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Research Article

INFLUENCE OF MIXED WEED COMPOST ALONG WITH GREEN MANURE, COVER CROP, BIOFERTILIZER AND INORGANIC FERTILIZER ON SOIL CARBON SEQUESTRATION AND GROWTH OF TEAK

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Abstract: A field trial was conducted to study the influence of mixed weed compost along with green manure, cover crop, biofertilizer and inorganic fertilizer on soil carbon sequestration and growth of teak (*Tectona grandis*) seedlings during 2007-2010 at Elanad, Thrissur Forest Division Kerala. The experiment comprised of nine treatments comprising of weed compost, cover crops, biofertilizers, green manures, chemical fertilizers and their combinations along with control. The results indicated that application of inorganic fertilizer was significantly superior over other treatments in increasing the height of teak plants, followed by compost alone and compost + biofertilizer. Significant enrichment of soil carbon stock both at 0-10 cm and 10- 20 cm layers was in the treatment compost alone followed by green manure.

Keywords: Teak, carbon sequestration, organic manure, green manure

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Introduction

In forest plantations, soil disturbances due to clear felling and burning the slashes during initial establishment of plantations, lead to increased CO_2 emissions. The influence of tropical climate coupled with no organic inputs worsens the soil health conditions. Several workers have found that continuous application of farmyard manure and green manure improved the soil organic carbon in different soils and cropping systems [1-3]. For an improved soil organic carbon management strategy, nutrients from all pools have to be considered. The continued depletion of soil organic matter resulting from continuous establishment of teak for long periods has been identified as a critical problem in most of the teak growing soils of Kerala. The organic carbon stored in the top soil contributing to active nutrient recycling and to gaseous exchange with the atmosphere is the key source of energy for life in the soil. Soils devoid of this energy source are degraded and need to be rejuvenated by elevating the levels of organic carbon through environment friendly techniques.

It is a known fact that application of continuous inorganic fertilizers causes lot of soil fertility problems leading to decline in productivity. However, increasing prices of chemical fertilizers coupled with awareness on their adverse impact on soil /and environment have made the plantation managers to rethink on the possibilities of locally available and sustainable management options. But limited information is available on the use of green manure, compost, integrated use of compost and fertilizer especially in teak plantations and also their impact on soil properties and CO_2 evolution. With this background, this study was conducted to examine the feasibility of applying organic amendments in teak plantations.

The experiment was conducted through field trial. In the field trial, influence of weed compost on growth of teak, CO_2 flux, soil carbon sequestration and soil properties were compared with other organic and inorganic inputs.

Material and Methods

A field trial was conducted to study the influence of mixed weed compost along with green manure, cover crop, biofertilizer and inorganic fertilizer on CO_2 flux, soil carbon sequestration and growth of teak seedlings during 2007-2010.

The detailed information on materials used and methodology adopted for field trial, soil sampling, plant growth data, laboratory analysis of soil, statistical analysis of data etc. are presented in this chapter.

Field trial

The experiment was carried out at Elanad in Thrissur Forest Division, Kerala, which is situated between 10°, 37' N and 76°, 23' E at an altitude of 100 m above mean sea level. The experimental site is 2 km away from Elanad, which is around 30 km from Thrissur (central zone of Kerala). This area receives an annual rainfall of about 2500 mm from both South - West and North - East monsoons and hence it is well distributed from June to November.

Establishment of field plots

Older teak trees of the experimental site had been clear felled, logged and removed by Kerala Forest Department. Without severe disturbances to the soil, pits of size 30 x 30 x 30 cm were taken in an area of 6000 m2 at the recommended spacing of 2 m x 2 m. Teak seedlings of about 3-4 month old and 15 cm height raised through root trainer technology from seed lot of Nilambur province were collected from Mannarappara, Konni Forest Division and planted in the pits during June - July 2007.

Treatment details

The experiment consisted of nine treatments comprising of weed compost, cover crops, biofertilizers, green manures, chemical fertilizers and their combinations along with control [Table-1]. Each treatment was applied to plots of size 10 x 10 m consisting of 25 teak seedlings. Compost made of mixed weeds containing 2.4 % N, 1.24 % P, 1.83 % K, 2.3 % Ca, 1.1 % Mg, 2340 ppm Fe, 127 ppm Cu and 57 ppm Zn were applied in the pits and mixed with soil before planting of seedlings.

In order to select suitable cover crops for teak, an allelopathic study was conducted. For this, seeds of various cover crops such as *Mucuna bracteata, Pueraria javanica* and *Centrosema pubescens* were collected and placed in petri dish lined with tissue paper.

