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Carbon Sequestration Potential of Oil Palm Plantations in Tamil Nadu Regimes, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author SSR as a part of doctoral thesis under the guidance of authors SPBK and VD is responsible for preparation of manuscript, performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Authors AL, SM, MV and EP provided technical guidance and assisted in statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

Oil palm (*Elaeis guineensis*), being a potential carbon sequestering perennial crop by biological means, has helped in mitigating global warming and climatic fluctuations. In our study, we selected Tenera hybrids in three oil palm plantations of major oil palm growing regions of Theni and Thanjavur districts of Tamil Nadu, India during the year 2019. Carbon sequestration potential was assessed by the standard procedures and methodology. The present study revealed that carbon

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sequestration was higher in trunks, which was found to be 2.57 t C/ha (tons of carbon per hectare) in 4 years, 22.33 t C/ha in 8 years and 59.79 t C/ha in 15 years with respect to the age of plantation. The roots sequestered carbon for about 0.67 t C/ha in 4 years, 5.80 t C/ha in 8 years and 15.54 t C/ha in 15 years old plantations and the fronds sequesters about 1.41 t C/ha in 4 years, 2.44 t C/ha in 8 years and 3.01 t C/ha in 15 years old oil palm plantations. The findings evidenced that the biomass production in oil palm increased proportionally with different age group of oil palm. This findings established the importance of oil palm plantation for carbon sequestration to reduce natural as well as anthropogenic sources for climatic fluctuations.

Keywords: Carbon sequestration; biomass; tenera hybrid; climatic fluctuations.

1. INTRODUCTION

Oil palm (*Elaeis guineensis*) is one of the most important agricultural crops in the tropics with the extensive production of 85% of global palm oil by Malaysia followed by Indonesia. Oil palm one of the most valuable cash crop of the tropical world which covers to the extent of 12 million hectares [1,2]. In consequences, this agro ecosystem seems to be a good candidate to sequester carbon in the tropical countries. It initially involves the capital expenditure when compared to other annual crops such as paddy for the period of the first four years to final yield of the crop. Now a days, land conversion causes negative environmental impacts viz., loss of natural vegetation, reduction in biodiversity, water pollution, and greenhouse gas emissions are the critical issues in many oil palm plantations [3]. In Indonesia, the oil palm plantations during the year 2015 reached up to 11.4 million hectares [4].

Moreover it sequesters the carbon in the biomass and trunk which was equivalent to the rainforest systems. Oil palm is one of the higher biomass and oil yielding plant per unit area than other oilseed crops which had been grown widely in Southeast Asia especially in Malaysia and Indonesia. In India, oil palm estates extended up to 0.33 million hectares in Andhra Pradesh, Karnataka, Tamil Nadu and Kerala. In Tamil Nadu, oil palm growing districts are Tanjore, Nagapatinam, Cuddalore, Theni, Dindigul and Coimbatore covers approximately 30,900 hectares with the annual production of 16,25,463 Metric tons of Fresh fruit bunches and 2,70,322 Metric tons of Crude Palm Oil [5]. The best management practices in oil palm plantation helps to obtain maximum yield and biomass. Increase in the biomass yield helps in the sequestration of CO_2 and proper management practices after the biomass generation helps in storage of carbon and other nutrients in the oil palm plantation regimes. The management practices such as prevention of biomass burning, mulching of fronds, returning of empty fruit bunches to the estates, biochar production, precise fertilization and co-composting are effective in a way of balancing carbon pools.

Sustainable intensification of oil palm can be achieved by higher net dry matter production and higher partitioning assimilates into fruit bunches [6]. The ratio of fruit bunch weight partitioning to the total aboveground dry matter production, the bunch index (BI), is an indicator for fruit production efficiency [7]. Comprehensive plantation and carbon measurements are imperative to assess the long-term effects of plantation carbon balance on greenhouse gases in the atmosphere. It is currently unprecedented interest to explore the contribution of oil palm as a potential carbon sink. The oil palm retain approximately 90-96% of total annual dry production in the above ground biomass as trunk, fronds, and bunches [8,9]. Maintenance is mainly by pruning of palms and continuous recycling of fronds contribute to annual dry matter production at approximately 10 t/ha per year in the Ivory Coast [10]. The standing stock of palms provides a semi permanent carbon pool, which is to be depend on the alternative land uses, would otherwise it enter into the atmosphere. Forest clearing contributes CO_2 to the atmosphere through combustion and decomposition of woody biomass. Over a 25-year typical oil palm plantation lifetime, intact forest conversion is estimated to contribute net emissions of approximately 9–20 t/ha per year [11]. Carbon emissions disconnected from plantations either in time or space and remain unaccounted for by current research. Logging before land clearing for oil palm may contribute 30–60% of emissions from plantation development [12,11].

