with an average value of 1.12 g cm^{-3}. Likewise, at the sub-surface soil, BD for maize-broadbean LUS ranged from 1.05-1.35 g cm^{-3} with an average value of 1.21 g cm^{-3}. In ginger LUS, it ranged from 1.06-1.32 g cm^{-3} with an average value of 1.17 g cm^{-3}. The highest average BD at the surface soil for maize-broadbean LUS and ginger LUS was recorded in Kateng (1.25 g cm^{-3} and 1.22 g cm^{-3}) whereas, the lowest average bulk density was found in Ruchung (1.05 g cm^{-3}) and Nalam (1.04 g cm^{-3}). Likewise, at the sub-surface soil for maize-broadbean and ginger LUS, the highest average bulk density was found both in Kateng (1.30 g cm^{-3} and 1.26 g cm^{-3}) whereas, the lowest average bulk density was also found in both in Ruchung (1.10 g cm^{-3}) and Nalam (1.09 g cm^{-3}). The bulk density was found to increase with depth probably due to presence of low organic matter in the sub-surface soil. The bulk density was negatively correlated with organic carbon (Table 4.(a), 4.(b), 4.(c) and 4.(d). Similar findings were reported by Dutta *et al*. (2010), where they revealed bulk density of sub-surface soils were higher than surface soils due to presence of organic matter and clay content surface soils and higher compaction in the sub-surface soils maybe due to absence of cultivation. The influence of organic matter on bulk density was also reported by Gupta (2010) and Rajan *et al.* (2014).

3.1.3 Particle Density (g cm^{-3})

The data related to particle density of different villages of Namthang block at the surface and sub-surface soils are presented in table 3. PD of the soils at the surface in maize-broadbean LUS ranged from 2.45-2.69 g cm^{-3} with an average value of 2.57 g cm^{-3}; whereas for ginger LUS, it ranged from 2.41-2.72 g cm^{-3} with an average value of 2.52 g cm^{-3}. At the sub-surface soil, PD for maize-broadbean LUS ranged from 2.53-2.86 g cm^{-3} with an average value of 2.67 g cm^{-3}, whereas, for ginger LUS, it ranged from 2.47-2.74 g cm^{-3} with an average value of 2.61 g cm^{-3}. The highest average PD at the surface soil for maize-broadbean LUS and ginger LUS was found in Kateng (2.67 g cm^{-3} and 2.65 g cm^{-3}). The lowest average PD was found in Ruchung (2.52 g cm^{-3} and 2.46 g cm^{-3}). Likewise, at the sub-surface soil for maize-broadbean and ginger LUS, the highest average PD was found in Kateng (2.79 g cm^{-3} and 2.71 g cm^{-3}) whereas, the lowest average PD was also found in Ruchung (2.61 g cm^{-3} and Kolbung 2.57 g cm^{-3}). The PD was found to increase with depth which might be due to decrement of organic carbon content in the sub-surface soil. In conformity with the present findings Amenla *et al*. (2010) also reported that PD of the soils increased with depth resulting to decrement of organic matter content. Similar findings were reported by Longchari *et al*. (2021).

3.2 CHEMICAL PROPERTIES

3.2.1 Soil reaction (pH)

The data of soil pH of different villages of Namthang block are presented in the table 4. The data revealed that the pH of surface soils (0-0.20 m) for both ranged from 4.8-6.2 with an average value 5.7 and 5.3-6.3 with an average value 5.7 in maize-broadbean and ginger LUS respectively. At the depth of 0.20-0.40 m, it ranged from 5.2-6.1 in maize-broadbean and ginger landuse system with an average value of 5.6 in both landuse system. The soils of Namthang block were found to be strongly acidic to slightly acidic in nature. The average maximum pH of maize-broadbean and ginger landuse system at the depth of 0-0.20 m was recorded in Nalam (6.07) followed by Kateng (5.9). Average minimum pH of maize-broadbean and ginger LUS was recorded in Bokrong (5.4). Average maximum pH in maize-broadbean LUS was recorded in Nalam (6.1) in surface soil and minimum was recorded in Ruchung at sub-surface soil (5.3). In case of ginger LUS, average maximum pH was recorded in Ruchung and Kateng (5.8) in surface soil and minimum (5.3) in sub-surface soil in Kolbung. The data revealed that the surface soils are less acidic as compared to sub-surface soil which might be due to higher amount of organic matter in surface soils, which restricts the change in soil pH by enhancing buffering capacity. Similar results were also reported by Odyuo *et al*. (2015) and Sarkar *et al.* (2002).

