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Soil carbon stocks in natural and man-made agri-horti-silvipastural land use systems in dry zones of Southern India

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ABSTRACT

A study was undertaken to assess the soil carbon stocks in 0-50 cm soil depth, under natural and man-made land use systems in the eastern dry zones of Karnataka in India. The carbon (C) stocks in soils ranged from 26.46 t ha^{-1} in dry land agricultural systems (without manure) to 89.20 t ha^{-1} in a mixed forest. Among natural systems, mixed forest (89.20 t ha^{-1}) and ungrazed grassland (71.78 t ha^{-1}) recorded higher levels of C stock than other systems, while grazing in grassland and litter removal in teak plantations correlated to reduced carbon stocks to 39.32 and 32.74 t ha^{-1}, respectively. Intensively managed horticultural systems namely, grapes plantation (85.52 t ha^{-1}) and pomegranate plantation (78.78 t ha^{-1}) maintained higher levels of C stock. However, agricultural systems recorded moderate to lower levels. Total carbon stocks in top 0-50 cm soils of agricultural systems was in the order: irrigated lands with manure application (52.77 t ha^{-1}) > irrigated lands without manure application (44.47 t ha^{-1}) > dry lands with manure application (37.79 t ha^{-1}) > dry lands without manure application (26.46 t ha^{-1}). It was observed that adoption of appropriate soil and crop management practices such as conservation tillage, good irrigation, incorporation of crop residues and application of manure etc. could enhance soil C pool by reducing existing carbon loss and promoting C accumulation in the soil.

Key words: Soil carbon, land use systems, residue recycling, forest, horticulture, grassland.

INTRODUCTION

Evidences are mounting that better soil management practices could contribute substantially to the mitigation of atmospheric carbon dioxide emissions (Yan *et al.*, 2005; Xu *et al.*, 2011). Conversion of natural ecosystems to agriculture in the last century has contributed to the extent of one sixth of atmospheric greenhouse gases through reduction in standing (vegetation) carbon (C) and soil C stocks (Tilman *et al.*, 2002).

Soil C constitutes a major pool in global C cycle (Scharlemann *et al.*, 2014). It is estimated that the Soils contain about 1550 Pg organic carbon and 950 Pg inorganic carbon in the upper 1m of soil layer (Lal, 2004). It is also well established that these trends could be reversed through management and land use changes (Robertson *et al.*, 2015). The carbon stored in soil of an ecosystem is controlled by the quality and quantity of biomass added and its loss through decomposition. The rate of C accumulation or loss from soil is determined by the quantity of recyclable biomass-C, temperature, rainfall, soil moisture content and management induced disturbances (Delon *et al.*, 2015; Mills *et al.*, 2014; Bhardwaj *et al.*, 2016). The carbon content is generally higher in the surface layer than deeper sub-surface layers as much of the plant and animal dead material reach the surface directly. Finally, the rate of C accumulation in soil is significantly controlled by the net balance between inputs and outputs per unit time (Fang *et al.*, 2015). Adoption of suitable management practices viz., conservation tillage, good irrigation practices, incorporation of crop residues, manure application etc. can enhance soil C pool by decreasing C losses and encouraging its sequestration in soil (Jarecki and Lal, 2003; Bhagat *et al.*, 2003). Important soil functions that are affected by agricultural land use are primary

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productivity, carbon storage and cycling, nutrients cycling and water purification and regulation (Bouma *et al.*, 2014; Schulte *et al.*, 2014).

Thus, soil can act as a large terrestrial sink of atmospheric CO_2 but the storage of C in soil is affected by the land use: crops / plant species, tillage and crop management, residue removal and incorporation and irrigation practices. Knowing the effect of these variables helps in land use planning as well as in accounting of C stocks at regional level. Keeping these in view, a study was undertaken in the Eastern dry zone of Karnataka in India to assess the soil carbon stocks (0-50 cm soil) under different land use systems, both natural and manmade, comprising of forests, grasslands, horticultural and agricultural systems.