Table-1 Details of treatments

SN	Treatments	Code No
1	Control	T1
2	Compost @ 2 kg plant^{-1}	T2
3	Cover crop seeds @ 3 kg ha^{-1}	T3
4	Compost (1 kg) + inorganic. fert. (1/2 of recommended dose) + *Azospirillum* and P solublizing bacteria (Phosphorus Solublizing Bacteria) @ 2 kg ha^{-1}	T4
5	Inorganic. fert. @ 30-40 g N, 15-20 g P_2O_5 and 15-20 g K_2O (full dose)	T5
6	Biofertilizer (*Azospirillum* and PSB) each @ 2 kg ha^{-1}	T6
7	Compost (1 kg) + inorganic. fert. (1/2 of recommended dose)	T7
8	Compost + (*Azospirillum* and PSB) @ 2 kg ha^{-1}	T8
9	Green manure (*Crotalaria juncea* (L.) seeds@ 25 kg ha^{-1}	T9

Different concentrations of teak leaf extract prepared from matured teak leaves (1.0, 1.5 and 2.0 percent) were applied to these seeds @ 2.5 ml petri dish every day and germination % for a period of 15 days was monitored. Based on percent of germination (81), *Pueraria javanica* was selected and used as cover crop for teak in the field experiment. Inorganic fertilizers were applied in a circular band 15 cm away from seedlings after planting. Biofertilizers such as P solubilizing bacteria (PSB) and *Azospirillum* were purchased from Tamil Nadu Agricultural University and applied through sand @ (1:20) after planting. Sun hemp (*Crotalaria juncea*) was used as green manure in the experiment. Seeds of this plant were sown around teak seedlings during May- June and incorporated into the soil before flowering. The treatments were arranged in randomized Block Design with three replications.

Collection of data on growth parameters

Out of twenty five plants from each plot, 12 plants in the centre of the plot were tagged for recording various biometric observations.

Plant height and Collar girth

Plant height was measured from ground level to the tip of the main shoot of the plants. Mean height of 12 plants was given as plant height in one treatment. Collar girth was measured using a tape at soil level. The data were recorded for a period of three years.

Collection of soil samples

Initial soil samples were collected from 0-10, 10-20 and 20-30 cm depths before the commencement of the experiment. After treatment application, soil sampling was carried out from all the plots annually for a period of three years from 0-10, 10-20 and 20-30 cm depths. The collected soil samples were air dried, sieved through 2 mm sieve and kept ready for analysis.

Soil analysis

Soil samples were collected from respective treatments, air dried and kept for analysis. The soil was subjected to analysis for soil texture, bulk density, organic carbon, available P and exchangeable bases as per standard procedures. Stock was estimated using the equation

$$SOC = \frac{OC\ (\%)}{100} \times \rho_b\ (Mg\ m^{-3}) \times \frac{(100 - \%\ coarse\ fraction)}{100} \times \text{layer depth (m)} \times 10^4\ (m\ ha^{-1})$$

where,

ρ_b = bulk density.

OC = soil organic carbon

Statistical analysis

Data on both plant and soil parameters were subjected to analysis of variance and mean comparison test was carried through Duncan's multiple range test (DMRT) using SPSS version 17.

Results and Discussion

Soils of the experimental site

The soil of the experimental site belonged to Velappaya series [Table-2], which belongs to the order Ultisol in bench mark soils of Kerala. The soil was medium reddish and clay loam in texture with bulk density of 1.29 Mg m-3. It was acid in reaction (pH 5.24) with very little content of soluble salts (EC 0.08). Compared to natural forests, the content of organic carbon was also low (0.81 %). With regard to plant availability of major nutrients, N was in the lower range (210 kg ha-1), while P (4.72 mg kg-1) and K (0.36 c mol (+) kg-1) were in the medium range.

Table-2 Initial soil characteristics of experimental site

SN	Particulars	Value
1	Physical properties	
a	Particle size distribution	
	Sand (%)	78
	Silt (%)	10
	Clay (%)	12
b	Bulk density (Mg m^{-3})	1.29
2	Chemical properties	
a	pH (1:2.5)	5.24
b	EC (1:2.5) dS m^{-1}	0.08
c	Organic carbon (%)	0.81
d	Available N (kg ha^{-1})	210
e	Bray extractable P (mg kg^{-1})	4.72
f	Exchangeable K (c mol (+) kg^{-1}	0.36

Growth parameters

Plant height

Measurements on plant height were recorded at the time of planting and also up to three years after planting. Data on mean height of seedlings [Table-3] at one year after planting varied from 74.7 to 84.1 cm and statistical analysis revealed no significant difference between treatments.

Application of treatments resulted in increased height of teak plants both after second and third year. The mean height of the plants after two and three years of planting varied from 107.7 to 164.0 cm and 243.7 to 409.2 cm, respectively. As observed in the first year, there was no significant difference between the treatments after second year also. But at the end of third year, application of inorganic fertilizer resulted in significant increase in height (409.2 cm) and this was found to be on par with the treatments - compost alone (397.3 cm), compost + inorganic fertilizer + biofertilizer (374.0 cm) and compost + biofertilizer (369.9 cm).

