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Carbon sequestration pattern in conventional and organic tea plantations

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ABSTRACT: A case study was undertaken to assess the terrestrial carbon sequestration potential of tea plantations under conventional (inorganic) and organic cultivation practices for a period of 10 years at Parry Agro Tea Plantations, located at Valparai, Coimbatore district, Tamil Nadu. During the investigation period, the above-ground (carbon accumulation in shoots) and below ground (soil organic carbon in surface and sub-surface horizons) carbon stocks have been assessed. The data collected were critically analysed and reported. Overall, the data suggest that continuous cultivation of tea plantation organically has resulted in the production of higher biomass in the above ground by 43% (194.4 t ha^{-1}) in comparison to conventional system of cultivation (136 t ha^{-1}). The below-ground carbon accumulation in organic tea plantation measured in terms of SOC stock was 135 t ha^{-1} while the conventional system had registered 125 t ha^{-1} with a gain in carbon stock of 10.26 t ha^{-1} in the organic system. The results clearly demonstrated that the maintenance of tea plantation organically has a distinct advantage of additional carbon sequestration in the system to the tune of 38.6 t ha^{-1} which was gained over a period of 10 years, in comparison to conventional system.

KEYWORDS: *Carbon sequestration pattern; ; Conventional; Organic; Tea Plantations; Biomass*

Introduction

Global warming is the major environmental concern seriously affecting the climate and agricultural productivity. One of the prime greenhouse gases responsible for global warming is CO_2 and hence, scientists are attempting to evolve various strategies to combat the greenhouse gas emissions (GHG). It has been estimated that the atmospheric CO_2 has increased from 280 ppm in the pre-industrial era to 390.5 ppm in the year 2011.[1,2] One of the plausible means to mitigate CO_2 emissions is through carbon sequestration that promotes productivity of crops, improves soil fertility while keeping the GHG emissions at the lowest possible level. Carbon sequestration refers to the transfer of carbon dioxide from the atmosphere into long lived stable carbon forms.[3] Thus, identifying viable sinks is a high priority with the objective of sequestration. Among the various options that are available, carbon capture by terrestrial sequestration is a natural process with ancillary benefits besides cost-effectiveness.[4] In comparison to annual crops, perennials are known to conserve greater quantities of C as the balance between additions and emissions is almost zero in field crops.

One of the widely recommended carbon sequestration strategies is the adoption of organic farming practices. Despite the fact that the organic farming is a less lucrative approach for field crops, such cropping option may be adoptable for the plantation crops particularly tea where the crop residue derived from the pruning is incorporated regularly; the rate of decomposition at high altitude is much lower than plains. It is reported that pruned litters of tea contribute towards the enrichment of organic status in tea plantations.[5] Further, tea plantations in south India are located at high altitude (more than 1,000 m MSL), the rate of decomposition of organic matter there being much slower rendering carbon accumulation in soil. Though this observation appears to be obvious, no systematic study has been undertaken to assess the relative carbon sequestration potentials of organic and conventional methods of tea cultivation. With this backdrop, a pioneering work has been attempted to examine the C sequestration pattern in tea plantations of Parry Agro which is about 100-year old being cultivated distinctly with organic or conventional crop husbandry practices.

Methodology

Description of the Study Area

The investigation was carried out in a tea plantation (1621 ha) which is situated in Anamalais (Valparai), Coimbatore District, Tamil Nadu, India lying between 8° and 13° N on the slopes of Western Ghats at an altitude

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Table 1: Below ground carbon sequestration pattern in tea plantations

Location	Soil Orgainc Carbon (%)			
	Organic		Conventional	
	0–9	9–18	0–9	9–18
1	1.25	2.30	3.38	3.51
2	2.63	2.97	2.70	3.11
3	2.88	3.65	2.84	2.97
4	2.50	2.70	2.03	2.16
5	1.63	2.03	1.76	1.89
6	1.50	1.76	1.62	2.16
7	3.25	3.51	1.49	1.76
8	2.38	2.57	1.89	2.30
9	4.13	2.84	1.89	2.43
10	1.75	1.89	1.79	2.57
Mean	2.39	2.62	2.14	2.49
C sequesterated (kg ha^{-1})	64530	70740	57780	67230
Total C sequesterated (kg)	5545980	6083640	7973640	9277740
	86 ha		138 ha	
C sequestrated in the system in kg (below ground)	11633220		17251380	
C sequestrated (kg ha^{-1})	135270		125010	
C gain in organic tea plantation (t ha–1)	10.26			