2. MATERIALS AND METHODS

2.1 Experimental Site

2.1.1 Field measurements and estimation of dry matter production

The aboveground dry matter production (fronds, fruit bunches and trunk) and biomass accumulation in the oil palms depended on key site factors which includes soil organic carbon, palm age, and annual rainfall had been estimated.

2.2 Soil Sampling and Analysis

The soil samples were collected from the oil palm plantations in the study sites of Theni and Thanjavur districts. The soil samples were air dried and sieved by means 0.2 mm sieve and subjected for analysis of pH, Electrical conductivity, soil organic carbon, total N concentration, extractable P and K as per standard procedure by Jackson [13].

Field measurements of vegetative growth parameters were recorded depending on the size of the commercial block, 15 palms were selected as sampling palms to account for 1% of the total number of palms in each block of one hectare plantation. Every tenth palm of every tenth row, excluding all abnormal palms and palms closest to the roadside were selected as sampling palms. The trunk dry matter was estimated by measuring trunk volume and trunk density. The trunk diameter was obtained at 1.3 m above ground level. The trunk height was measured by means of Blume-leiss altimeter. The annual production of total aboveground dry matter and the partitioning to fruit bunches, fronds, and trunk were calculated during the study period.

2.3 Weather Conditions

The prevailing monthly wise weather parameters viz., maximum temperature, minimum temperature, relative humidity and rainfall for Theni and Thanjavur districts during the period of 2017 - 2019 were obtained from Agro Climatic Research Centre, Tamil Nadu Agricultural University, Coimbatore (Table 3, Fig. 2 and Fig. 3).

Table 1. Description parameters of the study location in Theni and Thanjavur

S. No	Oil palm plantation	Age group (Years)	Latitude	Longitude	Area (Hectares)	Yielding palms(No's)
	Theni					
1	Muthalakampatti	4	10°03 E	77°61 N	10.0	1520
2	Bommaiyagoundenpatti	8	10°04 E	77°47 N	3.30	450
3	Upparpatti	15	9°93 E	77°41 N	2.05	270
	Thanjavur					
1	Eachankottai	4	10°66 E	79°15 N	1.0	140
2	Vizhar	8	10°74 E	79°15 N	3.1	429
3	Nadur, Marungulam	15	10°64 E	79°16 N	3.8	450

Table 2. Soil characteristics of oil palm plantations

Parameters	Theni			Thanjavur		
	4 years	8 years	15 years	4 years	8 years	15 years
pH	6.97	6.81	7.30	7.20	6.91	7.54
Electrical Conductivity (dS m^{-1})	0.25	0.40	0.58	0.43	0.56	0.25
Organic carbon (%)	0.52	0.68	0.59	0.60	0.42	0.71
Available N (kg ha^{-1})	249	288	227	210	190	175
Available P (kg ha^{-1})	11.7	10.0	13.6	10.5	8.7	9.0
Available K (kg ha^{-1})	198	144	128	250	237	210

Table 3. Weather parameters for Theni and Thanjavur districts

S. No	Place	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)	Monthly Rainfall (mm)	Rainy days (No's)
1	Theni	33	25	80	764.6	66
2	Thanjavur	34	24	74	890.1	70