3.2.2 Soil organic carbon (g kg^{-1})

Organic carbon content in the soils of different villages of Namthang block, South Sikkim are presented in Table 4. Surface soil for maize-broadbean and ginger LUS ranged from 10.23-13.14 g kg^{-1} and 9.48-12.28 g kg^{-1} with an average value of 11.69 g kg^{-1} and 11.05 g kg^{-1} respectively. Sub-surface soil for maize-broadbean and ginger LUS, recorded less OC content that ranged from 8.94-10.41 g kg^{-1} and 7.93-10.25 g kg^{-1} with an average value of 9.74 g kg^{-1} and 9.21 g kg^{-1} respectively. The maximum OC content (12.80 g kg^{-1}) was recorded at the surface soil for maize-broadbean in Ruchung and minimum (8.13 g kg^{-1}) was recorded in sub-surface soil of ginger LUS at Kateng. The maximum OC content was recorded in Ruchung for maize-broadbean (12.80 & 10.23 g kg^{-1}) and ginger LUS (12.07 & 10.03 g kg^{-1}) in surface and sub-surface soils. The surface soils had higher OC as compared to sub-surface soils due to incorporation of large amount of plant residues in the surface soil. Similar findings were reported by Sharma and Sarangthem (2017). Correlation coefficient values have been tabulated in Table 8, 9, 10 and 11. From the table, it is showed that, OC had a positive and significant relationship with available N, P, K and S.

3.2.3 Total organic carbon (g kg^{-1})

The values of TOC content in the soils of Namthang block, South Sikkim are presented in Table 4. TOC content of the soils of Namthang block, South Sikkim at the surface for maize-broadbean and ginger LUS ranged from 12.92-15.95 g kg^{-1} and 12.62-14.89 g kg^{-1} with an average value of 14.53 g kg^{-1} and 13.72 g kg^{-1} respectively. At sub-surface soil, maize-broadbean and ginger LUS, recorded less TOC content that ranged from 12.22-14.72 g kg^{-1} and 11.95-14.14 g kg^{-1} with an average value of 13.65 g kg^{-1} and 13.15 g kg^{-1} respectively. The maximum TOC content at the surface soil for maize-broadbean and ginger LUS was recorded in Ruchung (15.54 g kg^{-1} and 14.52 g kg^{-1}) whereas, the minimum TOC content was recorded in Kateng (13.23 g kg^{-1} and 12.94 g kg^{-1}) under maize-broadbean and ginger LUS respectively. The maximum TOC content at the sub-surface soil for maize-broadbean and ginger LUS was recorded both in Ruchung (14.48 g kg^{-1} and 13.92 g kg^{-1}) respectively. Minimum TOC content was recorded in sub-surface soil in Kateng (12.61 g kg^{-1} and 12.29 g kg^{-1}) under maize-broadbean and ginger LUS respectively.Correlation coefficient values have been tabulated in Table 8, 9, 10 and 11. TOC had a positive and significant relationship with organic carbon, available N, P, K and S.

3.2.4 Available nitrogen (kg ha^{-1})

The data related to available nitrogen content in the soils of Namthang block, South Sikkim are presented in table 5. available nitrogen content in the soils of maize-broadbean and ginger LUS at the surface varied from 306.78-391.24 kg ha^{-1} and 301.05-376.32 kg ha^{-1} with an average value of 344.75 kg ha^{-1} and 329.34 kg ha^{-1}, Whereas, at the sub-surface soil, available nitrogen in maize-broadbean and ginger LUS was 299.76-333.48 kg ha^{-1} and 289.56-328.14 kg ha^{-1} with an average value of 316.91 and 311.28 kg ha^{-1} respectively. The maximum average available nitrogen content at the surface for maize-broadbean and ginger LUS was found both in Ruchung (386.09 kg ha^{-1} and 364.06 kg ha^{-1}) ; whereas, the minimum average available nitrogen content was recorded both in Kateng (309.38 kg ha^{-1} and 303.78 kg ha^{-1}) respectively. Available nitrogen content decreased with depth. The maximum available nitrogen content at sub-surface soil for maize-broadbean and ginger LUS was found in Ruchung (329.85 kg ha^{-1}) and 323.29 kg ha^{-1}) respectively, considering depth, maximum available nitrogen content was recorded in surface soil under maize-broadbean LUS (386.09 kg ha^{-1}) and minimum (302.05 kg ha^{-1}) at sub-surface soil. Higher amount of available nitrogen in surface soil as compared to sub-surface soils maybe due to presence of high organic carbon and microbial activities in surface soil. Similar findings were reported by Sharma (2013) and Odyuo *et al*. (2015) where they revealed higher values of N were recorded in surface soils due to high organic matter. Correlation coefficient values have been tabulated in the Table 8,9,10 and 11. From the table, it was observed that at the depth of 0-0.20 m, available nitrogen had positive significant relationship with organic carbon, available P, K and S. Similar results were observed by Poji *et al*. (2017).

3.2.5 Available phosphorus (kg ha^{-1})

Available phosphorus content of the soils of Namthang block, South Sikkim have been presented in table 4. It was evident that the Avail. P_2O_5 content of the soils at the surface of maize-broadbean and ginger LUS ranged from 20.41-24.45 kg ha^{-1} and 19.62-22.47 kg ha^{-1} respectively, with an average value of 22.43 kg ha^{-1} and 21.14 kg ha^{-1}. At the sub-surface soil for maize-broadbean and ginger LUS, the Avail. P_2O_5 content ranged from 17.52-21.83 kg ha^{-1} and 16.91-20.43 kg ha^{-1} respectively, with an average value of 19.96 kg ha^{-1} and 18.72 kg ha^{-1}. Maize-broadbean LUS records higher Avail. P_2O_5 than ginger LUS at both the depths. The maximum Avail. P_2O_5 content at the surface soil for maize-broadbean and ginger LUS was found both in Ruchung (24.14 kg ha^{-1} and 22.16 kg ha^{-1}); whereas the minimum Avail. P_2O_5 content was recorded in Kateng (20.82 kg ha^{-1} and 17.19 kg ha^{-1}). Higher amount of Avail. P_2O_5 content was observed in surface soils (maximum avail. 24.14 kg ha^{-1} in Ruchung) as compared to sub-surface soils (minimum avail. 17.19 kg ha^{-1} in Kateng) under maize-broadbean and ginger LUS respectively. High amount of organic carbon in the surface soils can be attributed to formation of organophosphate complex and subsequent availability of phosphorus. Similar readings were reported by Sharma *et al*. (2006). Correlation studies present in the Table 8, 9, 10 and 11 showed that available phosphorus had a significant and positive correlation with organic carbon, available N, K and S. Similar results were observed by Poji *et al.* (2017).

