CARBON SEQUESTRATION POTENTIAL OF RUBBER PLANTATIONS UNDER DIFFERENT SOIL MANAGEMENT UNITS (SMUs) OF KERALA

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Climate and landforms exert considerable influence on carbon (C) sequestration potential of agroecosystems. The carbon storage potential and nutrient availability in rubber plantations under different soil management units (SMUs) in three locations of Kerala namely, Thiruvananthapuram district in the southern region, Kottayam in the central region and Palakkad in the northern region were estimated. Significant variation in soil organic carbon (SOC) was observed between different locations, SMUs and SMUs under each location, whereas the variation in SOC stock between locations and SMUs within locations was not significant. An increasing trend in available potassium (K), calcium (Ca) and magnesium (Mg) in soils was observed from the southern to the northern district. Moderate to acute Ca deficiency was also noticed in the southern and central regions indicating the need for scientific intervention with respect to Ca nutrition of rubber plants. The study provided comprehensive estimates of the C sequestration potential of rubber plantations over a period of 25 years in different SMUs in various locations. Rubber plantations of the central region sequestered around 20 per cent more C than the northern region and 12 per cent more than the southern region. Among the SMUs, the C sequestration potential of rubber plantation was the lowest in SMU 5, 6 and 7. The study thus yielded valuable information for developing site-specific integrated C conservation strategies from a more sustainable and climate change perspective.

Keywords: Carbon sequestration, Rubber, Soil available nutrients, Soil management units

INTRODUCTION

The impact of climate change on agroecosystems is a major concern worldwide and can have various effects on crop performance and ecosystem stability. In the traditional rubber growing tracts of India, rubber (*Hevea brasiliensis* Muell. Arg.) is grown in diverse soil and climatic conditions. The ideal climatic conditions required for optimum rubber growth are well distributed rainfall (RF) of 2000 mm or more without any marked dry season and 125 to 150 rainy days per year with maximum temperature of 29 to 34°C and minimum of 20°C or more (Webster and Baulkwill, 1989). Rubber plants can grow in a wide range of soils and it thrives well in deep and well-drained lateritic fertile soil with an acidic pH of 4.5 to 6. For identifying the suitable or non-suitable areas for rubber cultivation and introducing rubber in new

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areas, assessment of land suitability is essential. Land suitability is assessed based on the climate and various land characteristics (Bizuwerk *et al.*, 2005) and it also helps to understand the possibilities and limitations for developing suitable agromanagement practices in different areas for maximizing crop production.

Globally, the climatic resources of rubber growing regions are classified into six hydrothermal zones based on rain fall and temperature. The central and southern parts of the traditional rubber growing regions are in zone 2 (suitable zone) and the northern part in zone 3, the moderate zone (Rao *et al.*, 1993). With respect to rubber growing soils, a high degree of spatial variability was present due to the combined effect of physico-chemical and biological processes that function at various intensities and scales. Soil variability significantly influences the performance of rubber. In order to increase rubber productivity, the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP, 1999) conducted a reconnaissance soil survey in the major rubber growing tract in Kerala during 1996-97. Thematic maps on soil depth, soil gravelliness and slope were prepared and land suitability for rubber was generated through GIS. The survey identified 62 soil series and developed a soil information database for the rubber growing soils of Kerala and grouped the soils into 1 to 7 Soil Management Units (SMUs) with increasing order of the limitation from soil organic carbon (SOC), gravel and soil depth (NBSS & LUP, 1999).

In Kerala, availability of land is a limiting factor for expansion of rubber cultivation and the ever growing demand for natural rubber has necessitated considering areas with different levels of suitability for the expansion of rubber (Menon and Unni, 1990; Sethuraj *et al.*, 1991). Many scientists reported that the establishment of rubber plantation offers enhancement of soil physico-chemical properties and sequestration of atmospheric carbon (C) in the biomass or soil (Geetha and Balagopalan, 2009; Yasin *et al.*, 2010; Boakye, 2015). Plant biomass and soil estimates of rubber plantations in different locations have revealed a large accumulation of C, ranging from 1.4 to 6.7 Mg C ha^{-1} yr^{-1} (Cunha *et al.*, 2000; Yang *et al.*, 2005; Cotta *et al.*, 2006). According to Jacob (2003), the C sequestration potential of the world's rubber plantation is to the tune of 0.0782 Pg C yr^{-1} and it reduces two per cent of the rise in CO_2 in the atmosphere.