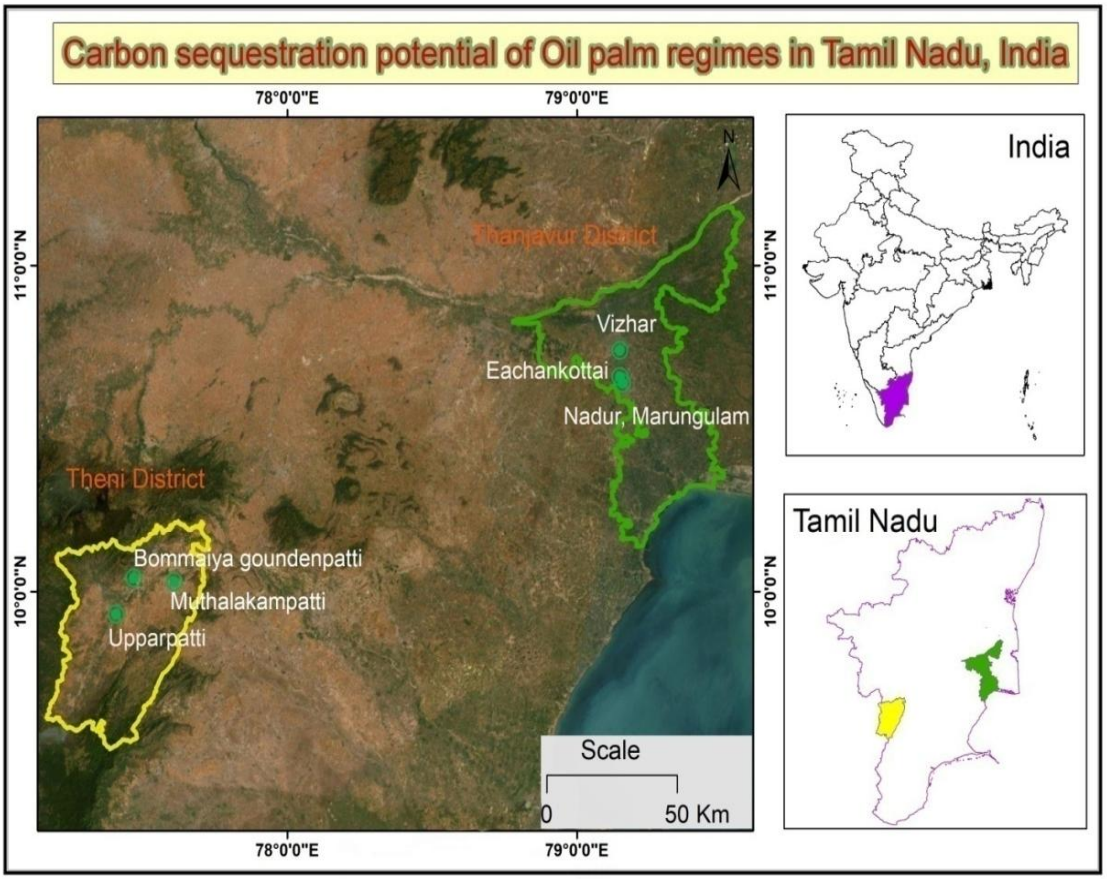

Fig. 1. Overview of experimental sites

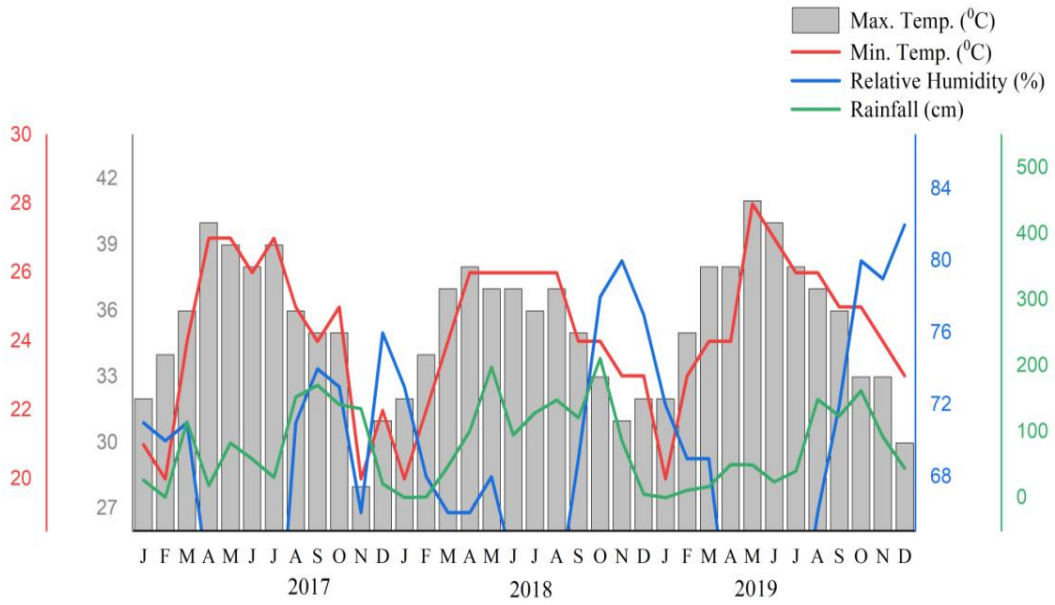

Fig. 2. Monthly wise weather parameters for Theni district from 2017-2019

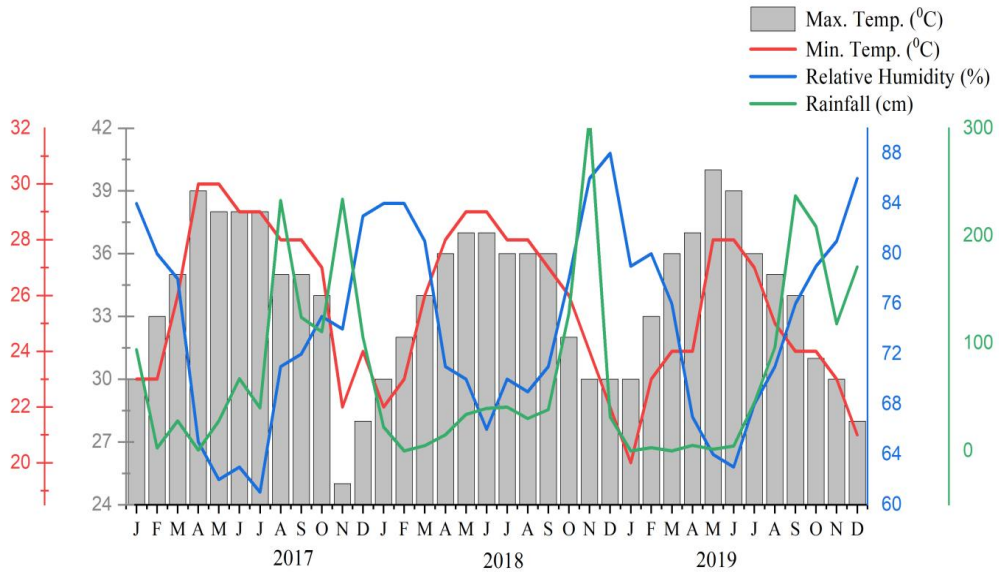

Fig. 3. Monthly wise weather parameters for Thanjavur district from 2017-2019

2.4 Quantitative Estimation of Carbon Sequestration in Oil Palm

The carbon stock in the oil palm plantations were estimated in four, eight and fifteen years age group plantation with the standard management practices and, the non-destructive method of carbon stock estimation was done by using the formula

$V = \pi r^2 h$

Where V is Volume of the oil palm in m^3; r = radius of the oil palm trunk at 1.3 m height from the ground in inches; h = height of the oil palm tree in meters

Diameter of the palm at 1.30 m above the ground level (dbh) measured in tape in cm and in four years palm trees and the basal diameter was calculated.

- Above ground biomass generation (kg/palm) = Volume × Wood density (400-600 kg/m^3)
- Above ground carbon sequestered (kg/palm) = Above ground biomass (kg/palm) × 0.50
- Below ground biomass production (kg/palm) = Above ground biomass (kg/palm) × 0.26
- Below ground Carbon sequestered (kg/palm) = Below ground biomass (kg/palm) × 0.50
- Total Biomass production = Above ground biomass generation (kg/palm) + Below ground biomass production (kg/palm)
- Total Carbon Stock (kg/palm) = Above ground Carbon sequestered (kg/palm) + Below ground Carbon sequestered (kg/palm)
- Total Carbon stock (t C/ha) = Average Total Carbon Stock (kg per palm) × Planting density (Palms/hectares) [14,15]

2.4.1 Frond carbon estimation

The fronds attached to the trunk were estimated in the oil palm plantation of different age groups and the single frond dry weight was c alculated using the digital weighing balance. Estimation of frond carbon stock in oil palm trees were calculated by following formula [16].