3.2.6 Available potassium (kg ha^{-1})

Available potassium content in the soils of Namthang Block, South Sikkim have been presented in table 5. The Avail. K_2O content at the surface for maize-broadbean and ginger LUS ranged from 217.54-268.74 kg ha^{-1} with an average value of 241.37 kg ha^{-1} and 214.36-260.87 kg ha^{-1} with an average value of 234.84 kg ha^{-1} respectively. At the sub-surface, the Avail. K_2O content for maize-broadbean and ginger LUS ranged from 201.48-235.49 kg ha^{-1} with an average value of 218.34 kg ha^{-1} and 198.47-232.16 kg ha^{-1} with an average value of 214.19 kg ha^{-1} respectively. From the table, it is evident that the highest content of potassium at the surface for maize-broadbean and ginger LUS was observed in Ruchung (267.59 kg ha^{-1} and 260.37 kg ha^{-1}) and lowest was observed in Kateng (218.51 kg ha^{-1} and 214.87 kg ha^{-1}). Average maximum Avail. K_2O was recorded in Ruchung (267.59 kg ha^{-1}) in surface soil of maize-broadbean LUS and average minimum Avail. K_2O was (199.50 kg ha^{-1}) recorded in sub-surface soil of ginger LUS at Kateng. Potassium content in the soil decreased with increasing depth possibly due to higher organic matter content and the favourable condition that facilitates labile K from organic residues in the surface soil. Similar findings were recorded by Sharma (2006) and Amenla *et al.* (2010). Correlation studies presented in the Table 8, 9, 10 and 11 show that in surface and sub-surface soil, potassium had positive and significant relationship with organic carbon, available N, P and S. Similar results were obtained by Poji *et al*. (2017).

3.2.7 Available sulphur (kg ha^{-1})

Available sulphur content in the soils of Namthang Block, South Sikkim are presented in table 6. The AVS content at the surface for maize-broadbean and ginger LUS ranged from 16.8-23.8 kg ha^{-1} with an average value of 20.5 kg ha^{-1} and 16.6-22.8 kg ha^{-1} with an average value of 19.6 kg ha^{-1} respectively. AVS content in sub-surface soil for maize-broadbean and ginger LUS ranged from 15.4-21.8 kg ha^{-1} with an average value of 18.1 kg ha^{-1} and 13.2-22.1 kg ha^{-1} with an average value of 17.3 kg ha^{-1} respectively. From the table, it is evident that the highest content of sulphur present at the surface for maize-broadbean and lowest in sub-surface soil of ginger LUS. Average maximum AVS was recorded in surface soil of maize-broadbean in Ruchung (23.1 kg ha^{-1}) and the lowest was recorded in sub-surface soil of ginger LUS in Kateng (14.08 kg ha^{-1}). Sulphur content also exhibited similar trend of spatial variation where content decreased with increasing depth. Comparatively high AVS in maize-broadbean LUS maybe because of higher biomass addition, higher mineralization of organic sulphur due to substantial microbial activity. Slower microbial activity in the sub-surface soil might have decreased its content irrespective of LUS. Similar findings were recorded by Sharma *et al*. (2012) and Amenla *et al.* (2010). Correlation studies presented in Table 8, 9, 10 and 11 have shown that sulphur had positive and significant relationship with organic carbon, available N, P and K. Similar findings were reported by Athokpam *et al*. (2013).

3.2.8 Exchangeable calcium [Cmol (P+) kg^{-1}]

Exchangeable calcium content of the soils under study is presented in Table 6. The Ex. Ca of both the LUS under study exhibited almost similar content at the depth of 0-0.20 m for maize-broadbean that ranged from 0.87-0.96 [Cmol (P$^+$) kg^{-1}] with an average value of 0.92 [Cmol (P$^+$) kg^{-1}] at surface soils. However at the depth of 0.20-0.40 m, the Ex. Ca for maize-broadbean and ginger LUS ranged from 0.70-0.79 [Cmol (P$^+$) kg^{-1}] with an average value of 0.75 [Cmol (P$^+$) kg^{-1}] and 0.67-0.78 [Cmol (P$^+$) kg^{-1}] with an average value of 0.73 [Cmol (P$^+$) kg^{-1}] respectively. From the table, it was evident that the highest average content of Ex. Ca was recorded in maize-broadbean LUS in Kolbung 1.17 [Cmol (P$^+$) kg^{-1}] at surface soil and lowest average at sub-surface soil of same LUS at Kateng 0.54 [Cmol (P$^+$) kg^{-1}]. Higher Ex. Ca was recorded in surface soils. Similar findings were reported by Sharma and Sarangthem (2017). Correlation co-efficients have tabulated in the Table 8, 9, 10 and 11. It revealed that Ex. Ca had a positive and significant correlation with organic carbon and total organic carbon. Similar findings were reported by Kavitha and Sujatha (2015).

