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CHANGES IN SOIL ORGANIC CARBON CONCENTRATION IN TROPICAL RAINFED CROPLANDS : EFFECT OF CHANGES IN LAND USE PATTERN AND APPLICATION OF VARIOUS SOIL AMENDMENTS

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Abstract

Maintenance of soil organic carbon is essential for the long-term sustainability of tropical rainfed croplands. Land use changes involving conversion of grassland to croplands and also agricultural management strategies exert influence on the dynamics of soil organic carbon. The present study was conducted to assess the effect of conversion of grassland to cropland and influence of application of exogenous inputs of varying C: N ratio on the concentration of soil organic carbon across the soil profile (0-15 and 15-30 cm) in tropical rainfed rice based cropping system. This experiment was designed to supply equivalent amount of nitrogen (120 kg N^{-1} ha^{-1}), through various exogenous soil inputs differing in chemical composition i.e. chemical fertilizer and three organic inputs viz. *Sesbania aculeata* shoot (high quality resource input), wheat straw (low quality resource input) and wheat straw + *Sesbania aculeata* shoot (combination of low quality and high quality resource input). Concentration of soil organic carbon was decreased after conversion of grassland to cropland at both the soil depths. The trend of soil organic carbon concentration through the soil profile was grassland > wheat straw > wheat straw + *Sesbania aculeata* shoot > *Sesbania aculeata* shoot > chemical fertilizer > control. Soil organic carbon concentration decreased through the soil profile across grassland and all the cultivated plots. Among the cultivated plots concentration of soil organic carbon was highest in the wheat straw and wheat straw + *Sesbania aculeata* shoot treatments and was comparable to grassland. It may be concluded that conversion of grassland to cropland results in significant loss of soil organic carbon concentration not only at upper layer but also at lower layer of soil. Organic inputs applied either singly or in combination are better as compared to chemical fertilizers for maintaining soil fertility in terms of soil organic carbon at both the soil depths in tropical rainfed croplands.
Key words: Soil organic carbon, tropical, rainfed, grassland, cropland, high quality, low quality, soil profile.

Introduction

The increasing level of atmospheric carbon dioxide concentration due to anthropogenic activities is expected to reach 550 ppm before the end of this century. Increase in concentration of greenhouse gases particularly carbon dioxide being the major greenhouse gas has resulted in global climate change (IPCC, 2013; IPCC, 2018). The impacts of global climate change have been observed not only on the structure and function of ecosystem but also on human health and well being. The principal mitigation strategies for the global climate change include reduction of emissions of greenhouse gases to atmosphere, carbon sequestration in soil amongst others (Sanchez, 2019). Many initiatives have been taken to decrease the concentration of carbon dioxide in atmosphere. One such initiative is '4 per mille' concept that aims to increase soil organic carbon stocks by 0.4 % per year to compensate for global emissions of greenhouse gases by anthropogenic activities to mitigate climate change and land degradation (Lal, 2016; Minasny *et al.*, 2017).

Soil organic carbon sequestration is the net removal of atmospheric carbon dioxide by plants and storing carbon in soil in form of soil organic matter i.e., transferring atmospheric carbon dioxide into resistant pools with slow turnover and storing it firmly so that it is not released immediately (Lal, 2004). Soil organic matter contains 50 to 58% carbon and is a complex mixture of organic compounds including particulate organic humus and charcoal along with living microbial biomass and fine plant roots with different turnover times (Nelson and Sommers, 1982; Christensen, 2001). Although soil is the largest terrestrial pool of organic carbon yet the potential of soil to store organic carbon is affected by many factors including soil type, climatic conditions, parent material, topography, soil moisture, texture, land use and management (Wiesmeier *et al.*, 2019).

Changes in land use pattern are considered to be the most potent factor of soil organic carbon changes (Poeplau *et al.*, 2011; Viscarra-Rossel *et al.*, 2014). The soil organic carbon pool is comprised of relatively stable pool which is not involved in the mineralization process and depends on the soil type, climate, land-use history and the landscape position; and the labile pool which depends on the management. The change in the soil organic carbon pool because of changes in land use patterns and management is mostly because of changes in the labile fraction. A strong link is present between the concentration of the labile fraction of the soil organic carbon and soil quality. Tropical soils contain approximately 26% of the soil organic carbon stored in the soils of the world (Batjes, 1996; Mishra and Mapa, 2019). Due to land misuse and mismanagement through conversion of natural ecosystem to cropland, urbanization or other developmental activities tropical soils have lost 60 to 80 per cent of their soil organic carbon pool (Lal, 2004). Approximately 52% land is covered by agricultural systems (Sanchez, 2019). Improper management of agricultural soils causes soil degradation which in turn decreases crop productivity resulting in reduction in organic inputs into the soil thus causing depletion of soil organic carbon pool.

