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Soil Organic Carbon and Total Nitrogen Changes in Croplands Converted to Apple Orchard System in South Kashmir Temperate Himalayas

S.A. BANGROO[1*], T. MUBARAK[2] AND H. ITOO[3]

[1] *Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar 190025, J&K, India*
[2, 3] *Krishi Vigyan Kendra, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Kulgam 192223 J&K, India*
Emails: [1] shalzsab@gmail.com, shabir@skuastkashmir.ac.in; [2] drtasneem.mubarak@gmail.com;
[3] hamidbhu@gmail.com
*Corresponding author

ABSTRACT

Land use and management change has profound effect on the soil organic carbon (SOC) and soil total nitrogen (STN) which are the most important indicators of soil health. There has been little research on the effect of paddy cropland conversion to apple - based orchard system in Kashmir temperate Himalayas. This study aimed to examine the effects of land use conversion from paddy to apple orchard system on SOC and STN. Soil samples at three depths 0-15 cm, 15-30 cm and 30-45 cm were collected and analyzed for SOC and STN from three land use systems: paddy crop system (PC), apple orchard system (AO) and apple intercropping system (AI). Both SOC and STN concentration decreased with the depth. About 75% of both SOC and STN concentration is present in first 30 cm. The SOC stocks at 0–45 cm depth were 4.32, 5.47, and 5.87 kg m^{-2} for PC, AO and AI systems, respectively. The STN stocks at 0–50 cm depth were 0.55, 0.64 and 0.72 kg m^{-2} for PC, AO, and AI systems, respectively. These results indicate that the stocks of SOC and STN in PC and AO were lower than that of AI. The findings demonstrate that apple intercropping system can potentially maintain more SOC and STN stocks than paddy crop and apple monoculture system.

Key Words: Soil Organic Carbon; Soil Total Nitrogen; Paddy Crop; Apple Orchard; Land Use Change

INTRODUCTION

Recommended management practices including adaptive agricultural activities are prerequisite to sustainable land management under changing climate (Lal et al. 2011). Research on impacts of intercrop land conversions occurring under various socio-economic and climatic factors is important to identify the sustainability of the systems (Eaton etal. 2008, Smith 2008). Consequently, land use/cover change is an important theme of climate change research, which underlines the understanding of SOC responses to land cover dynamics. In general, agro-forestry and/or intercropping system offer appreciable services of ecological balance besides improving soil quality, crop productivity, carbon sequestration capability and restoration of degraded lands (Bangroo et al. 2013). The soil organic carbon (SOC) and soil total nitrogen (STN) concentration are the immediate measures of soil quality (IPCC 2007). Both, SOC and STN concentrations have been used for comparison of soil quality and carbon storage capacity under various land uses. SOC maintains soil quality by supplementing nutrients, improving cation exchange capacity (CEC), supporting biodiversity, and improving soil aggregation and water-holding capacity (Bationo et al. 2007).

Carbon content in the soil (1 m depth) is almost twice the biotic pool or atmospheric carbon (Lal 2004, Smith 2008). Therefore, even slight changes in the SOC pool can significantly affect the global carbon cycle, climate, and soil properties (Powlson et al. 2011). It has been reported that converting natural vegetation to arable land effects soil carbon storage and fluxes (Islam and Weil 2000, Murty et al. 2002, Osher et al. 2003, Evrendilek et al. 2004, Jing-Cheng et al. 2004, Powers 2004, Yimer et al. 2007, Awiti et al. 2008, Wang et al. 2008, Mun˜oz-Rojas et al. 2012, Demessie et al. 2013). This invariably result in SOC and STN losses due to change in carbon biomass inputs, accelerated soil organic matter decomposition, and loss of particulates through mechanical clearing, water, and wind (Powlson et al. 2011). However, terrain parameters (elevation and slope), soil type, climate, soil microbial environment, initial C and N cycling, and land management practices are the driving factors of magnitude and rate of SOC changes in land use conversions.

