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Carbon sequestration in tea soil through burial of pruning and its impact on biomass production and soil characteristics

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Abstract

Global warming and climate change issues force the scientists to focus their attention on carbon sequestration by the terrestrial vegetation. Tea being a perennial crop, its pruned litters contribute to the organic carbon addition to the soils. In this context, randomized block design experiment was conducted to quantify the addition of organic carbon in tea plantations with respect to burial of pruning. Soils of the experimental plots were sampled regularly and subjected to nutrient analysis and population density of soil micro flora. On recovery, economically important crop shoots harvested at regular interval were recorded. There was a significant variation in the biomass produced over a period of one pruning cycle. Complete removal of pruned litter from the tea field registered lower quantum of biomass; however, it supported favourable compartmentalization in terms of economic yield which reflected upon the productivity index (54.86) at the cost of reduction in carbohydrate reserves in the roots. In other words about 55% of organic carbon was harvested as economic yield in burial of pruning. In terms of carbon sequestration, ~3.0 tons of organic carbon was removed as biomass in pruned year (in control blocks) while as high as 4.8 tons organic carbon/ha sequestrated where the burial of pruned litters was adopted. Organic carbon content of both the surface and bottom soils were significantly higher when the pruned litters were buried in the trenches. Post treatment results confirmed an increase in the populations of total bacteria, fungi, *Trichoderma* spp., Actinomycetes, *Azosprillum* spp, Phosphate solubilising bacteria and *Pseudomonas* spp. Even though burial of pruning is a laborious process, when considering the issues on global warming, this could be adopted in tea plantations as a measure of carbon sequestration, which in turn improved the soil fertility, soil micro flora and the economic yield besides the total biomass production. Data generated on enhanced economic yield and total biomass production are presented and discussed in terms of carbon sequestration and clean development mechanism.

Keywords: Biomass, organic carbon, productivity index, soil micro flora, yield potential

Introduction

Pruning is a periodical cultural operation that is being carried out to revitalize the bush vigour and to keep the bush at predetermined height which in turn favoured the cultural operations including harvesting (Sharma and Murthy, 1989). Number of factors influence recovery of tea bushes from pruning and are elaborated from time to time. Height of pruning, time of pruning and severity of the cut are the important criteria, which determine the crop productivity. Climatic variables and carbohydrate reserves also contributed to crop productivity a greater extent (Sharma, 1984; Spurgeon Cox, 2002; Ajaykumar, 2002). Since the tea plantations face acute labour scarcity, mechanization in pruning was introduced in South Indian tea gardens. Crop shoots, the economically important plant parts, are periodically harvested for manufacturing the commercial marketable tea removes significant quantum of nutrients, including the sequestrated carbon. Other uneconomic plant parts, particularly, mature leaves and stems did not gain importance in tea culture. However, being the photosynthetic

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machinery of the tea plants, maintenance foliage assimilate significant amount of atmospheric carbon dioxide (Raj Kumar *et al.*, 1998). At the time of pruning, the maintenance foliage and a portion of stem were removed, which is again recycled as organic carbon. It has already been established that biotic/abiotic variables influence the carbon dioxide assimilation and dry matter compartmentalization (Raj Kumar, 2003). To meet the challenges of global warming and climate change, scientists all over the world geared up the process of data generation on carbon sequestration by the terrestrial vegetation. In order to generate information on the role of pruning operation in carbon cycle, a field experiment was conducted with special reference to carbon sequestration and carbon recycling in tea ecosystem.

Materials and methods

A field experiment was conducted at UPASI Tea Research Institute, Experimental Farm at Vandiperiyar. The clone, UPASI-16 (B/6/182) was planted in 1975 and last pruned in 2006 at 60 cm above ground level. Randomized block design experimental plot consisted of 20 bushes and replicated three times. There were four treatments;

T1) pruned biomass chopped and covered (spreaded) in the plots

T2) pruned biomass chopped and buried in the trenches taken between the rows within the experimental plots between the rows (2 x 0.3 x 0.45 m) and covered with soil.