3.2.9 Exchangeable magnesium [Cmol (P$^+$) kg^{-1}]

Exchangeable magnesium content at the depth of 0-0.20 m for maize-broadbean and ginger LUS ranged from 0.46-0.50 [Cmol (P$^+$) kg^{-1}] with an average value of 0.65 [Cmol (P$^+$) kg^{-1}] and 0.51-0.72 [Cmol (P$^+$) kg^{-1}] with an average value of 0.64 [Cmol (P$^+$) kg^{-1}] respectively. However, at sub-surface Ex. Mg for maize-broadbean and ginger ranged from 0.38-0.71 [Cmol (P$^+$) kg^{-1}] with an average value of 0.50 [Cmol (P$^+$) kg^{-1}] and 0.36-0.61 [Cmol (P$^+$) kg^{-1}] with an average value of 0.47 [Cmol (P$^+$) kg^{-1}] respectively. The highest average Ex. Mg at the depth of 0-0.20 m was observed in Bokrong 0.76 [Cmol (P$^+$) kg^{-1}] and lowest average Ex. Mg was recorded in ginger LUS at sub-surface soil of Kolbung [0.40 Cmol (P$^+$) kg^{-1}]. Higher Ex. Mg was recorded in surface soils irrespective of LUS. The decreasing trend of Ex. Mg down the depth might be due to lesser organic matter in sub-surface soil that decreased CEC of soil.

3.3 BIOLOGICAL PROPERTIES OF SOIL

3.3.1 Soil Microbial biomass carbon (µg g^{-1} soil)

Data on soil microbial biomass carbon content are presented in table 7. The SMBC content at the depth of 0-0.20 m for maize-broadbean and ginger LUS ranged from 274.12-432.17 µg g^{-1} with an average value of 365.56 µg g^{-1} and 230.17-398.52 µg g^{-1} with an average value of 324.97 µg g^{-1} respectively. At the depth of 0.20-0.40 m, the SMBC content in the soils of Namthang block for maize-broadbean and ginger LUS ranged from 192.51-321.66 µg g^{-1} with an average value of 265.72 µg g^{-1} and 174.53-305.41 µg g^{-1} with an average value of 238.26 µg g^{-1} respectively. It is evident that the highest average content of SMBC was recorded at surface soil for both the LUS. Maximum average SMBC at the depth of 0-0.20 m for maize-broadbean LUS was recorded in Ruchung (429.66 µg g^{-1}); Whereas, the lowest average SMBC was recorded in sub-surface soil of ginger LUS in Kateng (177.66 µg g^{-1}). Results indicated that SMBC was greatly influenced by organic matter content in the soil. Moreover, SMBC depend on available nitrogen content. The high SOC and available nitrogen content in maize-broadbean LUS might have provided enough substrate materials with easily mineralizable nitrogen source for rapid multiplication of micro-organisms and thus increased to their mass. Correlation studies showed that soil microbial biomass carbon had positive and significant relationship with OC, available nutrients and dehydrogenase enzyme activity. Similar observations were reported by Reza *et al*. (2014).

3.3.2 Dehydrogenase activity (µg TPF g^{-1} hr^{-1})

Dehydrogenase activity in soils of different LUS is presented in table 7. DHA of the soils at the depth of 0-0.20 m for maize-broadbean and ginger LUS ranged from 6.54-14.86 µg TPF g^{-1} hr^{-1} and 5.54-13.76 µg TPF g^{-1} hr^{-1} with an average value of 10.23 µg TPF g^{-1} hr^{-1} and 9.34 µg TPF g^{-1} hr^{-1} respectively. At sub-surface (0.20-0.40 m), the DHA for maize-broadbean and ginger LUS ranged from 4.54-6.83 µg

TPF g^{-1} hr^{-1} with an average value of 5.74 µg TPF g^{-1} hr^{-1} and 4.14-6.13 µg TPF g^{-1} hr^{-1} with an average value of 5.23 µg TPF g^{-1} hr^{-1} respectively. Maize-broadbean LUS recorded more DHA compared to ginger LUS following the similar trend with SMBC. Highest average content of DHA was recorded in maize-broadbean LUS (14.56 µg TPF g^{-1} hr^{-1}) in surface soil in Ruchung, whereas, the minimum average DHA was recorded in Kateng (4.32 µg TPF g^{-1} hr^{-1}) in sub-surface soil of ginger LUS. It was evident from the result that DHA was greatly influenced by organic matter content in the soil and decreased with increase in soil depth. DHA reflects the total range of oxidative activity of soil microflora and depends on availability of substrate material *i.e.* organic matter. Besides high OM, better availability of available nutrients (N, P, K, S, Ca & Mg) may be attributed to higher DHA in maize-broadbean LUS. Velmourougane *et al*. (2013) revealed that the major reason for increased DHA in the surface soil compared to sub-surface soil is attributed to the greater availability of organic carbon, nutrients and stimulated microbial activity in the surface soil. Correlation studies showed that DHA had positive and significant relationship with OC, SMBC, available N, P, K and S. Similar observations were reported by Reza *et al*. (2014).