The sink capacity of tropical soils for sequestering atmospheric carbon dioxide can be enhanced by adoption of better management practices on agricultural lands and degraded soils (Lal, 2006; Paustian *et al.*, 2016; Luca *et al*., 2018). Soil organic carbon storage in agricultural soils is gaining increasing importance because of its significant impacts on atmospheric carbon sequestration and benefits for crop productivity. Maintenance of soil organic carbon is essential for the long-term sustainability of rainfed croplands as it would increase aggregate stability, nutrient supply, water retention, microbial activity and enhances soil fertility and productivity (Lal, 2016). In India approximately 52% of arable land is under rainfed farming conditions having no access to irrigation. Agricultural management strategies with crop rotations, exogenous organic inputs, crop residues, reduced tillage is helpful in enhancing soil organic carbon storage in tropics (Lal, 2004; Fujisaki *et al.*, 2018). Conversions of natural systems to croplands affect soil organic carbon dynamics not only in upper soil layer but also in deep soil horizons (Degryze *et al*., 2004). Information related to changes in soil organic carbon in deep soil horizons is limited. Study of changes in soil organic carbon through the soil profile under long term cultivation conditions will be helpful in identifying suitable agricultural measures for the sustainable management of cropland that are converted from grasslands.

The objective of the present study was to assess the changes in the concentration of soil organic carbon through the soil profile in a tropical rainfed rice based cropping system due to (i) conversion of grassland to cropland (ii) addition of exogenous inputs of varying C: N ratio. The three organic inputs included *Sesbania aculeata* shoot (high quality resource input), wheat straw (low quality resource input) and wheat straw + *Sesbania aculeata* shoot (combination of low quality and high quality resource input) along with chemical fertilizer. Wheat straw was used as recycled crop residue, obtained after harvesting the wheat crop and *S. aculeata* was grown during summer in separate plots in order to ensure long term sustainability of cropland.

Materials and Methods

Study Site

The experiment was conducted in the cultivated fields of the Botanical Garden of Department of Botany, Banaras Hindu University, Varanasi (25˚18′ N lat. and 83˚1′ E long., 76 m above the mean sea level). The fields have been cultivated for decades with intermittent fallows; before the commencement of the present study in July 2018. The pale brown, sandy loam, neutral (pH 7) soil of the site belongs to the order inceptisol and suborder orchrepts. The dry tropical climate of the region is characterized by strong seasonal variations with respect to temperature and precipitation. The year is divisible into a warm wet rainy season (July–September), a cool dry winter (November–February), and a hot dry summer (April–June); October and March constitute transitional months between seasons. The average annual rainfall is 1100 mm, of which approximately 80% is received during the rainy season. High temperature (24–34 ºC) and relative humidity (70–80%) prevail during the rainy season. In the winter season the temperature range is 4–25 ºC. The summer is dry and hot with a temperature range of 30–45 ºC during the day. In Indian rainfed regions the annual cropping cycle generally consists of a rotation of rainy and winter season crops followed by fallow during hot summer.

Experimental Design

The present experimental plots have been setup since June 2002 and maintained continuously till date. This experiment was designed to supply equivalent amount of nitrogen (120 kg N^{-1} ha^{-1}), through various exogenous soil inputs differing in chemical composition. The experimental plots (3×3m) were laid down in a randomized block design using four replicate plots per treatment; a 1 m strip was left to separate each block. The experimental design included following six treatments (1) Control (no inputs), (2) Chemical fertilizer (3) Wheat straw (4) *S. aculeata* shoot (5) wheat straw + *S. aculeata* shoot (6) Grassland (no cropping, no input). The crop sequence was rice (*Oryza sativa* var. Malviya 22/30) as rainy season crop (July-October) followed by wheat crop (*Triticum aestivum* var. Malviya 533) as winter season crop (November-March) and then the field was left fallow during summer (April- June). Both crops were directly seeded in the soil and receive natural rainfall only. No irrigation was provided and the experiment was maintained under rainfed conditions. Manual hoeing was thoroughly done (upto 15 cm depth) to prepare the plots for the sowing of rice. The exogenous inputs were applied only once in a year before the sowing of rice crop whereas no exogenous inputs were applied for the wheat crop. *S. aculeata* were incorporated directly into the soil after chopping the upper parts of shoot into approximately 2 to 3 cm pieces. Air dried wheat straw was cut into approximately 2 to 3 cm pieces applied to the soil. Wheat straw and *S. aculeata* shoots (corrected for moisture content) were incorporated singly or mixed as per treatment into the soil at 5 to 10 cm depth by manual hoeing, 1 or 2 days before the sowing of rice. Fertilizer was surface applied on the day of sowing.