District Kulgam of Jammu and Kashmir state of India, covering a total area of 410 km^2, has been witnessing the unprecedented land use conversion from paddy crop to apple orchard system especially in the middle altitude ranges from 1700 to 1850 m above sea level. This conversion mainly economic and social factor driven has been unscientific and without taking into the consideration the land capability. It has resulted in poor production, diseases and fertility decline. As the land use conversions is companied by changes in runoff, drainage, soil erosion, soil temperature, and SOC and STN pools stored in soil (Oelbermann et al. 2006, Peichl et al. 2006). It is therefore important to identify and quantity the dynamics of SOC and STN to establish the proper management techniques under various land use conversions. The land use conversions in district Kulgam has not been documented so far neither the SOC and STN dynamics has been attempted under such conversions. This study aimed 1) to determine the SOC and STN stocks in the soil and C:N ratio, and 2) to identify the changes in SOC and STN following land use conversion from paddy crop system to an apple orchard system.

MATERIAL AND METHODS

Site Description and Experimental Design

The study was conducted in the district Kulgam, which is located in the south Kashmir valley (33° 38' 40.42" N 75° 01' 9.23" E). The area is characterized by a cold temperate climate, with a mean annual temperature of 13.5 °C and an annual precipitation of approximately 809 mm. During late 1990s extensive paddy lands have been converted into apple orchards and the practice is still followed.

To examine the effects of this conversion on SOC and STN soil samples were collected from three sites adjacent to each other: 1) paddy crop system (PC), 2) paddy crop land converted to apple orchard system (AO), and 3) paddy crop land converted to apple orchard system with intercropping system (AI). Both the apple orchards were 15 years' old and of same variety.

Soil Sampling

Soil samples were collected in October after the harvest of the crop. In apple orchards soil samples were collected under the canopy of tree. In each land use type, simple random sampling was followed to collect soil samples at a depth of 0-15, 15-30, and 30-45 cm. Soil samples from each transect layer were mixed to form a composite sample and brought to the laboratory. Soil samples were processed, air-dried and ground to pass through a 2-mm sieve. The remaining gravel content was also weighted. Soil bulk density (ρ_b) was measured by the core method (Blake and Hartage 1986) using a 3cm diameter and 10cm deep core, particle size distribution by the International Pipette Method (Piper 1966), soil pH was measured by glass electrode pH meter (Jackson 1973). Nitrogen was determined by Kjeldahl method (Bremner 1996) and OC by Walkley and Black method (Nelson and Sommers 1982). Soil porosity was calculated by assuming a particle density of 2.65 g cm^{-3}. Uniform soil depths were used for a comparison between studied soils in order to avoid variation in results if sampling is done by genetic layers in entire soil profile (Bangroo et al. 2017) and was restricted to only 45 cm due to shallow bedrock in majority of the cases.

Data analysis

For each profile the layers, soil organic carbon stock (SOCS) and soil total nitrogen stock (STNS) were calculated by the following equations:

$$SOCS = \frac{\sum_{i=1}^{n} SOCC_i \, x \, \rho_{bi} x \, l_i (1 - \partial_i)}{100} \quad \text{(Eq. 1)}$$

$$STNS = \frac{\sum_{i=1}^{n} STNC_i \, x \, \rho_{bi} x \, l_i (1 - \partial_i)}{100} \quad \text{(Eq. 2)}$$

where, SOCS and STNS are the stocks of SOC and STN of all the soil sections considered (kg m^{-2}),respectively;

i is the i^{th} layer and n is the total no. of soil layers in a soil profile; $SOCC_i$ and $STNC_i$ are the SOC and STN concentrations (g Kg^{-1}) of the i^{th} layer, respectively; ρ_{bi} and l_i are the bulk density (g cm^{-3}) and the thickness (cm) of the i^{th} soil layers, respectively; ∂_i is the proportion (%) of course (>2mm) fragments in the i^{th} layer (IPCC 2003). All statistical analyses were performed using SPSS 20.0to examine the effects of land use patterns on soil physical and chemical properties. One-way analysis of variancewas used to analyze statistical significance at P=0.05.