3.3.3 Carbon Stock (Mg ha^{-1})

Soil Organic Carbon stock are calculated with the help of organic carbon and bulk density for each depth and presented in table 7. The average SOC stock for for maize-broadbean and ginger LUS at the surface was 27.09 (Mg ha^{-1}) and 24.75 (Mg ha^{-1}) respectively. Sub-surface soil recorded lower SOC stock as 25.53 (Mg ha^{-1}) and 21.55 (Mg ha^{-1}) for maize-broadbean and ginger LUS respectively. The maximum average SOC stock for maize-broadbean LUS at the surface was found both in Ruchung (32.00 Mg ha^{-1}) and minimum 19.19 Mg ha^{-1} at sub-surface soil of ginger LUS in Kateng The carbon stock was found to be decreasing with increase in soil depth which might be due to presence of more organic carbon in surface soil. Similar findings were reported by Kenye *et al.* (2019) where they revealed that highest SOC stock was found in the surface soil and decreased with increasing depth.

4 CONCLUSION

In the present study, it was observed that the soils of Namthang block, South Sikkim were moderate to strong in reaction irrespective of LUS. Surface soils are more fertile than sub-surface soils due to high organic carbon content and corresponding availability of primary and secondary nutrients. Substantial amount of soil organic carbon stock (SOC stock) was recorded in the soils of Namthang block under prevalent LUS; indicating a healthy soil. Though both LUS were conventionally managed; with locally available organic inputs especially FYM, maize-broadbean LUS was found to be superior over ginger LUSowing to enhanced soil fertility as well as biological parameters as evident from the result of present investigation. Thus, the maize-broadbean LUS that has been practiced by farmers of Namthang block of Sikkim can be recommended for large scale adoption in the state for maintaining soil health in a sustainable manner.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Table 2: Mechanical Analysis (%) of soils under different LUS

Land use system (LUS)								
Surface (0-0.20 m)								
Maize-Broadbean					Ginger			
Village	Sand(%)	Silt(%)	Clay(%)	Textural Class	Sand(%)	Silt(%)	Clay(%)	Textural Class
Bokrong	44.46	25.92	29.62	Clay Loam	45.12	26.02	28.86	Clay Loam
Kateng	45.12	26.15	28.73	Clay Loam	45.58	26.49	27.93	Clay Loam
Kolbung	42.54	27.14	30.32	Clay Loam	42.63	27.59	29.78	Clay Loam
Nalam	46.64	31.21	22.15	Loam	46.89	31.15	21.96	Loam
Ruchung	48.25	31.03	20.72	Loam	48.34	31.59	20.07	Loam
Sub-surface (0.20-0.40 m)								
Village	Sand(%)	Silt(%)	Clay(%)	Textural Class	Sand(%)	Silt(%)	Clay(%)	Textural Class
Bokrong	42.24	23.42	34.34	Clay Loam	43.49	24.89	31.62	Clay Loam
Kateng	43.84	25.12	31.04	Clay Loam	43.72	24.98	31.30	Clay Loam
Kolbung	40.59	25.97	33.44	Clay Loam	40.54	25.84	33.62	Clay Loam
Nalam	44.24	29.64	26.12	Loam	44.15	29.54	26.31	Loam
Ruchung	46.54	29.14	24.32	Loam	46.25	29.65	24.10	Loam

Table 3: Particle Density (g cm^{-3}) and Bulk Density (g cm^{-3}) under different LUS

Name of Villages	Land use system (LUS)							
	Maize-broadbean				Ginger			
	0-0.20 m		0.20-0.40 m		0-0.20 m		0.20-0.40 m	
	Particle Density (g cm^{-3})	Bulk Density (g cm^{-3})	Particle Density (g cm^{-3})	Bulk Density (g cm^{-3})	Particle Density (g cm^{-3})	Bulk Density (g cm^{-3})	Particle Density (g cm^{-3})	Bulk Density (g cm^{-3})
Bokrong	2.57	1.21	2.70	1.26	2.48	1.14	2.58	1.18
Kateng	2.67	1.25	2.79	1.30	2.65	1.22	2.71	1.26
Kolbung	2.53	1.16	2.64	1.21	2.49	1.14	2.57	1.19
Nalam	2.55	1.12	2.63	1.16	2.52	1.04	2.60	1.09
Ruchung	2.52	1.05	2.61	1.10	2.46	1.08	2.58	1.12
Overall	**2.57**	**1.16**	**2.67**	**1.21**	**2.52**	**1.12**	**2.61**	**1.17**