Poor initial fertility status of soil is thought to be a probable reason for delayed response of teak seedlings to various treatments. Among the treatments, significant increase in height was observed due to application of inorganic fertilizers, which always have a direct role in increasing the availability of nutrients in the soil and their absorption by teak plants [4]. But, mineralization and release of nutrient is comparatively a slow process with respect to organic manures. This is another possible reason for delayed response shown by teak seedlings in organic treatments. In addition to direct supply of nutrients through decomposition and mineralization, organic manures also had a solublizing effect on fixed form of nutrients in the soil thus favoring the availability of nutrients [5]. Beneficial effect of organic manures on yield also might be due to additional supply of plant nutrients as well as improvement in physical and biological properties of soil [6]. Integrated management of nutrient through chemical fertilizers, organic and green manures is extremely important for sustainable productivity [7].

Collar girth

The data on mean collar girth varied from 5.5 to 7.7 , 8.7 to 11.1 and 12.6 to 17.3 cm at first, second and third year after planting respectively [Table-2]. Even though there was an increase in collar girth with increase in the age of plants, it was not significant when treatments were compared. After three years of growth, maximum collar girth was recorded in the treatment inorganic fertilizer (17.3 cm) followed by compost + biofertilizer (15.3 cm) and compost+ inorganic fertilizer (14.1 cm).

Teak being a fast growing species is generally observed to put on its vertical growth during the initial years of growth. This can be the reason for the nonsignificance of various treatments on collar girth even after three years.

Soil properties

Bulk density

Bulk density is an important property influencing plant growth and its value indicates degree of soil compaction. Higher the bulk density, more is the soil compaction.

Table-3 Influence of various treatments on the growth of teak seedlings

SN	Treatments	Ist year		IInd year		IIIrd year	
		Height (cm)	Girth (cm)	Height (cm)	Girth (cm)	Height (cm)	Girth (cm)
1	Control	76.2	7.1	139.8	10.2	243.7^{d}	13.9
2	Compost	74.7	6.8	134.4	10.0	397.3^{ab}	13.4
3	Cover crop	77.3	6.9	160.9	9.8	267.8^{cd}	13.9
4	Compost + inorganic. fert.+ biofert.	76.3	5.6	122.9	11.1	374.0^{ab}	14.0
5	Inorganic. fert.	77.3	7.7	155.4	10.0	409.2^{a}	17.3
6	Biofertilizer	84.1	5.9	107.7	8.7	317.2^{bcd}	13.6
7	Compost + inorganic. fert.	78.0	5.6	109.7	9.8	328.8^{abc}	14.1
8	Compost + Biofertilizer	76.3	6.8	164.0	10.8	369.9^{ab}	15.3
9	Green manure	75.3	5.5	109.8	9.4	341.9^{abc}	12.6
	F value	0.521^{ns}	1.133^{ns}	1.372^{ns}	0.760^{ns}	5.254*	1.841^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-4 Influence of various treatments on bulk density of soil (Mg m^{-3})

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	1.28	1.25	1.33	1.21	1.22	1.34	1.23^{a}	1.28	1.34
2	Compost	1.27	1.25	1.32	1.16	1.22	1.34	1.14^{c}	1.20	1.30
3	Cover crop	1.27	1.26	1.33	1.17	1.19	1.33	1.18^{abc}	1.24	1.30
4	Compost + inorganic. fert.+ biofert.	1.25	1.24	1.33	1.17	1.19	1.32	1.16^{bc}	1.20	1.29
5	Inorganic. fert.	1.26	1.24	1.34	1.22	1.22	1.34	1.21^{ab}	1.26	1.34
6	Biofertilizer	1.22	1.28	1.35	1.20	1.21	1.35	1.24^{a}	1.30	1.34
7	Compost + inorganic. fert.	1.24	1.30	1.35	1.15	1.24	1.36	1.20^{abc}	1.23	1.34
8	Compost + Biofertilizer	1.23	1.26	1.35	1.18	1.31	1.34	1.19^{abc}	1.24	1.35
9	Green manure	1.19	1.26	1.33	1.19	1.23	1.36	1.15^{bc}	1.21	1.27
	F value	1.623^{ns}	0.975^{ns}	1.023^{ns}	1.622^{ns}	1.893^{ns}	1.341^{ns}	3.016*	2.55^{ns}	1.85^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-5 Influence of various treatments on pH of the soil