Rubber plantations have a great C sequestration potential and it varies with soil and climatic fluctuations (Kongsager *et al.*, 2013). The sequestration of C in the soil and plant biomass of rubber plantations has been estimated, but the amount of C sequestrated by rubber plantations under different SMUs in the rubber growing regions has not been fully evaluated. Because of the importance of C sequestration potential of the rubber plantations in the global C cycle, the present study assessed the carbon sequestration potential of rubber plantations under different soil management units (SMUs) in Kerala.

MATERIALS AND METHODS

In order to bring maximum variability in soil and climate, SMUs in three districts namely, Thiruvananthapuram in the southern region, Kottayam in the central and Palakkad in the northern region were selected for the study. In each district, SMUs were grouped in to three categories *viz.* good (SMU 1 & 2), moderate (SMU 3 & 4) and poor (SMU 5, 6 & 7) considering the limitations of gravel and soil depth (Meti, 2013).

Selection of rubber holdings and soil analysis

From each SMU category of Thiruvananthapuram, Kottayam and Palakkad districts, three rubber holdings were selected and the geographical location was noted using Global Positioning System (GPS). In Thiruvananthapuram district, the rubber holdings in SMU 1 & 2 were located in Nedumangad, SMU 3 & 4 in Maranallur and SMU 5,6 & 7 in Vilappil. In the case of Kottayam district, SMU 1 & 2 were located in Ramapuram, SMU 3 & 4 in Kadanad and SMU 5, 6 & 7 in Ullanad. In Palakkad district, the rubber holdings in SMU 1 & 2 and SMU 5,6 & 7 were located in Kizhakkanchery and SMU 3 & 4 in Vandhazy. Rubber plantations of clone RRII 105 aged 20-25 years with uniform management practices and tapping system (S/2 d2) were selected.

Composite soil samples (0-30 cm) were collected randomly from three rubber holdings in each SMU category of the selected location (a minimum of 10 soil samples were used to make up one composite sample). The collected samples were processed and analysed following the standard analytical protocols. Soil pH was estimated using pH meter, in 1:2.5 soil water suspension. Organic carbon (OC) was determined by wet digestion method (Walkley and Black, 1934). Available phosphorus (P) was extracted by Bray II extractant (Bray and Kurtz, 1945) and the P in the extract was estimated colourimetrically by chlorostannous blue colour. Available potassium (K), calcium (Ca) and magnesium (Mg) were extracted using neutral normal ammonium acetate and K was estimated using flame photometer (Jackson, 1973). Available Ca and Mg in the extract were determined using atomic absorption spectrophotometer. Soil bulk density (BD) was measured by the core sampling method (Black, 1965) and the values are given in Table 1. Soil OC stock in each SMU was calculated using the following formula,

$$\text{SOC stock (t ha}^{-1}\text{) = SOC (\%) x BD (g cm}^{-3}\text{) x depth of soil (cm)}$$

Estimation of C stock in plant biomass

The CO_2 fixation by above and below-ground biomass of rubber plants was estimated using allometric equations, which were previously adopted for rubber trees. For biomass estimation, 50 trees were selected from each rubber holding and the tree girth at a height of 150 cm from bud union was recorded. The average girth of

Table 1. **Growth and yield of rubber and BD of soils under different SMUs**

Parameter	Location	SMUs		
		SMU 1 & 2	SMU 3 & 4	SMU 5, 6 & 7
Girth (cm)	Thiruvananthapuram	80	78	70
	Kottayam	81	79	75
	Palakkad	73	72	71
Yield (kg ha^{-1})	Thiruvananthapuram	1746	1695	1463
	Kottayam	1766	1713	1576
	Palakkad	1365	1328	1313
BD (g cm^{-3})	Thiruvananthapuram	1.24	1.23	1.40
	Kottayam	1.20	1.22	1.23
	Palakkad	1.21	1.24	1.26

plants in each SMU category of selected locations is given in Table 1.