Frond carbon stock = N × SFDW × 0.38

Where N is number of fronds, SFDW is Single frond dry weight (kg/frond)

2.5 Statistical Analysis

Data were analyzed by statistical average and standard deviation.

3. RESULTS

3.1 Carbon Sequestration by Fronds

The fronds were found in Theni oil palm plantations of 4, 8 and 15 years sequesters carbon of 1.07 t C/ha, 2.20 t C/ha and 3.28 t C/ha, respectively. The Thanjavur plantations of 4, 8 and 15 years sequester about 1.76 t C/ha, 2.68 t C/ha and 2.74 t C/ha, respectively (Tables 4 & 5).

3.2 Above Ground Drymatter Production and Carbon Stock

The above ground biomass production in four, eight and fifteen years plantations of Theni was found to be 40.87 kg/palm or 5.85 t/ha, 348.7 kg/palm or 49.8 t/ha and 880.17 kg/palm or 125.8 t/ha, respectively. The above ground biomass production in four, eight and fifteen years plantation of Thanjavur was recorded 31.19 kg/palm or 4.46 t/ha, 275.92 kg/palm or 39.46 t/ha and 792.4 kg/palm or 113.31 t/ha, respectively.

The above ground carbon stock in four, eight and fifteen years plantation of Theni was found to be 20.44 kg/palm or 2.92 t C/ha, 174.38 kg/palm or 24.94 t C/ha and 440.09 kg/palm or 62.93 t C/ha, respectively. The above ground carbon stock in four, eight and fifteen years plantation of Thanjavur was noticed 15.59 kg/palm or 2.23 t C/ha, 137.96 kg/palm or 19.73 t C/ha and 396.20 kg/palm or 56.66 t C/ha, respectively

Table 4. Carbon stock distribution in oil palm plantations at Theni

S. No	Parameter	Four years	Eight years	Fifteen years
1	Total drymatter production (t/ha)	5.62(2.21)	49.72(10.29)	142.78(48.53)
2	Frond drymatter production (kg/palm/year)	33.09(5.20)	50.41(5.72)	50.47(5.64)
3	Frond drymatter production (t/ha/year)	4.63(0.73)	7.06(0.80)	7.07(0.79)
4	Above ground Carbon stock (kg/palm)	15.59(6.54)	137.96(28.56)	396.20(134.67)
5	Above ground Carbon stock (t C/ha)	2.23(0.88)	19.73(4.08)	56.66(19.26)
6	Below ground Carbon stock (kg/palm)	4.05(1.60)	35.87(7.43)	103.01(35.01)
7	Below ground Carbon stock (t C/ha)	0.58(0.23)	5.13(1.06)	14.73(5.01)
8	Total Carbon stock (kg/palm)	19.65(7.73)	173.83(35.99)	499.21(169.68)
9	Total Carbon stock (t C/ha)	2.81(1.11)	24.86(5.15)	71.39(24.26)
10	Frond carbon stock (kg/palm/year)	12.58(1.98)	19.16(2.17)	19.18(2.14)
11	Frond carbon stock (t C/ha/year)	1.76(0.28)	2.68(0.30)	2.74(0.31)

**The values presented in the table are the average of 15 oil palm trees with standard deviation is given in parantheses*

Table 5. Carbon stock distribution in oil palm plantations at Thanjavur

S. No	Parameter	Four years	Eight years	Fifteen years
1	Total drymatter production (t/ha)	7.36(2.59)	62.84(15.37)	158.59(28.87)
2	Frond drymatter production (kg/palm/year)	20.14(5.27)	41.39(5.52)	61.66(9.41)
3	Frond drymatter production (t/ha/year)	2.82(0.74)	5.79(0.77)	8.63(1.32)
4	Above ground Carbon stock (kg/palm)	20.44(7.75)	174.38(42.66)	440.09(80.10)
5	Above ground Carbon stock (t C/ha)	2.92(1.11)	24.94(6.10)	62.93(11.46)
6	Below ground Carbon stock (kg/palm)	5.31(2.02)	45.34(11.09)	114.42(20.83)
7	Below ground Carbon stock (t C/ha)	0.76(0.29)	6.48(1.59)	16.36(2.98)
8	Total Carbon stock (kg/palm)	25.75(9.77)	219.72(53.75)	554.51(100.93)
9	Total Carbon stock (t C/ha)	3.68(1.40)	31.42(7.69)	79.29(14.43)
10	Frond carbon stock (kg/palm/year)	7.65(2.0)	15.73(2.10)	23.43(3.58)
11	Frond carbon stock (t C/ha/year)	1.07(0.28)	2.20(0.29)	3.28(0.50)