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	5.38	5.16	5.20	5.36	5.16	5.20	5.08^{b}	5.16	5.20
2	Compost	5.31	5.34	5.21	5.41	5.31	5.21	5.63^{a}	5.31	5.21
3	Cover crop	5.62	5.37	5.22	5.51	5.39	5.22	5.48^{ab}	5.39	5.22
4	Compost + inorganic. fert.+ biofert.	5.38	5.44	5.26	5.54	5.39	5.26	5.70^{a}	5.39	5.26
5	Inorganic. fert.	5.60	5. 22	5.24	5.36	5.28	5.24	5.07^{b}	5.28	5.24
6	Biofertilizer	5.57	5.27	5.12	5.41	5.19	5.12	5.09^{b}	5.19	5.12
7	Compost + inorganic. fert.	5.67	5.22	5.29	5.40	5.18	5.29	5.5^{ab}	5.18	5.29
8	Compost + Biofertilizer	5.62	5.34	5.21	5.44	5.36	5.21	5.67^{a}	5.36	5.21
9	Green manure	5.64	5.38	5.34	5.41	5.27	5.34	5.46^{ab}	5.27	5.34
	F value	0.597^{ns}	0.879^{ns}	1.455^{ns}	0.293^{ns}	0.639^{ns}	0.798^{ns}	2.762*	0.776^{ns}	0.741^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-6 Influence of various treatments on the content of organic carbon (%) in soil

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	0.80	0.70	0.57	0.85^{d}	0.68^{c}	0.56	0.93^{c}	0.68^{c}	0.59
2	Compost	0.81	0.72	0.55	1.07^{a}	0.94^{a}	0.54	1.31^{a}	1.23^{a}	0.54
3	Cover crop	0.80	0.69	0.52	0.90^{cd}	0.79^{b}	0.56	1.01^{bc}	0.95^{c}	0.56
4	Compost + inorganic. fert.+ biofert.	0.85	0.71	0.49	1.04^{a}	0.85^{b}	0.56	1.26^{a}	1.06^{b}	0.60
5	Inorganic. fert.	0.80	0.75	0.54	0.92^{cd}	0.81^{b}	0.56	1.03^{bc}	0.83^{d}	0.59
6	Biofertilizer	0.84	0.69	0.51	0.88^{cd}	0.79^{b}	0.57	0.97^{c}	0.83^{e}	0.52
7	Compost +inorganic. fert.	0.85	0.74	0.54	0.94^{bcd}	0.83^{b}	0.53	1.08^{b}	1.06^{b}	0.52
8	Compost + Biofertilizer	0.83	0.75	0.59	1.03^{ab}	0.87^{ab}	0.54	1.24^{a}	0.98^{c}	0.57
9	Green manure	0.84	0.76	0.52	0.98^{abc}	0.94^{a}	0.53	1.24^{a}	1.12^{b}	0.51
	F value	1.1417^{ns}	1.567^{ns}	1.343^{ns}	6.214**	9.353**	0.656^{ns}	18.641**	72.477**	2.339^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-7 Influence of various treatments on SOC (Mg ha^{-1}) in the soil

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	8.69	7.69	6.58	8.72^{c}	7.13^{d}	6.20	9.74^{c}	7.29^{e}	6.47
2	Compost	8.84	7.97	6.20	10.39^{ab}	10.08^{a}	5.90	12.75^{a}	12.05^{a}	5.93
3	Cover crop	8.81	7.71	5.86	8.97^{bc}	8.10^{cd}	6.16	10.25^{c}	9.74^{cd}	6.11
4	Compost +inorganic. fert.+ biofert.	9.10	7.75	5.57	10.36^{ab}	8.79^{abc}	6.23	12.40^{ab}	10.51^{bc}	6.51
5	Inorganic. fert.	8.76	8.16	6.11	9.55^{abc}	8.37^{bcd}	6.03	10.77^{c}	8.78^{d}	6.52
6	Biofertilizer	8.73	7.72	5.90	8.98^{bc}	8.19^{cd}	6.19	10.24^{c}	8.74^{d}	5.86
7	Compost + inorganic. fert.	9.03	8.43	6.25	9.45^{abc}	8.76^{abc}	6.04	11.12^{bc}	10.76^{bc}	5.75
8	Compost + Biofertilizer	8.73	8.39	6.78	10.43^{a}	9.62^{ab}	6.02	12.63^{a}	9.97^{bc}	6.20
9	Green manure	8.61	8.41	5.79	10.15^{ab}	9.96^{a}	5.99	12.15^{ab}	11.12^{ab}	5.34
	F value	0.227^{ns}	1.283^{ns}	1.752^{ns}	2.566*	5.054**	0.254^{ns}	7.426**	13.329**	2.262^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-8 Influence of various treatments on available P in the soil (mg kg^{-1})