The grassland was left undisturbed. Common species in the region (viz. *Dichanthium annulatum, Cleome viscosa* L.*, Corchorus capsularis* L.*, Ageratum conyzoides* L.*, Cyperus rotundus* L.*, Urochloa ramosa* (L.) and *Imperata cylindrical L.*) invaded the plot. No fertilization and irrigation was provided in the grassland plots. Grasses above 50 to 70 cm were clipped at regular intervals and the clipped biomass was left on the soil surface.

Soil Sampling and Analysis

Soil sampling was done at 0-15, 15-30 cm soil depth during the month of July 2018 in three replicates from grassland and cropland plots and mixed homogeneously to make one composite sample per plot. The samples were air dried and sieved through a 2mm mesh screen. Soil organic carbon was determined by the dichromate titration and oxidation method (Kalembasa and Jenkinson, 1987).

Statistical Analysis

SPSS (version 16.0) package was used for the evaluation of the data. All the values were expressed as mean ± standard error (SE). Mean values were compared using Honestly Significant Difference (HSD). Significance of difference was indicated at $P < 0.05$.

Results and Discussion

Concentration of soil organic carbon was observed maximum in grassland and minimum in control plots across all treatments and soil depth and ranged from 0.55% to 0.89% at the upper layer (0–15 cm) and 0.38% to 0.74% at lower layer (15 - 30 cm) respectively (Table 1). At the upper soil layer conversion of grassland to cropland resulted in 38% decrease in concentration of soil organic carbon. Many studies have reported decline of 30% to 80% when grasslands are converted to cropland across the globe (Poeplau *et al.*, 2011; Li *et al.*, 2014; Tang *et al.,* 2019). Permanent vegetation cover and a high root turnover lead to high organic matter input resulting in higher accumulation of soil organic carbon in grasslands (Don *et al*., 2011). In croplands bulk of the above ground crop parts are harvested out of the system resulting in little return of plant residues to the soil that reduces carbon storage in soil (Wang *et al.*, 2011; Poeplau and Don, 2013; Li *et al.*, 2014). Lower concentration of soil organic carbon in croplands might also have resulted from surface soil disturbance during tillage operations and other farm practices during the preparation of croplands (Lal, 1998). Tillage of soil buries residues, reduces stability of soil organic matter due to deteriorated aggregation, increases aeration, and stimulates microbial breakdown of soil organic carbon resulting in loss of organic carbon from soil (Balesdent *et al.*, 2000; Gelaw *et al*., 2013). In grasslands where there are no disturbances due to farming activities might result in chemical stabilization of organic carbon which in turn is responsible for high soil organic carbon concentration (Percival *et al.*, 2000). Due to repeated sowing and harvesting soil cropland soils gets compacted causing decrease in soil aggregation (Celik, 2005). Variation in soil physico-chemical properties (e.g., soil texture, soil nitrogen content, bulk density, pH) also affects dynamics of soil organic carbon (Guo and Gifford, 2002; Doetter *et al.*, 2015). When grasslands are converted to croplands microbial communities also get changed due to change in substrate quality that might also affect soil organic carbon dynamics (Belay-Tedla *et al.*, 2009).