**The values presented in the table are the average of 15 oil palm trees with standard deviation is given in parantheses*

3.3 Below Ground Biomass Production and Carbon Stock

The below ground biomass production in four, eight and fifteen years plantation of Theni was found to be 10.63 kg/palm or 1.52 t/ha, 90.68 kg/palm or 7.13 t/ha and 228.85 kg/palm or 32.72 t/ha, respectively. The below ground biomass production in four, eight and fifteen years plantation of Thanjavur was registered 8.11 kg/palm or 1.16 t/ha, 71.74 kg/palm or 10.26 t/ha and 206.02 kg/palm or 29.46 t/ha, respectively (Tables 4 & 5).

4. DISCUSSION

4.1 Carbon Sequestration in Different Parts of Oil Palm

4.1.1 Trunk

The above ground biomass is one of the indicators of carbon budget in oil palm plantation. The carbon stock in oil palm plantations was largely due to trunk biomass as it increases with palm age which tends to increase of oil palm height [17]. The four years plantations recorded carbon stock which was found similar to the studies by Leblanc and Russo [18] and Suresh et al., [19] on oil palm hybrids with the carbon stock. The carbon sequestration is higher in trunks 8 years and 15 years plantations which was comparable to studies in forests in North eastern Brazil [20] and tropical deciduous forests has two fold increased carbon sequestration [21,22,23] and the lower carbon stocks are observed in 10 to 30 years of Oil palm in Malaysia [24,25]. The annual carbon sequestration in eight and fifteen years age group is still comparable with the studies of Suresh and Kumar [26] with 10 years age group plantations under irrigated and rainfed conditions. The oil palm possess higher annual carbon stock than eight forest species of 14 years which includes stems, branches, and leaves [27]. Ziegler et al., [28] reported that the carbon stocks are comparable to four and eight years age groups of oil palm. The carbon benefits depends very much on the land use history, length or rotational fallow period, pedoagroclimatic conditions between sites, plantation management practices, irrigation practices and supply of nutrients influences the oil palm growth and the degree of disturbance during cultivation [8,29,24,28]. Rakesh et al. [30] reported that among various parts of the plant, the trunk region sequestered the highest carbon and the trunk of a 5 year old oil palm sequestered 15.3 t Cha^{-1} whereas that of a 10 year old oil palm sequestered 26.6t C ha^{-1}.

4.1.2 Fronds

Oil palm is being a heavy biomass generating crop in which, the fronds sequesters the carbon considerably. The frond encompasses nearly 52% of the total biomass. In *E. oleifera* × *E. guineensis* F1 hybrid population, a wild palm was discovered that in addition to short trunk, had relatively short leaves due to spontaneous heritable changes in the leaf length. The fronds carbon stock was found to be 3 fold lower in 4 years plantation, while eight and fifteen year plantations carbon stock was still comparable with the research findings of Suresh and Kumar [31]. The increasing carbon stock was noticed in the fronds of oil palm with respect to age and this results may be similar to the findings of Leblanc and Russo [18] in which the fronds sequesters 59 % higher carbon stocks. Under irrigated condition, the carbon content in different fronds of a mature palm varied between 0.413 and 1.314 kg (Suresh *et al.,* 2018). Simanihuruk *et al*. [32] reported that the dry weight of the fronds ranged from 4 to 5 kg and pruned fronds ranged from 64 – 120 kg/tree/year or nearly 8.3 – 15.6 ton/ha/year [33]. Melling *et al.* [34] stated that frond biomass significantly increased from 1.2 Mg ha^{-1} in 3 year old plantation to 20.5 Mg ha^{-1} in a ten year old plantation, after which it declined to 2.3 and 3.4 Mg ha^{-1} in 20 and 30 years old, respectively. Rakesh *et al.* [30] reported that the fronds of a 5 year old oil palm sequestered 1.39 t C ha^{-1} whereas 10 year old oil palm sequestered 2.1 t C ha^{-1}.