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	4.30^{d}	3.86	3.52	4.21^{e}	4.09	3.36	4.59^{d}	4.26^{e}	3.54
2	Compost	4.76^{c}	3.91	3.53	6.09^{b}	4.11	3.70	6.86^{abc}	4.63^{bcd}	3.82
3	Cover crop	4.38^{d}	3.97	3.10	5.40^{c}	4.2	3.85	5.28^{d}	4.43^{cde}	3.73
4	Compost + inorganic. fert.+ biofert.	5.24^{b}	4.10	3.43	6.45^{a}	4.44	3.63	7.56^{a}	4.90^{ab}	3.63
5	Inorganic. fert.	5.61^{a}	3.77	3.54	6.50^{a}	4.43	3.58	6.97^{abc}	5.05^{a}	4.16
6	Biofertilizer	4.34^{d}	3.84	3.47	5.19^{cd}	4.36	3.54	6.24^{c}	4.39^{de}	3.70
7	Compost + inorganic. fert.	5.17^{b}	4.24	3.44	5.90^{b}	4.24	3.46	7.21^{ab}	4.79^{ab}	3.59
8	Compost + Biofertilizer	4.36^{d}	4.20	3.50	4.98^{d}	4.16	3.85	6.76^{abc}	4.70^{bc}	3.76
9	Green manure	5.05^{bc}	4.22	3.47	5.76^{b}	4.28	3.50	6.39^{bc}	4.78^{ab}	3.60
	F value	15.991**	2.305^{ns}	0.784^{ns}	41.423**	0.413^{ns}	1.223^{ns}	12.274**	8.003**	1.709^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-9 Influence of various treatments on exchangeable K (c mol (+) kg^{-1}) content in the soil

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	0.70	0.69	0.68	0.73	0.75	0.83	0.81	0.82	0.77
2	Compost	0.70	0.73	0.75	0.74	0.76	0.81	0.80	0.76	0.78
3	Cover crop	0.76	0.74	0.72	0.73	0.76	0.84	0.77	0.78	0.80
4	Compost + inorganic. fert.+ biofert.	0.77	0.78	0.74	0.69	0.71	0.82	0.75	0.80	0.82
5	Inorganic. fert.	0.75	0.77	0.75	0.73	0.76	0.83	0.80	0.82	0.79
6	Biofertilizer	0.76	0.74	0.76	0.75	0.77	0.85	0.77	0.79	0.78
7	Compost + inorganic. fert.	0.75	0.74	0.75	0.73	0.71	0.82	0.82	0.81	0.79
8	Compost + Biofertilizer	0.75	0.73	0.71	0.74	0.76	0.83	0.83	0.78	0.78
9	Green manure	0.76	0.73	0.77	0.71	0.74	0.82	0.79	0.82	0.76
	F value	1.192^{ns}	0.809^{ns}	1.054^{ns}	0.403^{ns}	0.808^{ns}	0.559^{ns}	1.666^{ns}	1.008^{ns}	0.370^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-10 Influence of various treatments on exchangeable Ca (c mol (+) kg^{-1}) content in the soil

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	1.15	1.10	1.02	1.26	1.15	1.04	1.28	1.10	0.95
2	Compost	1.17	1.06	1.04	1.34	1.02	1.03	1.27	1.04	0.98
3	Cover crop	1.16	1.09	1.10	1.22	1.09	1.01	1.22	1.05	0.99
4	Compost + inorganic. fert.+ biofert.	1.18	1.08	1.04	1.21	1.08	1.03	1.26	1.05	0.98
5	Inorganic. fert.	1.20	1.11	1.02	1.26	1.08	1.06	1.33	1.10	1.03
6	Biofertilizer	1.16	1.11	1.03	1.23	1.12	1.09	1.26	1.11	0.95
7	Compost + inorganic. fert.	1.12	1.10	1.00	1.25	1.14	1.09	1.26	1.12	0.97
8	Compost + Biofertilizer	1.15	1.17	1.01	1.30	1.06	1.07	1.28	1.07	0.94
9	Green manure	1.16	1.11	1.03	1.42	1.12	1.02	1.27	1.03	0.95
	F value	0.814^{ns}	1.247^{ns}	0.898^{ns}	1.157^{ns}	0.837^{ns}	1.022^{ns}	0.327^{ns}	1.442^{ns}	2.032^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

Table-11 Influence of various treatments on exchangeable Mg (c mol (+) kg-1) content in the soil

SN	Treatment	Ist year			IInd year			IIIrd year		
		0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
1	Control	0.62	0.62	0.58	0.64	0.60	0.58	0.57	0.57	0.61
2	Compost	0.60	0.55	0.58	0.61	0.60	0.57	0.62	0.61	0.59
3	Cover crop	0.61	0.60	0.57	0.63	0.59	0.60	0.59	0.57	0.59
4	Compost + inorganic. fert.+ biofert.	0.62	0.60	0.60	0.63	0.60	0.57	0.64	0.58	0.61
5	Inorganic. fert	0.58	0.60	0.60	0.60	0.56	0.58	0.60	0.56	0.59
6	Biofertilizer	0.61	0.61	0.61	0.63	0.59	0.58	0.62	0.58	0.59
7	Compost + inorganic. fert.	0.59	0.61	0.59	0.61	0.58	0.56	0.61	0.58	0.58
8	Compost + Biofertilizer	0.54	0.58	0.57	0.57	0.59	0.55	0.58	0.58	0.59
9	Green manure	0.56	0.61	0.55	0.60	0.60	0.58	0.60	0.57	0.54
	F value	0.231^{ns}	0.123^{ns}	0.168^{ns}	0.119^{ns}	0.085^{ns}	0.086^{ns}	0.341^{ns}	0.048^{ns}	0.216^{ns}