Table 4a: Total Organic Carbon, Organic Carbon and Soil pH under different LUS

Name of Villages	Land use system (LUS)											
	Maize-broadbean						Ginger					
	0-0.20 m			0.20-0.40 m			0-0.20 m			0.20-0.40 m		
	Total Organic Carbon (g kg^{-1})	Soil pH	Organic Carbon (g kg^{-1})	Total Organic Carbon (g kg$^{-1)}$	Soil pH	Organic Carbon (g kg^{-1})	Total Organic Carbon (g kg$^{-1)}$	Soil pH	Organic Carbon (g kg^{-1})	Total Organic Carbon (g kg$^{-1)}$	Soil pH	Organic Carbon (g kg^{-1})
Bokrong	14.64	5.4	11.67	13.69	5.5	9.63	13.53	5.6	11.20	12.64	5.6	8.96
Kateng	13.23	5.9	10.53	12.61	5.8	9.10	12.94	5.8	9.93	12.29	5.7	8.13
Kolbung	14.75	5.5	11.37	13.82	5.5	9.67	13.96	5.4	10.67	13.26	5.3	9.07
Nalam	14.52	6.1	12.10	13.64	5.8	10.07	13.84	5.7	11.13	13.24	5.7	9.93
Ruchung	15.54	5.7	12.80	14.48	5.3	10.23	14.52	5.8	12.07	13.92	5.7	10.03
Overall	**14.53**	**5.7**	**11.69**	**13.65**	**5.6**	**9.74**	**13.72**	**5.7**	**11.05**	**13.15**	**5.6**	**9.21**

Table 5: Avail. N, P_2O_5, and K_2O under different LUS

Name of Villages	Land use system (LUS)											
	Maize-broadbean						Ginger					
	0-0.20 m			0.20-0.40 m			0-0.20 m			0.20-0.40 m		
	Avail. N (kg ha^{-1})	Avail. P_2O_5, (kg ha^{-1})	Avail. K_2O (kg ha^{-1})	Avail. N (kg ha^{-1})	Avail. P_2O_5, (kg ha^{-1})	Avail. K_2O (kg ha^{-1})	Avail. N (kg ha^{-1})	Avail. P_2O_5, (kg ha^{-1})	Avail. K_2O (kg ha^{-1})	Avail. N (kg ha^{-1})	Avail. P_2O_5, (kg ha^{-1})	Avail. K_2O (kg ha^{-1})
Bokrong	324.62	22.26	239.99	309.05	19.62	211.37	318.39	21.38	233.58	305.48	18.31	209.66
Kateng	309.38	20.82	218.51	302.05	18.15	202.63	303.78	19.72	214.87	296.54	17.19	199.50
Kolbung	328.96	21.61	230.25	314.47	19.54	212.80	317.58	20.94	223.40	311.23	18.33	208.54
Nalam	374.67	23.25	250.49	329.11	20.93	229.93	342.87	21.37	242.02	319.86	19.74	221.72
Ruchung	386.09	24.14	267.59	329.85	21.22	234.98	364.06	22.16	260.37	323.29	20.14	231.57
Overall	**344.75**	**22.43**	**241.37**	**316.91**	**19.96**	**218.34**	**329.34**	**21.14**	**234.84**	**311.28**	**18.72**	**214.19**

Table 6: Avail. S, Exch. Mg and Exch. Ca under different LUS

Name of Villages	Land use system (LUS)											
	Maize-broadbean						Ginger					
	0-0.20 m			0.20-0.40 m			0-0.20 m			0.20-0.40 m		
	Avail. S (kg ha^{-1})	Exch. Mg [Cmol (P^{+}) kg^{-1}]	Exch. Ca [Cmol (P^{+}) kg^{-1}]	Avail. S (kg ha^{-1})	Exch.Mg [Cmol (P^{+}) kg^{-1}]	Exch. Ca [Cmol (P^{+}) kg^{-1}]	Avail. S (kg ha^{-1})	Exch.Mg [Cmol (P^{+}) kg^{-1}]	Exch. Ca [Cmol (P^{+}) kg^{-1}]	Avail. S (kg ha^{-1})	Exch.Mg [Cmol (P^{+}) kg^{-1}]	Exch. Ca [Cmol (P^{+}) kg^{-1}]
Bokrong	19.42	0.76	1.02	16.98	0.61	0.57	18.25	0.71	0.72	16.12	0.49	0.68
Kateng	17.13	0.58	0.58	16.23	0.56	0.54	17.29	0.68	0.79	14.89	0.57	0.78
Kolbung	20.12	0.65	1.17	18.16	0.42	0.85	19.26	0.65	1.13	17.36	0.40	0.81
Nalam	22.64	0.63	0.78	20.64	0.51	0.77	22.32	0.53	0.85	20.21	0.41	0.61
Ruchung	23.16	0.62	1.06	18.56	0.40	1.02	21.35	0.63	1.10	18.16	0.47	0.75
Overall	**20.54**	**0.65**	**0.92**	**18.12**	**0.50**	**0.75**	**19.64**	**0.64**	**0.92**	**17.35**	**0.47**	**0.73**