RESULTS AND DISCUSSION

Analytical Results

Soils were sandy loam in texture and soil pH ranged from 5.6 to 6.2 which in increases with the depth. The soil ρ_b plays a crucial role in the assessment of SOC contents (Howard et al. 1995). Across three land use systems, the soil bulk density (ρ_b) at 0-10 cm was higher than in both AO and AI (Table 1). For example, the ρ_b of PC was 11 and 13 % higher than those of AO and AI at 0-15 cm, respectively. The three land use systems exhibited nearly the same ρ_b at a depth of 30-45 cm and in all cases soil ρ_b increased with the soil depth (Table 1).

Soil porosity is an important indicator of soil structure influencing soil storage (Martin et al. 2017). In this study, total porosity differed in the 0–15 cm layer significantly under three land use types (P<0.05). However, beyond 15 cm depth, the variation among three land use systems decreased non significantly(P>0.05). Highest porosity was found in surface layersof AI and AO, which was in contrast to the dynamics of bulk density. In general, total porosity decreased with the depth in all the three land uses.

The study reveals that land use management and past land history has a remarkable influence on soil structure, porosity vis-à-vis surface (0-15 cm) soil bulk densities. Tillage intensity effects and differential organic matter composition produced different soil particles and aggregate bindings, also results in various soil bulk densities and levels of porosity (Deng et al. 2013). SOC besides improving the soil structure by promoting soil aggregate formation has a significant influence on the soil porosity characteristics (Canqui et al. 2006).

Impact of Land Use on SOC Concentration

SOC concentrations variation across the different land use types and depth is shown in Table 1. In general, SOC decreased with the depth in all three land use systems. The highest SOC concentration occurred in the surface layer (0-15 cm) of the AI and AO systems and varied from 14.71 to 11.45 g kg^{-1}. The lowest SOC concentration was noted in the 30–45 cm layer of PC (3.89 g kg^{-1}). Compared with PC, AO and AI generally exhibited greater SOC in each layer and the differences were statistically significant at depths of 15–30 and 30–45 cm (P<0.05). For example, SOC in AI was 43, 44, and 55 %

Table 1. Bulk density, soil organic carbon (SOC) concentration, soil total N (STN) concentration, and C/N ratio (mean±standarderror) at different soil layer depths for paddy crop system (PC), apple orchard system (AO), and apple intercropping system (AI)

Soil Depth	Land use	BD (Mg m^{-3})	Total Porosity (m^3 m^{-3})	SOC (g kg^{-1})	STN (g kg^{-1})	C/N
0-15	PC	1.45±0.03 $^{a\ A}$	0.45±0.03 $^{a\ A}$	08.32±0.76 $^{a\ A}$	1.17±0.06 $^{b\ A}$	7.11±0.73 $^{a\ AB}$
	AO	1.31±0.04 $^{a\ A}$	0.51±0.02 $^{a\ A}$	11.45±0.25 $^{a\ A}$	1.52±0.04 $^{b\ A}$	7.53±0.16 $^{a\ A}$
	AI	1.28±0.06 $^{a\ B}$	0.52±0.01 $^{a\ B}$	14.71±0.52 $^{a\ A}$	1.56±0.07 $^{a\ A}$	9.43±0.36 $^{a\ AB}$
15-30	PC	1.48±0.05 $^{a\ A}$	0.44±0.01 $^{a\ A}$	06.87±0.36 $^{b\ A}$	1.10±0.04 $^{b\ B}$	6.24±0.15 $^{a\ A}$
	AO	1.39±0.01 $^{b\ A}$	0.47±0.01 $^{b\ A}$	10.47±0.24 $^{a\ B}$	1.41±0.05 $^{a\ A}$	7.43±0.27 $^{a\ A}$
	AI	1.35±0.02 $^{a\ A}$	0.49±0.03 $^{a\ A}$	12.27±0.33 $^{a\ A}$	1.53±0.06 $^{a\ A}$	8.02±0.32 $^{a\ A}$
30-45	PC	1.78±0.05 $^{b\ A}$	0.33±0.02 $^{b\ A}$	03.89±0.27 $^{b\ B}$	0.69±0.05 $^{a\ C}$	8.45±0.41 $^{b\ B}$
	AO	1.42±0.03 $^{c\ A}$	0.46±0.02 $^{c\ A}$	06.34±0.18 $^{a\ C}$	0.72±0.03 $^{a\ B}$	8.56±0.39 $^{a\ A}$
	AI	1.38±0.04 $^{a\ A}$	0.48±0.03 $^{a\ A}$	08.64±0.31 $^{a\ B}$	0.78±0.03 $^{a\ B}$	9.29±0.23 $^{ab\ B}$