of 1050–1080 m MSL. The soil of this area is sandy loam in texture, acidic in pH (4.0–5.5), with organic carbon status ranging between 0.36 and 1.08 %, low in available N (250–280 kg ha^{-1}), high in available P (20–25 kg ha^{-1}) and high in available K (275–300 kg ha^{-1}). The tea plantation is cultivated with two distinct practices namely organic and conventional. The conventional tea plantation is maintained in an area of 138 ha and has received 500, 413 and 387 tonnes of urea, rock phosphate and muriate of potash, respectively, for the past 10 years (2000–2010). In order to meet the micronutrient requirements, 10 kg $MgSO_4$, 10 kg $ZnSO_4$, 1.5 kg $MnSO_4$ and 0.5 kg Boric acid were applied in conventional plantations through five foliar sprays at monthly intervals during the cropping season. On the other hand, the organic tea plantations maintained in an area of 86 ha has received a cumulative total of approximately 2464 tonnes of organic sources of nutrient inputs comprising compost, 'Farmboon', castor cake and neem cake for the past 10 years.

Carbon Estimation

The subterranean C sequestration was assessed based on the estimation of soil organic carbon (SOC) in two layers namely 0–9″ and 9–18″ soil layers. Ten sampling sites were fixed covering entire extent of conventional (138 ha) and organic (86 ha) tea plantations. In each location, surface and sub-surface soil samples were collected, processed and analyzed for their organic carbon content. Soil organic carbon (SOC) was estimated by modified Walkley and Black method.6,7 The quantity of soil organic carbon stock was calculated by multiplying the SOC content with the bulk density and volume of the soil stock.8 The carbon content of above ground tea biomass was measured by using high temperature TOC analyzer (Elementer, Model: Liqui TOC II, Germany) to calculate carbon sequestration by aerial parts of the bush. All the analyses were carried out at the Department of Soil Science & Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore.

Results and Discussion

Subterranian Carbon Sequestration

Soil organic carbon (SOC) measured at two depths (0–9″ and 9–18″) was converted into carbon stock by multiplying with bulk densities of respective soil horizons. The results have shown that the carbon stocks in the organic tea plantations were 64.5 and 70.7 t ha^{-1} in surface and sub-surface soils, respectively (Table 1). While conventional system had the soil organic stocks of 57.7 and 67.2

Table 2: Above ground carbon sequestration in tea plantations

Location	Organic			Conventional		
	Total Bush Wt (t ha^{-1})	Carbon content (%)	Carbon sequestrated (t ha^{-1})	Total Bush Wt (t ha^{-1})	Carbon content (%)	Carbon sequestrated (t ha^{-1})
1	222.7	48.4	107.8	116	48.6	56.4
2	57.0	48.9	27.9	79	48.7	38.5
3	520.2	49.5	257.5	240	49.3	118.3
4	177.1	48.0	85.0	86	48.4	41.6
5	151.3	49.3	74.6	180	49.1	88.4
6	299.0	48.7	145.6	368	48.9	180.0
7	110.9	48.1	53.3	48	48.3	23.2
8	125.2	49.3	61.7	110	49	53.9
9	177.4	49.0	86.9	82	49.3	40.4
10	103.4	48.4	50.0	48	48.3	23.2
Mean	194.4	48.8	95.0	135.7	48.8	66.4
C sequesterated (t ha^{-1})		95.0 C			66.4 C	
Total C sequesterated in above ground (t)		86 ha × 95.0 t C			138 ha × 66.4 t C	
		8170			9163	
C sequestrated (t ha^{-1})		95.0			66.4	
C gain in organic tea plantation (t ha^{-1})			29			

t ha^{-1}, respectively. There is a net gain of organic carbon stocks to the tune of 10 tonnes in organic tea plantations. The data coincided with the literature pertaining to organic practices leading to the accumulation of soil organic carbon.[5] Our data clearly demonstrated that enhancing organic carbon is quite complex and rarely get adjusted as a result of tropical environmental conditions. However, a slight increase of 10 tonnes of carbon sequestration in soil may have greater impact in terms of intense microbial activity and contribute towards passive pools of carbon which is recalcitrant in nature. Our data closely coincided with the observations of several researchers who have suggested that tea plantations serve as a strong carbon sink both *in situ* (biomass and soil) and *ex situ* (harvested leaf) that ultimately indicating the carbon sequestration.[9–11]