Above-ground biomass (AGB)

Allometric equation developed by Shorrocks *et al.* (1965) was used for the estimation of above-ground biomass (AGB) of trees.

$$AGB\ (kg) = 0.002604\ (G)^{2.7826}$$

Where, G is trunk girth (cm) at the height of 150 cm from bud union.

The C stock of the tree was calculated based on the C content in the standard rubber wood, *i.e.* 42 per cent of the total above ground biomass (Ambily *et al.*, 2012) and C sequestration potential (C_{AGB}) was calculated directly with 325 trees per ha.

Below-ground biomass (BGB)

The below-ground tree biomass was estimated by applying a conversion factor of 0.26 on the above-ground biomass (Jasmin, 2013).

$$BGB = AGB*0.26$$

Where 'AGB' is the above-ground biomass.

Carbon stock in latex

The C sequestration potential of latex was estimated by the following equation

$$C_{Latex} = R \times P \times N$$

Where R is the average C content in the dry rubber (88%), (Sivakumaran *et al.*, 2000), P is the average annual yield per ha. (Table 1) and N is the average economic life span of rubber plantation (18 years).

Finally C sequestration by rubber plantation as a whole was determined using the following equation (Cheng *et al.*, 2007).

Carbon sequestration by rubber plantation per ha (C_R) = $C_{AGB} + C_{BGB} + C_{Latex} + C_{Soil}$.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using the software SPSS and significant differences were reported at $P < 0.05$.

RESULTS AND DISCUSSION

The soil and growth parameters recorded from different soil management units (SMUs) of Thiruvananthapuram, Kottayam and Palakkad districts are presented in Tables 1 to 4.

Soil reaction (pH)

The soil pH of SMUs in different locations ranged from 4.55 to 4.87 and was very strongly acidic (Table 2). Significant variation in soil pH was observed between different locations,whereas variation between SMUs and SMUs under each location was not significant. Thiruvananthapuram (4.58) and Kottayam (4.62) districts showed significantly lower pH values compared to Palakkad district (4.80), indicating slightly more acidic soil reaction towards southern districts.

Acidification of soils is a serious constraint to crop production. The heavy RF prevailing in southern districts leaches all the basic elements (K, Ca and Mg) from the soil preventing soil acidification. According to Bolton (1960) rubber trees have a fair degree of adaptability to a low acidic environment and can grow in a wide range of soils with pH 4.0 to 6.5 (Dijikman, 1951).

Soil organic carbon (SOC)

Significant variation in SOC was observed between different locations, SMUs and SMUs under each location (Table 2). Among the districts, Kottayam (2.33 %) recorded the highest content of SOC compared to other districts. Under different

Table 2. **Variation in soil pH and organic carbon under different SMUs**

Parameter	Location	SMUs			Mean
		SMU 1 & 2	SMU 3 & 4	SMU 5, 6 & 7	
pH	Thiruvananthapuram	4.55	4.60	4.58	4.58
	Kottayam	4.59	4.63	4.63	4.62
	Palakkad	4.87	4.83	4.70	4.80
	Mean	4.67	4.69	4.64	4.67
		Location	SMU	Location * SMU	
	SE	0.04	0.04	0.08	
	CD (P < 0.05)	0.13	NS	NS	
SOC (%)	Thiruvananthapuram	2.26	2.17	1.50	1.97
	Kottayam	2.37	2.33	2.28	2.33
	Palakkad	2.36	2.28	1.55	2.06
	Mean	2.33	2.26	1.77	2.12
		Location	SMU	Location * SMU	
	SE	0.06	0.06	0.33	
	CD (P <0.05)	0.19	0.19	0.11	

SMU categories, SMU 5, 6 & 7 showed the lowest content (1.77 %) of OC in soil. Variation in SOC among different SMUs under each location was also observed. In Thiruvananthapuram and Palakkad, the lowest SOC was observed under SMU 5, 6 & 7, whereas the other SMU categories were on par. In Kottayam district, SOC content in all the SMU categories was on par. In general, SOC content in all the SMU categories under different locations was in the high (>1.5 %) range.