Values followed by different lowercase letters are significantly different between three land management systems for each soil layer atP<0.05. Values followed by different uppercase letters are significantly different between soil layers for each land use system at P<0.05

higher than that in PC, whereas SOC in AO was 27, 34, and 39 % higher than that in PC for 0–15, 15–30, and 30–45 cm depths, respectively. Across the entire soil profile of 0-45 cm, no significant difference in SOC was observed between AI and AO ($P>0.05$). This result showed that the conversion of paddy crop to apple orchard system increased the SOC concentration profile, whereas intercropping may maintain SOC effectively.

The variation in SOC distribution across the land use systems indicate the effect of land management practices. Higher SOC concentration the top layer could be attributed to higher vegetation density and culturally active layer. Higher application of fertilizers and manures in AI and AO also contribute to SOC concentration as fertilizer addition enhances SOC sequestration (Liang et al. 2016). Moreover, leguminous plants in the AI of this study area also contributed to the SOC concentration differences as some researchers found that the N_2-fixing species resulted in an increase of SOC in the system (Kass et al. 1997). Unlike the AI, the PC reduced SOC concentration across the 0–45 cm profile. The decreased SOC in PC can be attributed to the lack of added fertilizer, extensive tillage, presence of hardpans in sub layer, and less understory vegetation (Jandl et al. 2007). Tillage directly disrupts soil aggregation and microbial activities, thereby affecting aggregate stability and SOC decomposition (Lal 2004, Powers 2004, Batlle-Aguilar et al. 2011).

In the present study, non-significant change observed in the SOC between AI and AO, could be associated with the presence of rich understory vegetation. Our results were in agreement with Lee and Jose (2003), Oelbermann et al. (2006), and Maoet al. (2012) who argued that the observed intercropping with or without legumes did not significantly alter the SOC level. Furthermore, significant difference occurs under longer periods of land management (Birch-Thomsen et al. 2007, Yimer et al. 2007). Besides this, different climate conditions, soil type, crop and species diversity, and cultural practices used in different studies could contribute to the inconsistent results in terms of SOC accumulation (Zhang et al. 2013). In the present study, the slower SOC turnover and C stabilization in the cold temperate region and relatively low organic matter input at the early stage of the orchard establishment system may explain the slight change in SOC after paddy cropland was converted to apple orchard system (Lee and Jose 2003, Oelbermann et al. 2004).

Impact of Land Use on STN Concentration

STN concentrations varied with the soil depth and land use system (Table 1). Similar pattern was observed in STN variation as compared to SOC variation across different land use with the depth are highly related.

Significant differences in STN was observed in the top layer (0-15 cm) across all land use types as compared to sub-layers (15-30 cm). However, below 30 cm similar STN concentration under three land use types were observed (Table 1), indicating that the effect of land use conversion on soil STN was mainly restricted to the topsoil layer.