4.1.3 Roots

In oil palm root biomass is tedious to estimate and its measurement requires destructive sampling [35]. The root biomass varies with difference in soil type. The carbon sequestered in the roots of 4-15 years age of oil palm plantations was comparable with the study of Syahrinudin [24] 3- 30 years plantations while, it was recorded similar to study of Khoon *et al.,* [17], which is 11 – 29 years plantations. Henson [36] reported that the below ground carbon stock as for the replanting cycle of 25 years was comparable with our study on 8 years age group of oil palm. Dufrene [37] observed a total root biomass of 31.5 t ha^{-1} for ten year old palms in Ivory Coast. Furthermore, several studies has shown a significant increase in the root biomass

with plantation age [38,39,40,24,41]. Kirankumar *et al.* [42] stated that root accumulates 2.20 t ha^{-1}and sequesters 1.07 t C ha^{-1}. The quantity of dry matter accumulated by the roots was 0.61 t ha^{-1} y^{-1} under irrigated condition and 1.35 t ha^{-1} y^{-1} under rainfed condition respectively [26]. Rakesh *et al.* [30] reported that the roots of a 5 year old oil palm sequestered 4.0 t C ha^{-1} whereas 10 year old oil palm sequestered 6.93 t C ha^{-1}.

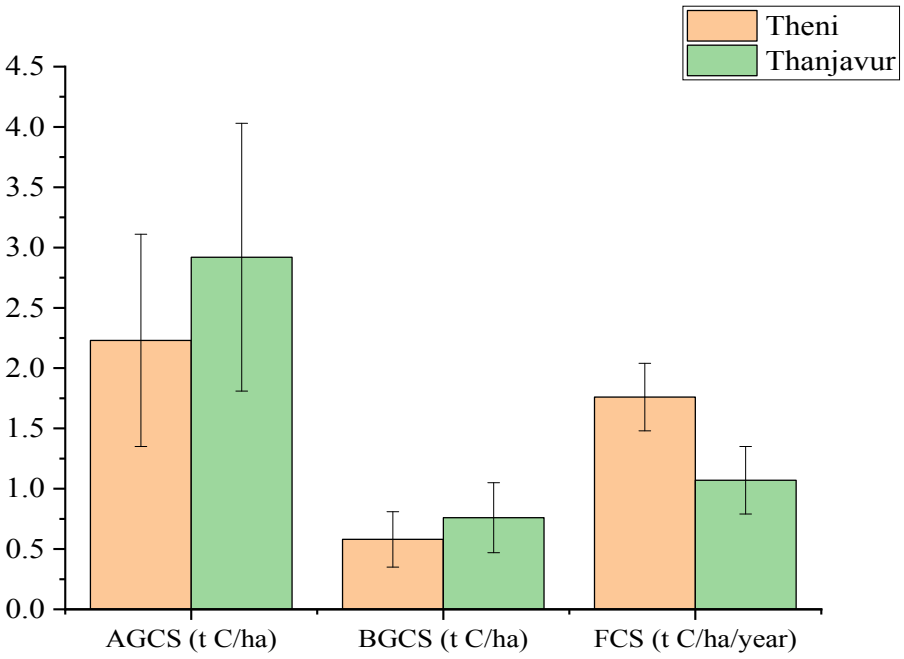

Fig. 4. Carbon stock distribution among four years oil palm plantation
**AGCS-Above ground carbon stock; BGCS-Below ground carbon stock; FCS-Fronds carbon stock*