The OC content in soil is directly related to the climate, soil type, management practices, the amount of biomass added and its turnover in the soil. Rainfall is a major driver of plant growth and biological activity which results in more biomass accumulation and decomposition in soil. For better biomass production, rubber plants require an annual RF of over 2000 mm and a well distributed RF throughout the year without any marked dry season (Vijayakumar *et al.*, 2000). The lower precipitation in Palakkad and Thiruvananthapuram districts (Guhathakurta *et al.*, 2020) resulted in comparatively lesser biomass production, thereby lowering OC in soil when compared to Kottayam district.

Available soil nutrient status (P, K, Ca and Mg)

The available soil nutrient (P, K, Ca and Mg) status under different SMUs are presented in Table 3.

The available soil P in different SMUs ranged from 6.9 to 8.6 mg kg^{-1} and did not show any variation between locations, SMUs and SMUs under each location. However, the available soil K, Ca and Mg status in SMUs significantly varied between locations. Among the districts, the highest available K (>125 mg kg^{-1}), Ca (>150 mg kg^{-1}) and Mg (>25 mg kg^{-1}) were observed in Palakkad district and all these nutrients were in the high range. In Thiruvananthapuram district, the available K (<50 mg kg^{-1}) and Ca (<100 mg kg^{-1}) were in the lower range and Mg in the medium range (10-25 mg kg^{-1}). In the

Table 3. **Variation in available soil nutrients under different SMUs**

Parameter	Location	SMUs			Mean
		SMU 1 & 2	SMU 3 & 4	SMU 5, 6 & 7	
Av. P (mg kg^{-1})	Thiruvananthapuram	8.3	7.8	6.9	7.7
	Kottayam	8.4	7.8	8.4	8.2
	Palakkad	8.6	8.3	8.1	8.3
	Mean	8.4	8.0	7.8	8.1
		Location	SMU	Location * SMU	
	SE	2.33	2.33	4.03	
	CD (P < 0.05)	NS	NS	NS	
Av. K (mg kg^{-1})	Thiruvananthapuram	49	45	48	47
	Kottayam	110	107	109	109
	Palakkad	209	214	185	203
	Mean	123	122	114	120
		Location	SMU	Location * SMU	
	SE	7.13	7.13	12.35	
	CD (P < 0.05)	21.19	NS	NS	
Av. Ca (mg kg^{-1})	Thiruvananthapuram	35	74	74	61
	Kottayam	51	47	51	50
	Palakkad	555	354	326	412
	Mean	214	158	151	174
		Location	SMU	Location * SMU	
	SE	10.5	10.5	18.2	
	CD (P < 0.05)	31.2	NS	NS	
Av. Mg (mg kg^{-1})	Thiruvananthapuram	18	19	17	18
	Kottayam	12	14	13	13
	Palakkad	114	112	110	112
	Mean	48	48	47	48
		Location	SMU	Location * SMU	
	SE	2.19	2.19	3.79	
	CD (P < 0.05)	6.51	NS	NS	

case of Kottayam district, the available K (50-125 mg ha^{-1}) and Mg (10-25 mg kg^{-1}) status were in the medium range and Ca (<100 mg kg^{-1}) in the lower range.

High degree of variability in available soil nutrient status was observed between districts which could be attributed to the variation in landforms and the parent material from which the soil is derived. In general, the available P status in rubber plantations was low (<10 mg kg^{-1}) due to the dominance of Kaolinite and Goethite in soil clay (NBSS & LUP 1999). The soils of Palakkad district, unlike the other two are fairly supplied with basic cations like K, Ca and Mg. Major reason for the high content of cations in Palakkad is that the district receives less RF compared to Thiruvananthapauram and Kottayam. Under low RF conditions leaching of all the exchangeable bases (Ca, Mg and K) and salts from the soil profile is very less (Joseph *et al.*, 2008). An increasing trend in available K, Ca and Mg was observed from the southern district (Thiruvananthapuram) to the northern district (Palakkad) and the northern district had significantly higher contents of all these nutrients. In southern and central districts, the available Ca status

Table 4. **Variation in C storage in soil, above and below-ground biomass and latex under different SMUs (t ha^{-1})**