T3) pruned biomass retained in the experimental plots as such without any chopping and

T4) complete removal of biomass from the experimental plots. Pruned phytomass was weighed per plot for computational purpose and according to the treatments, they were utilized. Plant samples were subjected to quantification of organic carbon content following the standard procedures (The fertilizer (control) order, 1985). Root samples collected at periodic interval were subjected to carbohydrate analysis (Sadasivam and Manickam, 1996).

Soils of the experimental plots were sampled prior to and after pruning every year. Soils were subjected to nutrient analysis and population density of soil micro flora adopting the standard procedures (Pikovskaya, 1948; Martin, 1950; Cochran, 1950; Kuster and Williams, 1964; Gordon *et al.*, 1973; Dobereiner and Day, 1976; Tandon, 2001). On pruning recovery, plants were tipped at 75 cm above ground level and weighed freshly. Economically important crop shoots harvested at regular interval were recorded. Harvesting was carried out manually upto 18 months after pruning and integrated shear harvesting was adopted thereafter coinciding with the crop seasons. Yield was calculated for 10000 bushes per hectare at an out turn of 22.5%. *Grevillea robusta* were planted in the field for provision of shade and were periodically pollarded. Regular cultural operations were executed according to the UPASI recommendations with respect to soil/foliar application of nutrients and plant protection measures (Muraleedharan *et al.*, 2007). Yield potential and productivity index were computed (Spurgeon Cox, 2002). Data obtained from the study were subjected to statistical analysis and interpreted in relation to carbon sequestration.

Results and discussion

There was a significant variation in the biomass both in the economically important crop shoots and uneconomic plant parts produced over a period of one pruning cycle (Table 1). Complete removal of pruned litter from the tea field registered lower quantum of biomass when compared to other treatments. Total biomass produced was significantly higher than any other treatments wherein the phytomass was chopped and buried followed by other treatments. Except the control, all other treatments exhibited marginal variation in terms of yield but there was a significant improvement when compared with control. When the economic yield computed as organic carbon (OC) equivalents, control plants registered lower values over the study period (Table 2). Similar trend was observed in the case of total biomass production and their OC equivalents.

Table 1. Biomass produced by clonal tea and harvested in the pruned year

Treatment	Mean green leaf yield (kg/ha/year)	Fresh weight of pruned wood (kg/ha)	Fresh weight of maintenance foliage (kg/ha)	Total biomass (kg/ha)
T1	15222	14567	6367	36155
T2	15925	15267	8083	39225
T3	15270	13200	6033	34504
T4	14298	8067	3700	26065

Table 2. Organic carbon sequestrated as plant parts in the pruned year (Dry matter basis)

Treatment	Yield as OC (kg/ha/yr)	Pruned wood as OC (kg/ha)	Maintenance foliage as OC (kg/ha)	Total biomass as OC (kg/ha)
T1	1199	2723	633	4554
T2	1254	2763	770	4787
T3	1203	2426	570	4198
T4	1126	1502	368	2996

Productivity index values were higher in the control blocks, which may be due to the unfavorable dry matter compartmentalization (Table 3); while other three treatments registered lower productivity index. About 40.6 to 54.9% of organic carbon was harvested as economic yield in accordance with the treatments. In view of carbon sequestration, ~3.0 tons of organic carbon was removed as biomass in pruned year (in control block) while as high as 4.8 tons organic carbon/ha sequestrated where the burial of pruning was adopted. Yield potential of the control was on par with the mean field yield but burial of pruning showed significant variation followed by other two treatments. Enhanced yield potential was due to unfavourable compartmentalization of dry matter at the cost of reduction in carbohydrate (CHO) reserves in the roots (Table 3). It may be noted that prior to pruning, the CHO reserves ranged from 18.2% to 19.3%, irrespective of the treatments.