Among the cultivated plots highest concentration of soil organic carbon was found in wheat straw treatments followed in decreasing order by *S. aculeata* shoot + wheat straw, *S. aculeate* shoot, chemical fertilizer and lowest in control throughout the soil profile. Wheat straw treatment resulted in significant increase in the concentration of soil organic carbon relative to control. Wheat straw is a low quality resource with high C: N ratio (82: 1) and plant residues with higher C: N ratio decomposes slowly and remain in soil for longer time and enhances and stabilizes aggregates which in turn facilitates greater accumulation of soil organic carbon in soil (Bossuyt *et al*., 2001; Hagedorn *et al.*, 2003; Gomez-Munoz *et al.*, 2014). Thus resulting in higher concentration of soil organic carbon. *S. aculeata,* shoot showed a significant increase in concentration of soil organic carbon relative to control but this increase was less than the wheat straw treatment. Organic residues with low C: N ratio undergoes decomposition and releases nutrients rapidly (Whitehead, 1995; Zhang *et al.*, 2019). *S. aculeata,* shoot is a high quality resource with low C: N ratio (16: 1) that decompose rapidly within 120 days (Singh *et al*., 2007) and probably could not facilitate higher accumulation of organic carbon in soil as compared to wheat straw. Combined application of low quality resource input and high quality resource input i.e., wheat straw + *S. aculeata,* shoot showed a considerable increase in soil organic carbon relative to control and this increase was comparable to that of wheat straw treatment although the carbon input was less as compared to wheat straw. Addition of *S. aculeata,* shoot to wheat straw produced a synergistic effect resulting in increase in decomposition rate so there was a prolonged release of nutrients that resulted in increase in storage of soil organic carbon. Moreover, carbon that persists in soil as recalcitrant partially decomposed mass might lead to accumulation of organic carbon (Singh *et al.*, 2009). This implies that combined application of wheat straw + *S. aculeata* (low quality resource input and high quality resource input) is more effective than single application of wheat straw or *S. aculeata* shoot. Addition of chemical fertilizer also resulted in significant increase of concentration of soil organic carbon relative to control but this increase was lower as compared to other organic inputs. The tropical soils are themselves deficient in nutrients, water availability and carbon. Application of chemical fertilizer can manage nutrient deficiency but is unable to meet the nutrient requirements as they only increase input of carbon by enhancing retention of root and stubble biomass and did not incorporate organic matter into the soil as done by other exogenous organic inputs. Thus lowest concentration of soil organic carbon was found in plots receiving only chemical fertilizer as compared to other organic inputs (Han *et al.*, 2016).

Concentration of soil organic carbon decreased through the soil profile across grassland and all cultivated plots. Plant litter containing cell wall components, intracellular and storage materials contribute primarily to soil organic carbon formation serving as carbon source for microbes; microbial residues which in turn serve as secondary source for soil organic carbon formation (Krull *et al*., 2003). This explains higher soil organic carbon in the upper layers due to more accumulation of leaf litter and residues. Also major portion of root biomass of grasses and crops are restricted at 0-20 cm soil depth due to greater availability of nutrients, water, aeration and organic matter at upper soil layer (Kondo, 2000; Stone *et al.*, 2001; E. Sathiyavani *et al*., 2017). Increase in depth of soil results in greater compaction of soil. This would subsequently lead to pore size reduction that could not penetrate roots which will affect microbial growth including fungi thus lowering the production of glomalin and polysaccharides from active roots and their exudates. Glomalin content in soil greatly contributes to soil organic carbon storage (Singh *et al.*, 2017; Kumar *et al.*, 2018). Thus causing decrease in concentration of soil organic carbon at the lower soil layer.

Conclusion

On the basis of the present study this may be concluded that conversion of grassland to cropland resulted in significant loss of soil organic carbon concentration not only at upper layer but also at lower layer of soil. Application of soil amendments increased the concentration of soil organic carbon throughout the soil profile. Organic inputs applied either singly or in combination are better as compared to chemical fertilizer for maintaining soil fertility in terms of soil organic carbon at both the soil depths. Among the organic inputs, low quality resource input was better than high quality resource input. However the combination of high quality and low quality resource inputs proved to be more efficient in storing organic carbon in soil throughout the soil profile.

Table 1 : Changes in the concentration of soil organic carbon through the soil profile in a tropical rainfed rice based cropping system. The values are mean ± standard error at 0-15 cm and 15-30 cm soil depths respectively. In each column values having different superscripts are significantly different from each other ($P < 0.05$).

Treatments	Soil Organic Carbon (%)	
	Soil depth (cm)	
	0-15	15-30
CO	0.55 ± 0.02^{a}	0.38 ± 0.02^{a}
CF	0.67 ± 0.03^{b}	0.52 ± 0.03^{b}
SS	0.70 ± 0.02^{b}	0.53 ± 0.03^{b}
WS + SS	0.82 ± 0.03^{c}	0.69 ± 0.03^{c}
WS	0.86 ± 0.02^{c}	0.72 ± 0.03^{c}
GL	0.89 ± 0.03^{c}	0.74 ± 0.03^{c}
HSD	0.118	0.134

CO: Control; CF: Chemical fertilizer; SS: *Sesbania* shoot WS: Wheat straw; WS + SS: Wheat straw + *Sesbania* shoot; GL: Grassland

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