C Storage	Location	SMUs			Mean
		SMU 1 & 2	SMU 3 & 4	SMU 5, 6 & 7	
Soil	Thiruvananthapuram	84	81	65	77
	Kottayam	86	86	84	85
	Palakkad	86	85	59	77
	Mean	86	84	69	80
		Location	SMU	Location * SMU	
	SE	3.6	3.6	6.2	
	CD (P < 0.05)	NS	10.8	NS	
Above-ground biomass	Thiruvananthapuram	69	64	49	61
	Kottayam	78	73	63	72
	Palakkad	59	57	55	57
	Mean	69	65	56	63
		Location	SMU	Location * SMU	
	SE	1.2	1.2	2.1	
	CD (P < 0.05)	3.7	3.7	6.4	
Below-ground biomass	Thiruvananthapuram	18	17	13	16
	Kottayam	19	18	15	17
	Palakkad	14	14	13	14
	Mean	17	16	14	16
		Location	SMU	Location * SMU	
	SE	0.3	0.3	0.5	
	CD (P < 0.05)	0.9	0.9	1.6	
Latex	Thiruvananthapuram	28	27	23	26
	Kottayam	28	27	25	27
	Palakkad	22	21	21	21
	Mean	26	25	23	25
		Location	SMU	Location * SMU	
	SE	0.2	0.2	0.3	
	CD (P < 0.05)	0.6	0.6	1.0	

in soil was low, whereas low available K status was observed in the southern district only. Therefore, in areas with low available K and Ca status, intervention is needed with respect to K and Ca nutrition of rubber plants.

Soil organic carbon stock

Soil organic carbon stock between SMUs varied significantly whereas between locations and SMUs within locations, difference was not significant (Table 4). Among the SMUs, the highest SOC stock was found in SMU 1 & 2 (86 t ha^{-1}) and was on par with SMU 3 & 4 (84 t ha^{-1}) and the lowest in SMU 5, 6 & 7 (69 t ha^{-1}). Around 20 per cent less SOC stock was observed in SMU 5, 6 & 7. The values of SOC stock varied in accordance with the amount of SOC and BD of soil. The SOC and BD of soil in a system are determined by topography, climate, hydrology, type of vegetation and the soil (Gupta and Rao, 1994). The relatively high BD and low SOC contributed to low SOC stock in SMU 5, 6 & 7. Based on the soil characterization by NBSS & LUP (1999), the SMUs 5, 6 & 7 were considered as poor soils with low soil depth.

Carbon storage in above and below-ground biomass and latex

The amount of C accumulated in the above-ground biomass of rubber significantly varied between different locations, SMUs and SMUs under each location (Table 4). The highest quantity of C in the above-ground biomass was observed under rubber plantations of Kottayam district (72 t ha^{-1}) followed by Thiruvananthapuram (61 t ha^{-1}) and the lowest in Palakkad (57 t ha^{-1}). Among the SMUs, the C storage potential of above-ground biomass of rubber was in the order: SMU 1 & 2 > SMU 3 & 4 > SMU 5, 6 & 7. With respect to SMUs under each location, in Thiruvananthapuram and Kottayam district SMU 1 & 2 and SMU 3 & 4 stored significantly higher C than SMU 5, 6 & 7. However, in Palakkad district significant difference was not observed among SMUs.

The C sequestration potential of below-ground biomass of rubber also showed a similar trend as in the case of above-ground biomass C (Table 4).

The significant difference in C sequestration by latex was also observed between different locations, SMUs and SMUs under each location (Table 4). The variations in yield of rubber plants under different SMUs contributed to the difference in C sequestration by latex.

Estimation of plant biomass C is the most critical step in measuring C stocks of land use systems and is strongly correlated with biomass production (Gibbs *et al.*, 2007). For any crop to perform better, suitable climate and soil are the pre-requisites. Variation in the performance of rubber trees in terms of growth and yield under different climate and soil conditions has resulted in significant differences in biomass C stock between different locations, SMUs and SMUs under each location. The non-uniform RF distribution along with the long dry period has resulted in lower growth and yield of rubber trees in Palakkad compared to Thiruvananthapuram and Kottayam. Ding *et al.* (2018) reported that SOC has a profound impact on soil quality and plant growth.