Table 3. Impact of burial of pruning on yield potential, productivity index and root reserves

Treatment	Yield potential	Productivity index	Root reserves as CHO in (%)*
T1	1.07	42.10	16.8
T2	1.12	40.60	20.6
T3	1.07	44.26	17.1
T4	1.01	54.86	15.2

*CHO reserve quantified at the end of fourth agricultural year

Variations in organic matter content were evident which has direct relation with OC content. Considering the importance of soil organic carbon in relation to carbon cycle, OC content of various treatments are presented and discussed. When compared to that of pretreatment soils, organic carbon content marginally increased in the surface soil irrespective of the treatments (Table 4). The organic carbon content of both the surface and bottom soils were significantly higher when the pruned litters were buried. Per cent increase in organic carbon content between surface and bottom soils ranged from 12.80 to 15.93 (bottom soil) and when compared to the samples collected prior to implementation of the treatments, the increase in OC was rapid and attained its peak at the end of fourth agricultural year.

Certain soil nutrients were also documented in the present study, which has been presented in Table 5. Physico-chemical analysis of the soils revealed that both top and bottom soils showed marginal variation in terms of pH and electrical conductivity, prior to pruning and during the course of the study. Considering the mean values of organic matter (OM) irrespective of the treatments, there was no tremendous variation; but marginal improvement in the bottom profile was evident. There was no clear trend in nutrient retention between top and bottom profiles of the tea soils, which necessitated both top

Table 4. Soil organic carbon (%) enrichment in response to burial of pruning

Treatment	Soil profile (in inches)	Pre-treatment	OC (%)				
			1st year	2nd year	3rd year	4th year	Mean
T1	0-9	2.35	2.35	2.39	2.38	2.58	2.42
	9-18	2.22	2.38	2.38	2.37	2.64	2.44
T2	0-9	2.42	2.67	2.71	2.70	2.85	2.73
	9-18	2.26	2.44	2.62	2.62	2.80	2.62
T3	0-9	2.47	2.49	2.49	2.50	2.70	2.54
	9-18	2.37	2.35	2.42	2.45	2.54	2.44
T4	0-9	2.29	2.38	2.24	2.22	2.41	2.31
	9-18	2.33	2.38	2.36	2.35	2.32	2.35
Mean	0-9	2.38	2.47	2.45	2.45	2.63	2.50
	9-18	2.29	2.39	2.45	2.44	2.57	2.46
Statistical significance		S.E.	C.D. (0.05)	C.V (%)			
Between the treatments		0.012	0.026	7.29			

Table 5. Physico-chemical analysis in response to burial of pruning prior to and during pruning cycle

Year of sampling	Treatment	Soil profile (in ")	pH	EC	Chemical properties				
					OM (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Prior to pruning	T1	0-9	4.2	0.1	4.05	16.5	232.3	101.0	44.7
		9-18	4.0	.02	3.82	8.1	248.0	104.3	39.0
	T2	0-9	4.0	0.2	4.67	11.4	259.3	67.7	37.0
		9-18	4.2	0.1	4.24	8.7	312.0	128.7	46.3
	T3	0-9	4.1	0.3	4.26	15.1	310.3	147.0	46.3
		9-18	4.0	0.3	3.57	16.9	270.0	174.7	61.3
	T4	0-9	4.1	0.2	4.11	23.4	251.7	125.3	48.3
		9-18	3.8	0.3	4.01	14.3	311.3	125.7	48.3
	Mean	0-9	4.1	0.2	4.27	16.6	263.4	110.3	44.1
		9-18	4.0	0.1	3.91	12.0	285.3	133.4	48.7
4th yr after pruning	T1	0-9	4.5	0.1	4.11	19.0	247.0	155.3	90.7
		9-18	4.3	0.1	4.11	14.3	233.0	143.3	88.0
	T2	0-9	4.3	0.1	4.67	21.4	314.0	140.3	121.3
		9-18	4.4	0.2	4.52	20.2	318.0	215.3	142.7
	T3	0-9	4.4	0.1	4.29	17.7	342.0	215.7	89.3
		9-18	4.3	0.1	4.18	18.9	312.0	179.7	116.7
	T4	0-9	4.1	0.1	3.85	16.9	270.7	116.3	59.0
		9-18	4.1	0.1	4.07	13.9	241.3	134.0	60.0
	Mean	0-9	4.3	0.1	4.23	18.8	293.4	156.9	90.1
		9-18	4.3	0.1	4.22	16.8	276.1	168.1	101.9