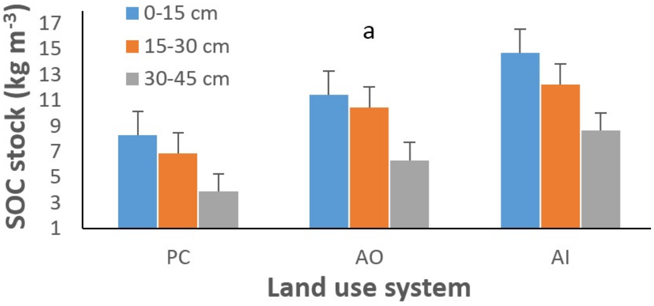
Compared with AI and AO, PC presented the lowest STN concentration across the measured profile. Higher STN in AI and AO could be attributed to the presence of the N_2-fixing plants, higher litter input, high understory vegetation, and fertilizer and manure addition. Generally, the N_2 fixation capacity of leguminous plants planted in AI and rich understory vegetation in AO increases the soil N level as compared to PC. The application of N fertilizer application in apple orchards also increased the concentration of STN in the soil (Diekow et al. 2005, Ouédraogo et al. 2006, Smal and Olszewska 2008). Besides, the variation of soil N losses under different land uses with soil erosion and leaching may also cause the differences.

Impact of Land Use on Soil C/N Ratios

The soil C/N ratio has considerably been developed and used as a sensitive indicator for the assessment of soil quality and C and N nutrition balance in soils. The C/N ratio is related to the patterns of nitrogen immobilization and mineralization during organic matter decomposition by micro-organisms (Moscatelli et al. 2007). High soil C/N ratio slowdowns the decomposition rate of organic matter and organic nitrogen by limiting the soil microbial activity, whereas low soil C/N ratio accelerates the process of microbial decomposition of organic matter and nitrogen, which is not conducive for carbon sequestration. Table 2, shows the soil C/N ratios existing across three land uses systems and soil depth. The C/N in all the systems was near to 10, which was far below the critical ratio (25) at which net N mineralization is considered to occur (Chapin et al. 2002). The study illustrated that the net mineralization rates of organic carbon are higher than those of organic N compounds, which indicates that the current incorporation level of organic carbon into the soil was low (Yimer et al. 2007). There was not much variation in the C/N ratio along the depth. At the surface layer of 0-15 cm, the soil C/N ratios ranged from 7.11 to 9.43 and no significant difference was found under three land management practices (P>0.05). This indicated that C/N ratio is slightly affected by the land management practices although significant difference was found between PC and AI. The results are in consistent with the conclusions of Lou et al. (2012) and Lozano-Garcia and Parras-Alcantara (2013). However, it also depends on the nitrogen contents of the litter itself (Swift et al. 1979). Therefore, it can be concluded that the soil C/N ratio is slightly affected by land use systems, soil disturbance, N sources, and time period from land use conversion. To maintain the steady growth of soil C/N ratio, it is advocated that the addition of carbon be paid more attention than the input of nitrogen, such as incorporating crop residues into soil and inputting more organic fertilizers into soils for future farming practices.