MATERIALS AND METHODS

Study Area and land use systems

The soils of the study area originated from granite and gneiss, and are classified as Kaolinitic, isohyperthermic, belonging to Typic Kandiustalf. The study area is situated at a latitude of 12^o 58’ N and longitude of 77^o 35’ E at an elevation of about 930 MSL. The climate that prevailed was cool summer and warm winter with bimodal distribution pattern and a mean annual rainfall of 844 mm.

The forest systems comprised of mixed forest (>20 tree species) and a teak plantation. The grassland systems studied consisted of two natural grassland patches with and without grazing, and one man made napier patch. Horticultural systems included mango plantations with complete in situ litter turnover, and intensively managed grapes and pomegranate plantations. Agricultural systems comprised of both irrigated and dryland systems, with and without farmyard manure (FYM) along with recommended doses of fertilizers. Detailed descriptions of each land use system are given in Table 1.

Quantification of biomass produced and recycled

Quantity of biomass produced, removed and recycled were determined separately for each land use system. In grassland systems, the above ground biomass was harvested from one square meter while the below ground biomass was removed by digging and the roots were washed thoroughly and dried. Quantity of biomass was expressed on dry weight basis. Similarly, in grazed and napier grasslands the stubble and root biomass left after grazing / harvest were quantified. Biomass quantification was restricted only to annual litter turnover in forest systems as the methodology for annual root biomass estimations are not available. The litter samples were collected from one square meter area at a regular interval to get the annual

Table 1. Details of the studied land use systems.

Land use systems	Vegetation	System	Management Practices	Biomass Removed
Grassland Systems				
Ungrazed	Grasses	Natural	None	None
Grazed	Grasses	Natural	G	Grasses
Napier	Grasses	Manmade	C, F, H	Grasses
Forest Systems				
Mixed	Trees, Bushes	Natural	None	None
Teak	Teak	Manmade	Litter Removal	Litter
Horticultural Systems				
Grapes	Grapes	Manmade	C, IR, P, W, F, M, H	Fruits + Cane
Pomegranate	Pomegranate	Manmade	C, IR, P, W, F, M, H	Fruits
Mango	Mango	Manmade	C, P, F, H	Fruits
Agricultural Systems				
Irrigated Plots (Fert. + FYM)	Finger Millet + Corn	Manmade	C, IR, M, F, H, W, P	Grain + Straw
Irrigated Plots (Only Fert.)	Finger Millet + Corn	Manmade	C, IR, F, H, W, P	Grain + Straw
Dryland Plots (Fert. + FYM)	Finger Millet	Manmade	C, M, F, H, W, P	Grain +Straw
Dryland Plots (Only Fert.)	Finger Millet	Manmade	C, F, H, W, P	Grain + Straw

Cultivation (C); Irrigation (IR); Weedicide (W); Pesticides (P); Fertilization (F); Manuring (M); Harvesting (H); Grazing (G).

turnover (Shylaja *et al.*, 1993).

The biomass produced in horticultural systems was quantified by collecting the litter samples from one square meter and recording the annual fruit yield. Annual root biomass was not estimated in these systems, as the destructive method of sampling would result in large economic losses. In agricultural systems, the quantity of fodder and grain produced were used from the actual yield data and the biomass left in the field after the harvest of the crop was determined as detailed in grasslands.

Soil sampling and estimation of soil-C stocks

Three sampling sites were chosen for each land use system. In each site, soil samples were collected from 3 different spots at 0-15, 15-30 and 30-50 cm depths and the samples were pooled to get composite samples for each depth separately. These composite soil samples (depth wise) were air dried and passed through 2 mm sieve for further analyses. The soil present in 0-50 cm layer was determined by measuring the bulk density of soils for three depths separately and the carbon content for the collected soil samples were determined by adopting modified Walkley and Black (1934) wet oxidation method. Soil carbon stock was estimated by considering the soil bulk density and fine fractions.

Statistical analysis

All parameters were tested using a one-way analysis of variance (ANOVA) and separation of means was subjected to Tukey's honestly significant difference test (Steel and Torrie, 1960). Correlation analysis was conducted to identify relationships between the measured parameters. All tests were performed at 0.05 significance level.

RESULTS AND DISCUSSION

Biomass produced and recycled

The data on the quantity of biomass produced, removed and recycled annually among different land uses systems are given in Table 2.