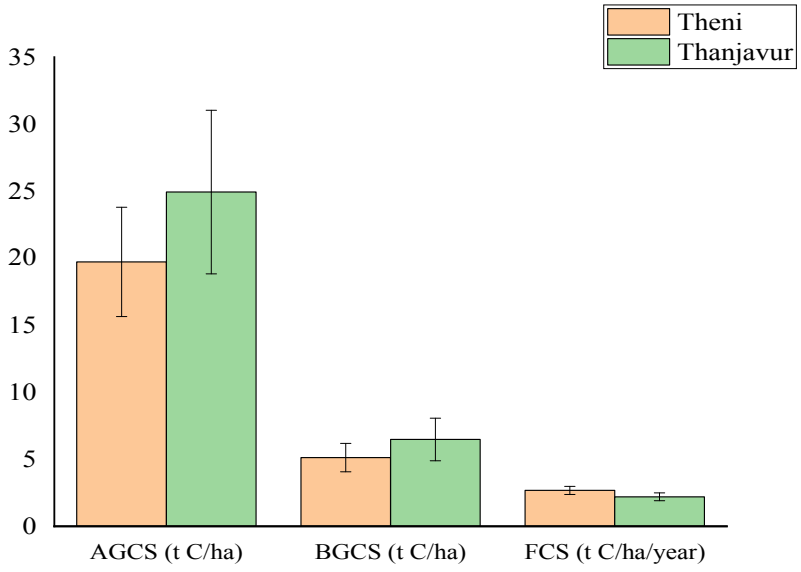

Fig. 5. Carbon stock distribution among eight years oil palm plantations
**AGCS-Above ground carbon stock; BGCS-Below ground carbon stock; FCS-Fronds carbon stock*

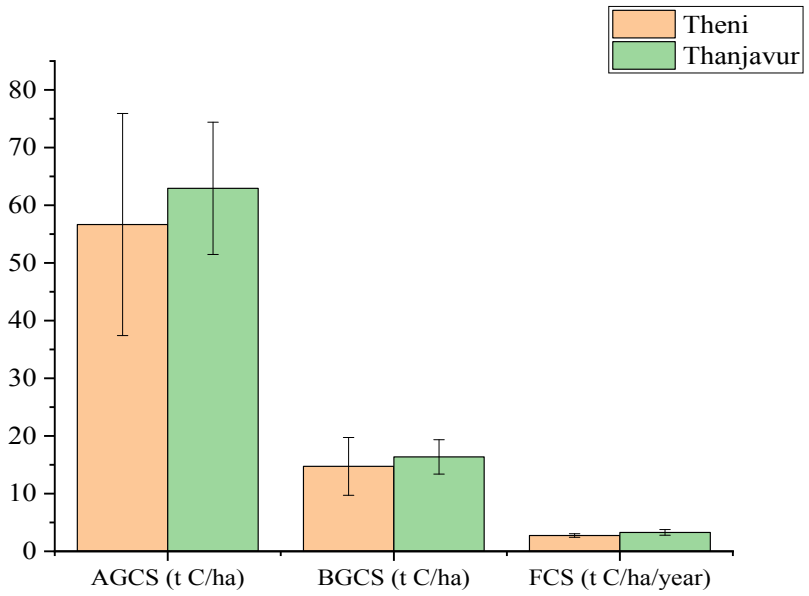

Fig. 6. Carbon stock distribution among fifteen years oil palm plantations
**AGCS-Above ground carbon stock; BGCS-Below ground carbon stock; FCS-Fronds carbon stock*

5. CONCLUSION

The present study revealed that the standing stocks of palm provide a semi-permanent carbon pool, which depends on the alternative land uses, otherwise it would enter into the atmosphere. The organic carbon content of oil palm plantations ranges from 0.42% - 0.68% and the Stocks of Soil Organic Carbon (SOC) depends on the balance between soil carbon inputs from vegetation and outputs from SOC mineralization, erosion, and leaching. The height of the oil palm trees was one of the main factor in terms of biomass production and accumulation in oil palm trees and its increment mainly by genome sequence of asparagines synthase related proteins which might responsible for the tree height variations, that would play a major role for biomass production. The height, diameter and age of the trees specifies the carbon sequestration process in increasing rate of oil palm growing areas of Theni and Thanjavur. Based on the age of oil palm, different areas showed a evidence in increasing rate of above ground biomass, below ground biomass, above ground carbon, below ground carbon and carbondioxide uptake. Hence, the cultivation of oil palm plantation is a right key role to sequester atmospheric carbon and to mitigate the green house gas emission under changing environmental conditions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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