Table 7: SMBC, Dehydrogenase Activity and Carbon stock under different LUS

Name of Villages	Land use system (LUS)											
	Maize-broadbean						Ginger					
	0-0.20 m			0.20-0.40 m			0-0.20 m			0.20-0.40 m		
	SMBC (µg g^{-1})	Dehydrogenase Activity (µg TPF g^{-1} hr^{-1})	Carbon stock (Mg ha^{-1})	SMBC (µg g^{-1})	Dehydrogenase Activity (µg TPF g^{-1} hr^{-1})	Carbon stock (Mg ha^{-1})	SMBC (µg g^{-1})	Dehydrogenase Activity (µg TPF g^{-1} hr^{-1})	Carbon stock (Mg ha^{-1})	SMBC (µg g^{-1})	Dehydrogenase Activity (µg TPF g^{-1} hr^{-1})	Carbon stock (Mg ha^{-1})
Bokrong	359.13	8.52	24.51	252.18	5.64	21.38	300.76	7.94	23.30	216.85	4.85	19.47
Kateng	278.84	6.76	25.48	195.41	4.89	22.93	233.56	5.72	22.64	177.66	4.32	19.19
Kolbung	355.36	9.67	26.38	246.63	5.96	23.40	322.25	9.14	24.33	207.63	5.26	21.59
Nalam	404.95	12.14	27.10	315.64	6.13	23.36	370.83	10.36	24.04	287.11	5.67	22.24
Ruchung	429.66	14.56	32.00	319.24	6.41	26.60	397.38	13.41	29.45	302.25	5.93	25.28
Overall	**365.56**	**10.23**	**27.09**	**265.72**	**5.74**	**25.53**	**324.97**	**9.34**	**24.75**	**238.26**	**5.23**	**21.55**

Table 8: Correlation co-efficient between different soil properties at the depth of 0-0.2m for maize-broadbean landuse system.

	Sand	silt	clay	pH	O.C	T.O.C	B.D	P.D	N	P	K	S	Ex. Ca	Ex. Mg	SMBC
Sand	1.000														
Silt	0.771**	1.000													
Clay	-0.929**	-0.952**	1.000												
pH	0.368	0.355	-0.384	1.000											
O.C	0.637*	0.760**	-0.748**	-0.089	1.000										
T.O.C	0.348	0.559*	-0.492	-0.303	0.821	1.000									
B.D	0.346	0.291	-0.336	0.281	-0.168	0.058	1.000								
P.D	0.334	0.462	-0.429	0.301	-0.286	0.036	0.528*	1.000							
N	0.780**	0.963**	-0.935**	0.254	0.516*	0.567*	0.247	0.446	1.000						
P	0.733**	0.830**	-0.835**	0.003	0.563*	0.625*	0.197	0.325	0.617*	1.000					
K	-0.849**	0.826**	0.768**	-0.004	0.602*	0.618*	0.166	0.332	0.597*	0.558*	1.000				
S	0.575	0.865**	-0.779**	0.121	0.587*	0.549*	0.191	0.425	0.589*	0.567*	0.619*	1.000			
Ex. Ca	0.693**	0.861**	-0.834**	0.132	0.609*	0.612*	0.204	0.281	0.423	0.870**	0.890**	0.803**	1.000		
Ex.Mg	-0.212	-0.239	0.241	-0.305	0.077	0.214	0.337	-0.227	-0.066	0.071	0.047	-0.117	0.056	1.000	
SMBC	0.578*	0.826**	-0.758**	-0.029	0.941**	0.874**	0.058	0.344	0.784**	0.928**	0.947**	0.939**	0.872**	0.067	1.000
DHA	0.713**	0.914**	-0.874**	0.052	0.895**	0.800**	0.294	0.265	0.724**	0.931**	0.948**	0.906**	0.929**	-0.110	0.938**

* = Significant at 5% level of significance, ** = Significant at 1% level of significance

Ex Ca= Exchangeable Calcium, Ex Mg= Exchangeable Magnesium, SMBC= Soil Microbial Biomass Carbon,
DHA= Dehydrogenase Activity

Table 9: Correlation co-efficient between different soil properties at the depth of 0.2-0.4m for maize-broadbean landuse system.

	sand	silt	clay	pH	O.C	T.O.C	B.D	P.D	N	P	K	S	Ex. Ca	Ex.Mg	SMBC
sand	1.000														
Silt	0.643*	1.000													
clay	-0.888**	-0.923**	1.000												
pH	-0.101	0.009	0.046	1.000											
O.C	0.444	0.711**	-0.649**	-0.229	1.000										
T.O.C	0.232	0.474	-0.401	-0.445	0.777	1.000									
B.D	0.526*	0.536*	-0.586*	0.109	-0.418**	-0.335	1.000								
P.D	-0.222	-0.303	0.293	0.016	-0.256	-0.247	0.615*	1.000							
N	0.530*	0.869**	-0.788**	-0.238	0.572*	0.664**	0.611*	-0.024	1.000						
P	0.461	0.684**	-0.642**	0.256	0.587*	0.722**	0.627*	0.258	0.532*	1.000					
K	-0.854**	0.872**	0.658**	0.232	0.608*	0.731**	0.607*	0.011	0.581*	0.574*	1.000				
S	0.236	0.774**	-0.583*	0.222	0.696**	0.482	0.508	0.057	0.564*	0.589*	0.624**	1.000			
Ex. Ca	0.236	0.624*	-0.493	-0.335	0.541*	0.698**	0.436	0.259	0.603*	0.614*	0.814**	0.665*	1.000		
Ex.Mg	-0.189	-0.529*	0.412	0.286	-0.446	-0.453	-0.535	0.224	-0.464	-0.370	-0.466	-0.323	0.496	1.000	
SMBC	0.515*	0.807**	-0.743**	0.187	0.912**	0.733**	0.571*	0.155	0.814**	0.910**	0.972**	0.814**	0.844**	-0.377	1.000
DHA	0.286	0.622*	-0.517*	-0.313	0.856**	0.797**	0.537*	0.059	0.793**	0.773**	0.820**	0.604*	0.824**	-0.522*	0.833**