Biomass Production: Among 12 different land use types, pomegranate orchards recorded the least biomass production with 3.6 t ha^{-1}, while irrigated agricultural systems with two crops of finger millet and maize, supplemented with manures and fertilizers, produced 30.0 t ha^{-1} of biomass. In grassland systems, the annual biomass production ranged from 6.0 - 13.8 t ha^{-1} with least production in grazed land and the highest in napier grassland. Irrigated agricultural systems recorded very high biomass production compared to dryland systems. The moisture limitations in dryland restricted the cropping to only one crop per year, which was able

Table 2. Quantity of in-situ and ex-situ annual biomass turnover (t ha^{-1}) among different land use systems.

Land use system	*Biomass Produced	‡Biomass Removed	§Residue BM Recycled	FYM added	†Net OM Recycled
Grassland Systems					
Ungrazed	6.7	0.0	6.7	0.0	6.7
Grazed	6.0	3.5	2.5	0.0	2.5
Napier	13.8	7.0	6.8	0.0	6.8
Forest Systems					
Mixed#	6.7	0.0	6.7	0.0	6.7
Teak#	5.2	4.2	1.0	0.0	1.0
Horticultural Systems					
Grape#	7.2	7.1	0.1	50.0	50.1
Pomegranate#	3.6	2.4	1.2	12.5	13.7
Mango#	5.4	1.0	4.4	0.0	4.4
Agricultural Systems					
Irrigated (FYM + Fert.)	30.0	20.0	10.0	15.0	25.0
Irrigated (Fert. Alone)	24.9	17.5	7.5	0.0	7.5
Dryland (FYM +Fert.)	17.1	10.5	6.6	10.0	16.6
Dryland (Fert. Alone)	8.2	3.4	4.8	0.0	4.8

***** *Biomass produced* included litter, fruit, grain, straw and root; **‡** *biomass removed* included grain, fodder, litter and fruit; **§** *Residue biomass recycled* included roots and stubble in annuals and only litter (leaves + twigs) in perennial trees; **†** *Net organic matter (OM) recycled* = Residue BM recycled + FYM added; # Below ground BM produced / recycled not considered.

to produce 8.2 and 17.1 t ha^{-1} of biomass. The litter biomass (fallen leaves and stems) ranged from 3.6 - 7.2 t ha^{-1} among land use systems with perennial trees. Natural mixed forest recorded 7.2 t of litter biomass, while teak plantations produced 5.2 t of litter per hectare. In case of horticultural systems, the above ground biomass produced in grape and mango orchards were 7.2 t ha^{-1} and 5.4 t ha^{-1}, respectively.

Residue biomass recycled

Land management practices adopted in a given system determine extent of the biomass recycling. There was no removal of biomass in the non-grazed grasslands and mixed forests, and hence, all the biomass produced was allowed to recycle. While in grazed land, 3.5 t ha^{-1} of grass biomass were removed as fodder and hence, only 2.5 t ha^{-1} of biomass was allowed to recycle in the form of stubble and roots. Among irrigated agricultural systems, biomass was removed (grain and fodder) to an extent of 20.0 t ha^{-1} in fertilizer and FYM treated plots and 17.5 t ha^{-1} in no-FYM plots (only fertilizer). Thus, the quantity of biomass allowed to recycle was 10.0 and 7.5 t ha^{-1}, respectively. However, the moisture limitations in dryland restricted the turnover to 6.6 and 4.8 t ha^{-1}, respectively in plots with fertilizer plus manure and fertilizer alone plots. Among tree based perennial systems, mixed forest recorded an in situ biomass turnover of 6.7 t ha^{-1}. Litter removal in teak plantations, to prevent fire damages, resulted in a biomass turnover of mere 1.0 t ha^{-1}. Extraction of fruits was the major source of biomass removal in horticultural systems except in grapes, where the biomass was also removed in the form of canes and leaves during pruning operations. Thus, the management practices adopted in a given system and the quantity of biomass recycled is likely to have an influence on the net soil carbon stocks.