Note: Means in each column with same letter as superscript are homogeneous, ns- nonsignificant, ** - significant at P= 0.01, *- significant at P= 0.05

The problems due to higher soil compaction can be resolved by decreasing soil disturbance and increasing soil organic matter. The management practices that use cover crops, crop residues, perennial sod, and/or reduced tillage usually result in increased soil organic matter and hence reduced bulk density. The data obtained in the present study [Table-4] revealed that soil bulk density of soil varied from 1.19 to 1.28, 1.24 to 1.30 and 1.32 to 1.35 Mg m-3 in 0-10, 10-20 and 20-30 cm depths respectively after the first year. But the effect of various treatments on this soil property was not significant during this period with respect to bulk density. After a period of two years also, the effects due to various treatments on bulk density was not significant at all the three depths and the mean data varied from 1.15 to 1.22, 1.19 to 1.31 and 1.32 to 1.36 Mg m-3 at 0-10, 10-20 and 20-30 cm depths respectively. By the end of third year, mean bulk density varied from 1.14 to 1.24, 1.20 to 1.30 and 1.27 to 1.35 Mg m-3 at 0-10, 10-20 and 20-30 cm depths respectively. The data evidently demonstrated the fact that application of compost significantly reduced the bulk density of surface soil when compared with control and other treatments. It was further noticed that all treatments those involved the application of compost, either alone or in combination with other treatments also resulted in lower bulk density. Lower bulk density is supposed to increase infiltration, percolation, aeration and also shown to promote seedling survival in neotropical forest [8]. However, the bulk density of soil at 10-20 and 20-30 cm depths were not significantly affected by the application of various treatments. It was further observed that the bulk density increased with increase in the depth of soil irrespective of the treatments. This may be due to the intense laterisation process that was prevailing in the study area coupled with compaction brought out by the weight of overlying soil.

pH

The data on pH of the soil given in [Table-2] indicated that the pH of soil selected for the study was strongly acid in reaction with a pH of 5.24. After a period of one year, pH varied from 5.31 to 5.67, 5.16 to 5.44 and 5.12 to 5.34 at 0-10, 10-20 and 20-30cm layers respectively [Table-5]. But any of the treatments couldn't produce significant changes in all these depths. After a period of two years, pH varied from 5.36 to 5.54, 5.16 to 5.39 and 5.12 to 5.34 in 0-10, 10-20 and 20-30 cm depths respectively. Here also, application of different treatments had no significant effect on soil reaction at all the three depths. This could be due to the fact that the soil of the experimental site had a relatively high acidity, which cannot be ameliorated immediately by the application of the treatments. But after three years, soil pH increased significantly in most of the plots treated with organic amendments compared to mineral fertilizer and control at 0-10 cm depth. Mean pH values at this depth varied from 5.07 to 5.70. Among the treatments, compost alone, compost + inorganic fertilizer + biofertilizer and compost + biofertilizer were significantly superior over other treatments in increasing soil pH. But at lower depths, the effects due to treatments were not significant and mean values ranged from 5.16 to 5.39 and 5.12 to 5.34 at10-20 and 20-30 cm depths, respectively. The above results corroborated with the results reported by [9], where organic managed systems increased soil pH levels in mildly acidic soils. Regular application of compost was found out to maintain or enhance soil pH [10]. The alkaline cations which are released during the decomposition of organic matter might be playing a key role in enhancing the pH of the soil. In Kerala, application of compost to Dalbergia latifolia could cause significant increase in soil pH [11].

Organic carbon

The data given in [Table-6] revealed that after a period of one year, the content of organic carbon in soils applied with various treatments varied from 0.80 to 0.85, 0.69 to 0.76 and 0.49 to 0.59 % at 0-10, 10-20 and 20-30 cm depths respectively. But, the effect of treatments was not significant at any of the depths. It was also noted that there was a general decrease in its content with increase in the depth of soil in all the treatments. After a period of two years, the content of organic carbon ranged from 0.85 to 1.07, 0.68 to 0.94 and 0.53 to 0.57 % at 0-10, 10-20 and 20-30 cm depths, respectively. In general, there was an increase in the content of organic carbon especially at Ist two layers compared to first year. Compared to control, all the treatments had significant influence in enhancing the organic carbon content of soil at these two depths. The treatments compost alone and compost+ inorganic fertilizer + biofertilizer were significantly superior over other treatments at 0-10 cm depth while, compost alone and green manure were significantly superior at 10- 20 cm depth. The treatment compost + biofertilizer was found on par with the above superior treatments at both layers. But significant changes due to the application of any of the treatments could not be observed at 20- 30 cm depth. As observed during 2nd year, at the end of the 3rd year also significant influence of various treatments in enriching the organic carbon was observed at both 0-10 and 10-20 cm depth layers of soil. The treatments compost alone, compost+ inorganic fertilizer + biofertilizer, compost+ biofertilizer and green manure were significantly superior over other treatments at 0-10 cm depth. But at 10-20 cm depth, the treatment compost alone was found superior. This was followed by the treatments green manure, compost+ inorganic fertilizer + biofertilizer and compost+ biofertilizer. Impact of various treatments on enhancing the organic carbon at 20-30 cm depth couldn't be observed during this year also. Results in general, indicated that those plots which received compost as one of its treatments significantly improved the soil organic carbon content. These observations were in line with [12] and [13], where application of organic amendments improved the soil organic carbon to a considerable extent. The direct addition of high quality compost might be enriching the soil organic pool at a faster rate. There was a significant increase in organic carbon percentage in the soil after four years of application of farm yard manure and green manures. According to them, accumulation of organic matter was greater with farm yard manure than green manures [14]. Compost, being a final product of decomposition contain mostly recalcitrant form of carbon. But in contrast, easily degradable carbon is more dominant in green manure than compost. This could be the reason for higher retention of carbon in compost applied plots than green manure.