Carbon Sequestration by Aerial Parts

The above ground carbon sequestration is measured as C accumulated in primary, secondary and tertiary branches of tea plantations that remain in the system for a considerable period of time. Carbon sequestered in above ground biomass was 95 and 66.4 t ha^{-1} under organic and conventional systems, respectively (Table 2), with a net gain of 29 t ha-1 in organic tea plantations. Organic addition is known to promote physical, chemical and biological properties of soil that facilitate the overall growth of the tea bushes. It is obvious that favourable soil conditions may have assisted the bushes to be physiologically active and producing abundance of above ground biomass. Despite the fact that tender shoots are harvested as the economic produce, permanent stock of carbon accumulates in the bushes that have greater potential for carbon sequestration. Consequently, it is widely believed that similar to agro-forestry, tea plantations are known to be a "sink" of carbon that is retained in the system for a prolonged period of time. It is shown that agro-forestry plantations are permanent "sinks" of carbon in the above ground biomass.[12] Results of this study corroborate the existing literature that tea plantations are a potential system for carbon trading.

Carbon Accumulation in Fresh Leaves

Carbon content in the pruned leaves was assessed periodically that accrued over a period of time and reported as carbon accumulation in fresh leaves. Contrary to the above ground biomass, carbon accumulation in the pruned fresh leaves of organic plantation was only 2.54 t ha^{-1} which is nearly 50% lower than conventional system (4.78 t ha^{-1}). Such phenomenal reduction in biomass is

Table 3: Carbon Accumulation in Fresh Tea Leaves

Location	Organic		Conventional	
	Fresh Leaf (kg ha^{-1})	Carbon accumulation (kg ha^{-1}) on DW basis	Fresh Leaf (kg ha^{-1})	Carbon accumulation (kg ha^{-1}) on DW basis
1	4737.7	1895	11004.44	4402
2	3924.4	1570	11337.78	4535
3	7288.8	2916	12906.67	5163
4	5760.0	2304	16520.00	6608
5	7195.5	2878	12333.33	4933
6	4813.3	1925	12551.11	5020
7	6604.4	2642	6413.33	2565
8	8564.4	3426	11551.11	4620
9	6648.8	2660	10400.00	4160
10	7857.7	3143	14200.00	5680
Mean	6339.6	2536	11921.8	4769
C removal (t ha^{-1})	2.54 t		4.78 t	
Total C removal by the system (t)	86 ha × 2.54 t C		138 ha × 4.78 t C	
	218		659	
C removal (t ha^{-1})	2.54		4.78	

attributed to the slower rate of decomposition of organic inputs in hilly regions which may not have fulfilled the need of nutrition (Table 3). On the other hand, chemical fertilizers are designed to deliver nutrients immediately following application in suitable proportions, meeting the demand of the requirement. Eventually, organic tea plantations yielded lower by 50% but the quality of the produce may be better in terms less pesticide residues and free from metal contaminants which may not account for carbon sequestration potential of the plantations. It has been extensively reported in annual crops that organic farming will produce lower yield due to the slower mineralization of organic nutrients besides imbalanced fertilization.[13]

Carbon Budget in Tea Plantations

Carbon budget was assessed amongst organic and conventional systems of tea plantations by considering the above and below ground carbon accumulations. The net C gain in organic tea plantation was 230 t ha^{-1} while this was only 191.4 t ha^{-1} in conventional system with a difference in two systems was 38.6 t ha^{-1}. The data clearly suggested that the organic tea plantation has enormous potential for carbon trading and deserving to be considered for carbon credits. This study will be a guiding tool for the assessment of carbon stock in the plantations and qualify their plantations for carbon trading.

Table 4: Carbon Budget in Tea Plantations

Systems	Below Ground C sequestration (t ha^{-1})	Above Ground C sequestration (t ha^{-1})	C Removal (t ha^{-1})	Net C gain (t ha^{-1})
Organic	135	95.0	2.54	230.0
Conventional	125	66.4	4.78	191.4
Carbon gain in organic tea plantation				38.6

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