Net organic matter recycled

In manmade agricultural and horticultural systems, unlike the natural ones, organic matter was added in the form of compost/manure to maintain yield and quality. Thus, the net organic matter recycled would be the sum of residue biomass and manure. The net organic matter recycled was as high as 50.1 t ha^{-1} in grape orchard and it was low in pomegranate plots with a net turnover of 13.7 t ha^{-1}. However, there was no addition of manure to mango and thus the biomass recycled was equal to the net organic matter recycled. In FYM treated agricultural systems, irrigated lands recorded a net biomass turnover of 25.0 t ha^{-1} while, dryland system recorded 16.6 t ha^{-1}. However, the net biomass recycled among no-FYM plots (only fertilizer applied), in both irrigated and dryland agricultural systems, were equal to that of residue biomass recycled. Application of organic sources enhances all the pools of soil carbon (Khursheed *et al.*, 2013) indicating recycling of organic matter. Similarly, the net biomass recycling was unchanged in ungrazed grassland and forest systems as there was no addition of organic matter from external sources.

Soil carbon stocks

The data on seasonal changes in soil organic-C under different land use systems at various depths are given in Table 3. The amount of total soil carbon stocks present in 0-50 cm of soil layer is depicted diagrammatically in Fig. 1. The surface soils (0-15 cm) of all land use systems in all the three seasons recorded highest soil organic-C. In general, the soil organic-C was higher in winter season and lower in summer.

Carbon present in these soils is mostly organic in nature and is present in the form of humus coat over soil particles. It decreased with depth in all the treatments and it differed significantly among treatments as well as seasons (Table 3). There are no records of elemental carbon in these soils as

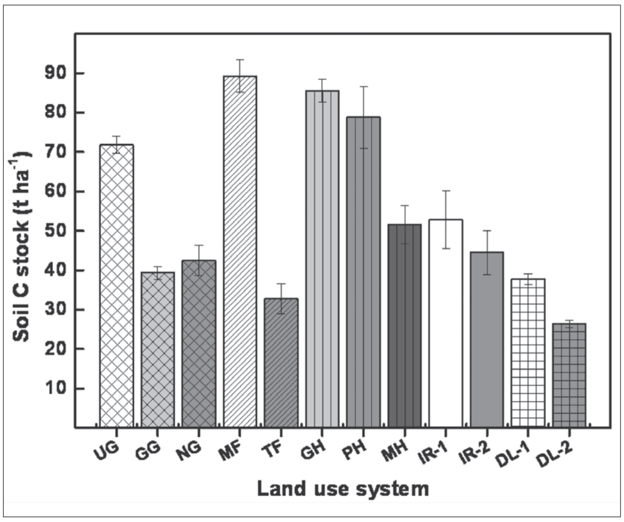

Fig. 1. Soil carbon stocks among different land use systems. UG = Ungrazed grasses, GG = Grazed grasses, NG = Napier grass, MF = Mixed forest, TF = Teak Forest, GH = Horticultural plantation-Grape, PH = Horticultural plantation-Pomegranate, MH = Horticultural plantation-Mango, IR-1 = Irrigated agricultural system with FYM and fertilizer, IR-2 = Irrigated agricultural system with fertilizer alone, DL-1 = Dryland agricultural system with FYM and fertilizer, and DL-2 = Dryland agricultural system with fertilizer alone.

Table 3. Seasonal changes in soil organic carbon (*per cent*) under different land use systems.

Land use system	Winter	Summer	Rainy
SOIL ORGANIC CARBON (%)			
Grassland Systems			
Ungrazed	1.27	1.28	1.17
Grazed	0.56	0.52	0.60
Napier	0.62	0.71	0.52
Forest Systems			
Mixed	1.85	1.58	1.68
Teak	0.38	0.56	0.45
Horticultural Systems			
Grape	1.41	1.39	1.28
Pomegranate	1.32	1.40	1.01
Mango	0.67	0.89	0.69
Agricultural Systems			
Irrigated (FYM +Fert)	0.96	0.59	0.79
Irrigated (Fert. Alone)	0.74	0.51	0.64
Dryland (FYM +Fert)	0.62	0.52	0.54
Dryland (Fert. Alone)	0.35	0.38	0.39

The values indicated are the mean of three depths.

there are no natural deposits of coal/coke.