and lower profile of soil sampling for the analysis. However, other macro- and secondary nutrient levels varied marginally to moderate levels after pruning where pruned litters retained in the experimental blocks. It may also be noted that there was no improvement or deterioration in soil pH and electrical conductivity of the soils and interestingly no variation among the treatments when compared to that of pre and post-treatment soils with respect to OM content as well.

Burial of pruning enhanced the soil biota (Table 6). When compared to the pretreatment analysis of soil micro flora, the post treatment results confirmed an increase in the populations of total bacteria, fungi, *Trichoderma* spp., actinomycetes, *Azosprillum* spp, phosphate solubilising bacteria (PSB) and *Psedomonas* spp. Presence of soil microbes varied from marginal to moderate levels two years after pruning and that too in the treatments were pruned litters are retained in the experimental

Table 6. Abundance in soil micro flora with respect to burial of pruned materials

Sampling time	Soil micro flora colony forming unit (cfu)/g soil	Treatment			
		T1	T2	T3	T4
Pre-treatment	Total bacteria (10^6)	1.44	1.58	1.61	1.27
	Total fungi (10^3)	47.33	44.83	40.67	34.00
	Trichoderma sp. (10^3)	2.67	3.83	5.33	5.00
	Actinomycetes (10^4)	34.33	9.00	10.47	7.82
	Azosprillum sp.	8.17	6.35	5.67	5.50
	PSB	6.00	5.83	5.17	4.13
	Psedomonas sp.	5.67	5.00	5.27	3.67
4th year after pruning	Total bacteria (10^6)	1.77	1.72	1.88	1.18
	Total fungi (10^3)	53.00	51.17	47.33	33.00
	Trichoderma sp. (10^3)	3.30	4.97	6.67	4.33
	Actinomycetes (10^4)	36.80	10.97	11.80	7.12
	Azosprillum sp.	8.83	6.92	6.27	28.57
	PSB	6.83	7.00	5.40	4.10
	Psedomonas sp.	6.17	6.27	6.07	5.57

blocks. In control blocks rapid improvement in *Azosprillum* spp., was observed. The influence of abiotic factors and altered microclimate through application of weedicides, synthetic fertilizers, spillage of foliar applied pesticides and fungicides have negative impact on soil borne microorganisms.

As mentioned earlier, management of the tea bush by periodical pruning had been suggested as main reason for revitalizing the plant vigour. Indeed, low standing biomass of tea when compared to the juvenile forests is due to the continuous plucking that limits the quantum of photosynthetic machineries as well as favourable partitioning of assimilates (Magambo and Cannell, 1981). Kamau *et al*. (2000) reported that tea plants partitioned most of the dry matter in the woody tissue of the frame compared to roots and foliage. In the present study, partial strand left above ground at the time of pruning and below ground mass were not quantified. It may be noted that determination of above ground mass is quite possible while below ground mass lead to erratic results.

Relatively higher amount of dry matter was partitioned towards the above ground parts, particularly woody tissue, representing 70-80% of total phytomass based on the severity of the cut (Satyanarayana *et al*., 1994). Stem to maintenance leaf ratio was found to be 1:0.47, irrespective of the treatments which substantiate the findings of Kamau *et al*. (2000). Compared to the dry matter partitioning towards the canopy (stem), roots and foliage drained the photoassimilates in a range of 12–20% and 8–10%, respectively (Raj Kumar, 2002; Raj Kumar and Jibu Thomas, 2005).