Carbon sequestration by rubber plantations

The total C sequestration by rubber plantations over a period of 25 years per hectare in different SMUs is presented in Figure 1. A significant difference in C sequestration was observed between locations and SMUs. Among the districts, the plantations in Kottayam (201 t ha^{-1}) recorded the highest C sequestration potential compared to Thiruvananthapuram (179 t C ha^{-1}) and Palakkad (168 t ha^{-1}). Between SMUs, the SMU 1 & 2 (197 t ha^{-1}) and SMU 3 & 4 (189 t ha^{-1}) sequestered significantly higher C than SMU 5, 6 & 7 (162 t ha^{-1}).

The total C accumulation in rubber plantations under different locations and SMUs is significantly affected by land use systems, climate, physico-chemical properties of soil and agromanagement practices adopted in different locations. The potential of rubber plants to sequester C has been reported by many researchers (Yang *et al.*, 2005; Jia and Zhou, 2009; Song and Zhang, 2010). In this study, it was observed that the rubber plantations in Kottayam district had around 20 per cent more C sequestration potential than Palakkad and 12 per cent more compared to Thiruvananthapuram district. The uneven distribution of RF, long dry period and available soil nutrients especially Mg exerted a negative impact on the performance of rubber in Palakkad district, indicating low C sequestration potential of rubber plantations in northern districts compared to central and southern districts. Under the unfavourable climatic conditions in Palakkad district, adequate soil and water conservation measures like rain water harvesting, construction of terraces, silt pits and conservation tillage should be adopted to store excess RF received over a short period to reduce water stress during summer season and increase the growing period. Among the

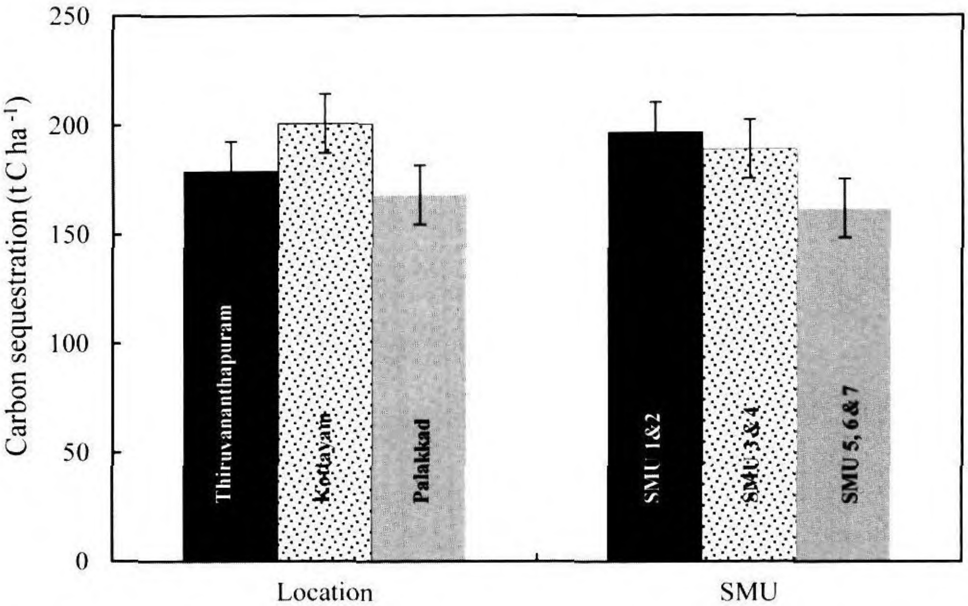

Fig. 1. Carbon sequestration potential of rubber plantations (over a period of 25 years). Error bars indicate LSD at $P < 0.05$.

SMUs, the lowest C sequestration was observed in SMU 5, 6 & 7 due to the shallow nature of the soil and low SOC content.

CONCLUSION

Climate and landforms have a significant influence on spatial variability of soil nutrients and performance of rubber plants, which in turn is intrinsically linked to the C sequestration potential of rubber plantations. In order to improve the performance of rubber and to achieve soil sustainability in rubber plantations, adequate SOC conserving practices like fertilizer application, intercropping and soil and water conservation need to be adopted. Properly managed rubber plantations have a great potential to act as a continuous sink for atmospheric CO_2. Hence more emphasis should be given to identify, design and evolve site-specific sustainable land management strategies within the soil management units, thereby reducing the emission of CO_2 to the atmosphere.

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