Impact of Land Use on SOC and STN Stocks

The SOC and STN stocks varied significantly in different land use systems(P=0.05) (Figure 1 and Table 2) especially in the top soil layer (0-15 cm). This variation was even significant at 30-45 cm for PC as compared to AI and AO, which illustrates the impact of land use conversion on SOC stocks. However, no such significant variation at 30-45 cm depth was observed for STN stocks, which suggests least effect of land use conversion on STN stocks at sub-layers. In measured 0–45 cm soil layer, the amounts of SOC and STN stocks varied from 4.32–5.87 and 0.55–0.72 kg $m^2$with respect to land use types (Table 2). The SOC and STN stocks of AI and AO were remarkably larger at the measured 0–45 cm profile than those of the PC system.In the present study, the decrease in SOC stock at 0–45 cm depth was 1.55 kgm^{-2} in the PC compared with the AI, whereas the levels of SOC stock remained steady in the AO. In contrast to AI, the levels of STN decreased by 0.17 kg m^{-2} in the PC, but the AI system remained steady. It can be therefore concluded that the intercropping system (AI) significantly prevents SOC and STN losses and enhance SOC and STN sequestrations in contrast to the conversion from paddy cropland to apple monoculture. Besides, there are other numerous factors as reported by many researchers which effect the SOC and STN stocks changes like vegetation type, soil management practices, topography, addition of inorganic fertilizer, biological N_2 fixation, soil temperature and moisture which effect nutrient cycling in the ecosystem and hence the SOC and STN storage. Moreover, wind and water erosions through runoff and sediment transport also contribute to the differences in SOC and STN losses (Van Oost et al. 2005, Novara et al. 2011). Therefore, our result indicated that the proper management of AI systems could be more beneficial to store substantial soil C and N than AO system.



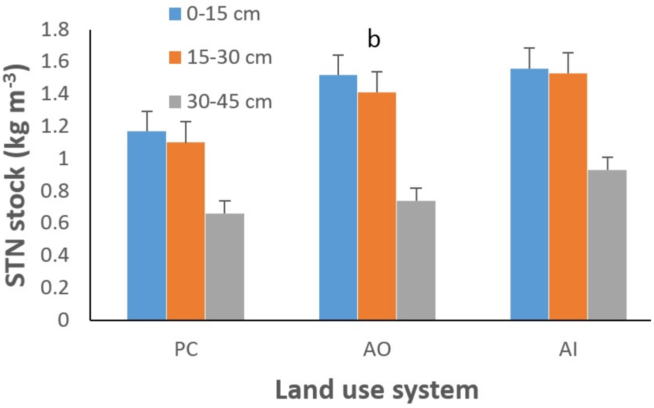


Figure 1. **(a)** Soil organic carbon (SOC) and **(b)** soil total nitrogen (STN) stock distribution in paddy crop system (PC), apple orchard system (AO) and apple intercropping system (AI) at three depths of soil horizon (0-15 cm, 15-30 cm, and 30-45 cm)

Table 2. Soil organic carbon (SOC) and soil total nitrogen (STN) stocks (kg m^{-2}; mean ±standard error) in 0-45 cm depth for paddy crop system (PC), apple orchard system (AO), and apple intercropping system (AI)

Stocks	PC	AO	AI
SOC	4.32 ±0.25 b	5.47 ±0.07 a	5.87 ±0.09 a
STN	0.55 ±0.02 b	0.64 ±0.02 a	0.72 ±0.03 a

Values followed by different lower case letters within rows are significantly different between three land management systems at P<0.05

In the present study, the calculated SOC stocks at 0-45 cm depth under PC, AI, and AO were 4.32, 5.47, and 5.87 kg m^{-2}, respectively. Difference in SOC and STN stocks across different regions and same land use and management system could be attributed to difference in topography and climate.

CONCLUSIONS

This study investigated the effects of paddy cropland conversion to apple orchard and apple intercropping system on SOC and STN. The results indicated that the conversion of paddy cropland to apple intercropping system did not significantly change the SOC and STN stocks after 7 years of continuous management. However, the conversion of paddy cropland to apple orchard significantly decreased the SOC and STN stocks. This result indicated that intercropping between apply tree rows is more favorable than apply monoculture for SOC and STN maintenance.

Although limited information exists on the effects of agroforestry systems on soil C and N sequestrations in temperate regions, the results of this study showed that combining apple tree with crop was a more viable option to maintain SOC and STN stocks compared with converting from paddy cropland to apple monoculture. Although a longer period might be required to fully determine the effects of agroforestry systems on soil quality improvement at temperate regions, our study suggests that intercropping is a sustainable practice and can potentially maintain considerable SOC and STN stocks in the vegetation restoration.

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