Soil organic carbon stock (SOC)

Soil organic carbon stock is highly sensitive to land use changes and management practices. Soil organic carbon stock gives an idea about the amount of carbon sequestrated in soil over years. Here in this part of the study it is attempted to quantify the stock of organic carbon in the soil as influenced by various treatments.

The data given in [Table-6] showed that after a period of one year SOC varied from 8.61 to 9.10, 7.71 to 8.43 and 5.57 to 6.78 Mg ha-1 at 0- 10, 10-20 and 20-30 cm depths, respectively and there was no significant difference among the treatments at any of the depths. Decomposition and humification of organic amendments is a time consuming process and this can be the reason for the non significance between the treatments. By the end of second year, mean SOC ranged from 8.72 to 10.43, 7.13 to 10.08 and 5.90 to 6.23 Mg ha-1 at 0- 10, 10-20 and 20-30 cm depths, respectively and there was significant difference between the treatments at 0- 10 and 10-20 cm layers. At 0 - 10 cm layer, the treatment compost + biofertilizer was significantly superior and this was on par with compost alone, compost + inorganic fertilizer + biofertilizer and green manure. At 10 - 20 cm layer, the treatments compost alone and green manure were significantly superior in enriching the organic carbon stock of the soil and on par with the treatments compost + biofertilizer. At 20 - 30 cm layer SOC was found unaffected by any of the treatments. At the end of third year also, SOC was significantly influenced by various treatments at both 0 - 10 and 10 - 20 cm layers. Significantly superior treatments at 0-10 cm layer were compost alone and compost + biofertilizer and they were on par with the treatments compost + inorganic fertilizer + biofertilizer and green manure. At 10 - 20 cm layer, compost alone was significantly superior and this was on par with green manure treatment. Here also at 20- 30 cm layer, SOC was found unaffected by any of the treatments. The results, in general, conveyed that application of compost @ 2 kg / plant increased the stock of soil organic carbon and this was probably due to the presence of more stable organic carbon in compost [15]. Significantly higher stock of carbon even at a depth of 10- 20 cm by the application of green manure is assumed due to the contribution from decayed root mass present in this soil layer [16].

Available P

Statistical analysis of the data on soil available P [Table-8] revealed that after one year, it varied from 4.30 to 5.61, 3.77 to 4.24 and 3.10 to 3.54 mg kg-1 at 0- 10, 10-20 and 20-30 cm depths. Various treatments were significantly different from each other in influencing the available P at 0- 10 cm depth. Significantly higher available P (5.61mg kg-1) was observed due to the application of inorganic fertilizer. This was followed by the treatments compost + inorganic fertilizer + biofertilizer (5.24 mg kg-1) and compost+ biofertilizer (4.36 mg kg-1). But at 10-20 and 20-30 cm depths, the effect due to various treatments was not conspicuous. By the end of second year, the mean available P varied from 4.21 to 6.50, 4.09 to 4.44 and 3.36 to 3.85 mg kg-1 at 0- 10, 10-20 and 20-30 cm depths, respectively. At 0-10 cm layer, all the treatments were significantly different from each other. Significantly higher content of available P was noted due to the application of inorganic fertilizer alone (6.50 mg kg-1) and compost + inorganic fertilizer + biofertilizer (6.45 mg kg-1). The treatments compost alone, compost+ inorganic fertilizer and green manure were also found contributing significantly to the available P pool. The effect due to treatments at 10-20 and 20-30 cm depths was not significant during this period also. After a period of three years, the effect of treatments was significant at both 0-10 and 10-20 cm depths. The mean values of available P ranged from 4.59 to 7.56, 4.26 to 5.05 and 3.54 to 4.16 mg/ kg at 0-10, 10-20 and 20-30 cm depths, respectively. At 0 -10 cm depth, the treatment compost+ inorganic fertilizer + biofertilizer was significantly superior in enhancing the available P content followed by compost+ inorganic fertilizer and compost alone. At 10-20 cm depth, the treatment inorganic fertilizer was significantly superior followed by compost + inorganic fertilizer + biofertilizer, compost + inorganic fertilizer and green manure. Results, in general, indicated that plots received mineral fertilizer, however, had higher levels of available P than those under other treatments, in all the three years of study and this is presumably due to the direct impact of applied chemical fertilizers. This direct effect of inorganic fertilizers were also noted when they were applied along with compost. The influence of compost in elevating the available P pool has become conspicuous only by the second year and the treatments involving composts became on par with inorganic treatments by the end of third year. Lower availability of P in plots applied with organic amendments during first year might be due to its slow release from organic bonds [17,18]. The increase in available P in organic amendment applied plots during subsequent years is attributed to the solubilization of native P through the release of various organic acids during decomposition of organic amendments in addition to its direct release. Improvements in available P status due to integrated use of manures and fertilizers have been noted by [19]. Incorporation of manure and crop residues resulted in improvements in available P [20]. However, the results pointed out that the effects of organic amendments are not restricted to the year of application and its beneficial effects are found spread over a long period of time.