* = Significant at 5% level of significance, ** = Significant at 1% level of significance

Ex Ca= Exchangeable Calcium, Ex Mg= Exchangeable Magnesium, SMBC= Soil Microbial Biomass Carbon, DHA= Dehydrogenase Activity

Table 10: Correlation co-efficient between different soil properties at the depth of 0-0.2m for ginger landuse system.

	sand	silt	clay	pH	O.C	T.O.C	B.D	P.D	N	P	K	S	Ex. Ca	Ex.Mg	SMBC
sand	1.000														
Silt	0.705**	1.000													
clay	-0.906**	-0.939**	1.000												
pH	0.535*	0.230	-0.397	1.000											
O.C	0.581**	0.659**	-0.675**	0.123	1.000										
T.O.C	0.352	0.722**	-0.602*	-0.153	0.800	1.000									
B.D	0.237	0.344	-0.320	0.582	-0.448	-0.338	1.000								
P.D	0.223	0.427	-0.363	0.059	-0.248	-0.020	-0.157	1.000							
N	0.656**	0.807**	-0.800**	-0.042	0.614*	0.660**	0.587*	0.215	1.000						
P	0.436	0.628*	-0.586*	0.178	0.598*	0.832**	0.200	0.122	0.622*	1.000					
K	-0.860**	0.821**	0.762**	0.202	0.547*	0.800**	0.251	0.055	0.637*	0.587*	1.000				
S	0.510*	0.886**	-0.777**	0.089	0.589*	0.619*	0.088	0.511	0.549*	0.576*	0.621*	1.000			
Ex. Ca	0.679**	0.846**	-0.835**	-0.015	0.624*	0.777**	0.382	0.131	0.594*	0.827**	0.714**	0.819**	1.000		
Ex. Mg	-0.325	-0.622*	0.529*	-0.209	-0.153	-0.390	-0.014	-0.459	-0.442	-0.268	-0.335	-0.502	-0.307	1.000	
SMBC	0.513*	0.882**	-0.776**	0.009	0.852**	0.891**	0.233	0.214	0.823**	0.852**	0.905**	0.871**	0.871**	-0.503	1.000
DHA	0.579**	0.873**	-0.802**	0.036	0.874**	0.921**	0.373	0.066	0.840**	0.838**	0.936**	0.775**	0.900**	-0.419	0.967**

* = Significant at 5% level of significance, ** = Significant at 1% level of significance
Ex Ca= Exchangeable Calcium, Ex Mg= Exchangeable Magnesium, SMBC= Soil Microbial Biomass Carbon,
DHA= Dehydrogenase Activity

Table 11: Correlation co-efficient between different soil properties at the depth of 0.2-0.4m for ginger landuse system.

	Sand	silt	clay	pH	O.C	T.O.C	B.D	P.D	N	P	K	S	Ex. Ca	Ex.Mg	SMBC
Sand	1.000														
Silt	0.606*	1.000													
Clay	-0.877**	-0.914**	1.000												
pH	0.524*	0.188	-0.381	1.000											
O.C	0.446	0.898**	-0.770**	0.006	1.000										
T.O.C	0.337	0.751**	-0.626*	-0.054	0.797**	1.000									
B.D	0.577*	0.552*	-0.628*	0.502	-0.433	-0.374	1.000								
P.D	0.069	0.325	-0.231	0.068	-0.208	-0.279	0.547*	1.000							
N	0.370	0.842**	-0.698**	-0.038	0.519*	0.772**	0.582**	0.270	1.000						
P	0.514*	0.893**	-0.802**	0.038	0.564*	0.765**	0.487	0.113	0.598*	1.000					
K	-0.883**	0.916**	0.646**	0.114	0.591*	0.831**	0.594*	0.123	0.612*	0.543*	1.000				
S	0.177	0.772**	-0.556*	0.129	0.542*	0.475	0.447	0.487	0.586*	0.556*	0.618*	1.000			
Ex. Ca	0.241	0.753**	-0.578**	-0.085	0.612*	0.827**	0.520*	0.231	0.431	0.871**	0.856**	0.766**	1.000		
Ex. Mg	0.213	-0.399	0.132	0.457	-0.633*	-0.533*	0.183	-0.160	-0.457	-0.482	-0.417	-0.495	0.552*	1.000	
SMBC	0.648**	0.955**	-0.908**	0.179	0.946**	0.789**	0.621*	0.265	0.873**	0.937**	0.978**	0.738**	0.842**	-0.420	1.000
DHA	0.363	0.867**	-0.709**	-0.126	0.921**	0.872**	0.474	0.171	0.914**	0.928**	0.920**	0.735**	0.928**	-0.560*	0.898**

* = Significant at 5% level of significance, ** = Significant at 1% level of significance
Ex Ca= Exchangeable Calcium, Ex Mg= Exchangeable Magnesium, SMBC= Soil Microbial Biomass Carbon, DHA= Dehydrogenase Activity