Biomass produced and carbon stock of given vegetation had a direct relationship. According to the adopted agricultural practices, it is pertinent that the tea ecosystem serve as a strong C sink both *in situ* (biomass and soil) and *ex situ* (harvested leaf) and eventually sustains the sequestration of atmospheric carbon source to a greater extent (Ajayakumar, 2002; Ayyappan *et al*., 1987a,b; Marimuthu *et al*., 1993). It has been established that carbon stock of architecturally manipulated strands of tea was comparable with that of 30 year old forests (Glenday, 2006). As the age increases from pruning, productivity index declined sharply indicating the rate of dry matter accumulation, while the yield potential increased linearly with age from pruning attributed to its ground cover. In accordance with the cultural operations adopted, particularly mode of harvesting, severity of cut and other cultural practices, the productivity index was manipulated to an extent and it was inversely correlated with the yield potential (Spurgeon Cox, 2002).

Unlike annual crops, soils under tea plantations are believed to be adequately protected by ground cover (Hartemink, 2005). However, it is being cultivated on high rainfall, hilly terrains and tea soils are vulnerable to soil erosion/degradation which may cause poor biomass productivity (George and Singh, 1990). Carbon sequestration in relation to soil stocks of tea ecosystem did not vary much. However, results of the present study authenticated that burial of pruned litters sustained the soil organic carbon while the enhancement was marginal or rather negligible in other treatments. It has also been noticed that there was not much difference between the top and bottom profile in terms of soil OC, irrespective of the treatments. As a consequence of burial of pruning, crop residues may have reduced soil erosion and run-off and therefore maintained the fertility. The age after pruning did not reflect upon accumulation of organic matter content in the soil. Generally, with increasing amount of C and nutrients reserves, the ratio between mobile and structural material increases as was shown for annual crops (Spiertz, 1977). Therefore, it can be concluded that the amount of reserves is more important than the level of N, P or K contents in the soil.

In general, soils of tea plantation are rich in organic matter (OM) content at varying degree which sustain the plants to an extent, even no fertilizers applied at times. The OM flux of south Indian tea soils and its conservation to sustain the soil fertility has been reported earlier (Ranganathan *et al*., 1980). The study indicated that due to periodical harvesting, the OM content of the soil decreased even after burial of pruning which warrants to replenish the soil nutrients, particularly nitrogen. Otherwise decomposition of buried litters may not be completed due to abiotic factors where the soil borne microbes required favorable conditions for their proliferation on the organic matter. It has been observed that the biomass incorporated in the tea soils required a relatively longer period for decomposition since tea is a rainfed crop. Qualis and Haines (1992) demonstrated the difference in decomposition of the dissolved OM samples, where decomposition was inversely related to the content of the humic substances or the initial content of the carbohydrate-rich hydrophilic neutral fraction. They also claimed that the decomposition was inversely related to the content of possibly inhibitory polyphenols and related to the initial organic N or P in the solutions.

Soil borne microbes are the strongest sink in carbon cycle of which rhizosphere microbes are directly involved in maintaining soil fertility and its physical and chemical characteristics. Soil microbes derive nitrogen from the decomposition of soil organic matter, but this microbial activity is driven by recent plant carbon inputs. Changes in plant carbon inputs, resulting from plant species shifts, lead to a negative feedback through microbial nitrogen immobilization (Qualis and Haines, 1992). Precise variations in climatic pattern influence the secondary variables in tea ecosystem which ultimately affect the biomass productivity (Raj Kumar and Mohan Kumar, 2009; Muraleedharan, 2009). The vulnerability of the tea industry in Sri Lanka to global warming and climate change has been reported by Wijerante (1996).

Tea, being an ever green plantation crop there is a lot of potential in carbon sequestration. When compared to that of old forest strands or degraded forests, carbon cycling ability of tea plantations seem to be rhythmic. Even though burial of pruning is a laborious process, when considering the issues on global warming, this could be adopted in tea plantations as a measure of carbon sequestration, which in turn improved the soil fertility, soil biodiversity and the economic yield. Enhanced economic yield and total biomass production per unit area is viable in terms of carbon sequestration and clean development mechanism. Recommended agricultural operations and judicious use of synthetic agrochemicals should be adopted in order to minimize the carbon dioxide emission and to protect the "mother earth" for our future generation.

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