Exchangeable bases

This section deals with important exchangeable bases like K, Ca and Mg. As the presence of exch. Na is significantly low in laterite soil, its effect is not considered in this study.

Exchangeable K

The statistical analysis of the data on soil exchangeable K [Table-8] revealed that there was no significant difference between treatments at any of the depths after one year. Its values varied from 0.70 to 0.76, 0.69 to 0.78 and 0.68 to 0.77 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths. After a period of two years, exch. K varied from 0.69 to 0.74, 0.71 to 0.77 and 0.81 to 0.85 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths, respectively. As observed in previous year, there was no significant difference among the treatments at any of the depths. Similar to first and second year, the effect of treatments on exch. K after a period of three years was not significant at any of the depths. The mean exch. K ranged from 0.75 to 0.83, 0.76 to 0.82 and 0.76 to 0.82 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths, respectively.

Exchangeable Ca

The statistical analysis of the data on soil exchangeable Ca [Table-10] revealed that there was no significant difference between treatments at any of the depths after one year of application of treatments. The data on exch. Ca varied from 1.12 to 1.20, 1.06 to 1.17 and 1.0 to 1.10 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths. After a period of two years, exch. Ca varied from 1.21 to 1.42, 1.02 to 1.15 and 1.01 to 1.09 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths, respectively. As observed in previous year, there was no significant difference among the treatments at any of the depths. Similar to first and second year, the effect of treatments on exch. Ca after a period of three years also was not significant at any of the depths. The mean exch. Ca ranged from 1.22 to 1.33, 1.03 to 1.12 and 0.94 to 1.03 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths, respectively.

Exchangeable Mg

The data on soil exchangeable Mg [Table-11] revealed that there was no significant difference between treatments at any of the depths after one year of application of treatments. The data on exch. Mg varied from 0.54 to 0.62, 0.55 to 0.62 and 0.55 to 0.61 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths. After a period of two years, exch. Mg varied from 0.57 to 0.64, 0.56 to 0.60 and 0.55 to 0.60 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths, respectively. As observed in previous year, there was no significant difference among the treatments at any of the depths. Similar to first and second year, the effect of treatments on exch. Mg after a period of three years was not significant at any of the depths. The mean exch. Mg values ranged from 0.57 to 0.64, 0.56 to 0.61 and 0.54 to 0.61 c mol (+) kg-1 at 0- 10, 10-20 and 20-30 cm depths, respectively. Teak, being a moist deciduous species, show an affinity towards bases available in the soil and accumulate them within the plant parts. So, the non significant effect of various treatments on exchangeable base status of soil is thought to be due to their faster absorption by the fast growing teak seedlings. Moreover, teak is considered as a calcicore and hence, utilises maximum calcium from the soil. Another probable reason for the non significant effect of treatments can be due to the relatively lower contribution of bases from the applied inputs in comparison with the increased demand by the growing plants.

Conclusion

The results clearly indicated that application of inorganic fertilizer was significantly superior over other treatments in increasing the height of teak plants, followed by compost alone and compost + biofertilizer. No significant improvement in collar girth was observed by the application of any of the treatments. With respect to soil properties, significant reduction in bulk density to a depth of 10 cm was achieved by the application of compost alone while pH was significantly improved by the treatments compost + inorganic fertilizer + biofertilizer and compost + biofertilizer. Significant enrichment of soil carbon stock both at 0-10 cm and 10- 20 cm layers was in the treatment compost alone followed by green manure.

Application of research: Teak plantations have the potential of sequestration of organic carbon in soils if inorganic application of fertilizer replaces with organic manures. This study gave an outline of the improved capacity of soil to sequester soil carbon without effecting growth of teak plants using organic manure application.

Research Category: Soil science, soil fertility

Abbreviations:
SOC – soil organic carbon, P- phosphorus, K – potassium, OC- organic carbon

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