Higher level of carbon was recorded in mixed forest patches (2.91 %) during rainy season and lowest was observed during summer in dryland agricultural plots with no FYM. Among the systems, based on mean depths and season, the ungrazed control plot (1.24 %), grapes (1.36 %), pomegranate orchards (1.24 %) and mixed forests (1.70 %) systems recorded more than 1.0 % of soil organic-C. Moderate levels of soil organic-C were observed among other systems except teak plantations (0.46 %) and dryland plots receiving only fertilizers (0.38 %). The variations in soil organic-C among different land use systems would be attributed to the net biomass turnover and land management practices adopted in the system (Post and Kwon, 2000). Influence of management practices and biomass addition/turnover on soil carbon stocks is well documented (Liao *et al.*, 2010).

The amount of soil carbon present in the form of humus is a function of bulk density and soil organic-C content. It was determined using the soil volume and its corresponding soil organic-C contents. The amount of carbon stored in the top 0-50 cm soil layer ranged from 32.7 t ha^{-1} in teak plantations to 89.5 t ha^{-1} in mixed forest. Similarly, the soil carbon stock in ungrazed grassland (71.8 t ha^{-1}) was higher than grazed (39.3 t ha^{-1}) and napier (42.5 t ha^{-1}) grasslands. The data also indicate that the quantity of carbon stored in horticultural systems was much higher than the disturbed forest and grassland ecosystems. The amount of soil carbon present in top 0-50 cm soil layer was 85.5, 78.8 and 51.6 t ha^{-1} in grapes, pomegranate and mango systems respectively. Interestingly, the soil carbon stocks was almost near to that of disturbed natural systems and lesser than horticultural systems. Irrigated agricultural systems had stored 52.8 t ha^{-1} in FYM and fertilizer treated plots compared to 44.5 t ha^{-1} in fertilizer alone treated plots. Similar trend was observed in dryland agricultural systems with much lesser quantities of humus carbon. The corresponding values in dryland agricultural systems were 37.8 t ha^{-1} (with manure and fertilizer) and 26.5 t ha^{-1} (with fertilizer alone).

Soil organic-C of any ecosystem is determined by the quality and quantity of C-inputs through biomass addition (Liu *et al.*, 2014) and its loss through decomposition (Zhu *et al.*, 2014, Toosi *et al.*, 2014). Larger the biomass turnover higher would be the soil organic carbon. Large carbon stocks were observed in natural forest and ungrazed grasslands and it could be attributed to high biomass turnover and no disturbances. However, manmade napier and grazed grasslands recorded much lower carbon stocks than ungrazed plots. Reduction in soil organic-C in napier grasslands could be due to regular cultivation practices adopted (Panagos *et al.*, 2015) and higher soil temperature as the surface was not covered most of the time (Hopkins *et al.*, 2014). Litter removal in teak plantation to prevent fire damages might have severely reduced the soil carbon stocks.

Agroforestry system results in leaf litter fall that recycles the C as well as nutrients to the soil (Solanki and Arora, 2015). This suggests that the cultivation and removal of surface cover would reduce soil carbon through enhanced decomposition rates (Sayer, 2006; Leff *et al.*, 2012; Fekete *et al.*, 2014).

CONCLUSION

The carbon preserved in the form of humus on soil particles could be used effectively as a mean to sequester atmospheric CO_2 and hence in mitigating global warming effects. The amount of carbon stored is determined by the quality and quantity of biomass added and its loss through decomposition. Deforestation, expansion of agriculture, shifting cultivation, irrigation etc. would lead to oxidation of organic matter in soil. These processes would result in CO_2 release, leading to increased concentration of CO_2 in the atmosphere. However, substantial carbon accumulation can also occur in soil with increase in biomass turnover and reduction in mechanical disturbances. Thus, adoption of conservation tillage, good irrigation practices, crop residue incorporation, manure application etc. could enhance soil carbon to a great extent by decreasing the loss of existing carbon mass and encouraging carbon accumulation. Results of the present study clearly indicate that there is a great scope to mitigate atmospheric CO_2 through better land management practices.

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