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Original Research Article

Aboveground and Soil Carbon Stock of Teak Plantations Under Varied Rainfall Regimes

ABSTRACT

Aims: Forest plantations are considered to be the most effective approach to reducing the atmosphere's rising carbon dioxide levels. The variation in the carbon stock under important plantation species and the heterogeneity across climatic regimes, however, are urgently needed.

Place and Methodology: Research was conducted on seven-year-old teak plantations in Karnataka, India, to determine the above-ground and soil carbon sequestration potential of teak plantations under various rainfall regimes.

Results: The teak plantations under high rainfall zone (RFZ) accumulated maximum above-ground biomass revealing the positive effect of rainfall the productivity. This was reflected in the total above-ground carbon sequestration of the plantations leading to maximum carbon storage under the high RFZ followed by medium and low RFZ. Further, the variation of the SOC along the soil depth was evident in the present study.

Conclusion: According to the findings, rainfall significantly impacted above-ground carbon sequestration and SOC, with high rainfall leading to the greatest sequestration. The climate sensitivity of carbon sequestration demands elaborate studies to improve carbon storage in the plantations in future climate change scenarios.

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Keywords: Carbon, Teak, Soil organic carbon, Rainfall

1. INTRODUCTION

Since the Industrial Revolution, human-caused rapid increases in atmospheric CO₂ have drawn attention to the Earth's carbon stores and fluxes. There is a great deal of uncertainty over the quantity of carbon stored in and emitted from, terrestrial ecosystems, although many of the stocks and fluxes within the global carbon cycle are very well defined and understood [1]. Compared to soil carbon, global phyto-mass carbon stocks and their distribution have been fairly thoroughly studied and measured [2]. Although soil and surface litter store two to three times as much carbon in organic form as the atmosphere globally, as defined by the Kyoto Protocol, soil carbon is expected to be of significant importance in addition to phyto-mass carbon. About two-thirds of global soil carbon is held as soil organic carbon (SOC), with the remaining one-third being inorganic carbon [3]. Despite extensive research, there is currently significant uncertainty regarding the quantity of global SOC stocks, their spatial distribution, and carbon emissions from soils, and these have received relatively little attention from decision-making bodies. For improved carbon management and climate change mitigation options, as well as to assist in parameterizing global circulation models used to inform climate policy, a better knowledge of carbon stocks and fluxes is crucial.

Through direct seeding and planting, plantation forestry, management or preservation of secondary or successional forests, and other methods, interest has been sparked among the common people to improve tree cover through afforestation and reforestation. For more accurate projections of the current and future implications of changes in land use and land

36 cover on the global carbon cycle, it is imperative to comprehend the function of plantation
37 forests as carbon reservoirs. Soils that were exhausted during intense farming can be
38 replenished with nutrients and organic matter owing to plantations [4]. Plantation forests can
39 provide a habitat for avian biodiversity in fragmented landscapes, as well as for secondary
40 forest species in the understory[5]. Through better-forested management techniques, tree
41 plantings may contribute to the objectives of restoring forest ecosystem services and
42 providing residents with economic opportunities [6]. To maximize carbon sequestration and
43 enhance our capacity to restore fertility to damaged soils, it is important to understand how
44 soil carbon reacts to growing tree cover during forest development and planting. Accurate
45 evaluations of carbon stocks in original and replacement biomass, as well as in soils, are a
46 limitation of accounting models that quantify the impacts of deforestation and reforestation
47 on the global carbon cycle [7]. It is even more crucial to pinpoint the variables that influence
48 soil carbon content under various land-cover types to improve projections of the feedback
49 effects between vegetation, land-use change, and climate change. One such significant
50 plantation species that has become well-known around the world for the beauty and
51 toughness of its wood is Teak (*Tectona grandis*). Teak can be used for a variety of purposes,
52 including constructing, making furniture and cabinets, railway sleepers, ornamental veneer,
53 joinery, building ships and automobiles, mining, and making reconstituted wood [8].
54 Plantations have been established both inside and outside of their original nations as a result
55 of market needs [8]. Therefore, the current study focuses on the teak plantations' capacity to
56 store carbon under various rainfall regimes.

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58 **2. MATERIAL AND METHODS**

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60 The study was conducted on Seven-year-old plantations at different locations in Karnataka
61 state, India (Fig 1). Based on the mean annual precipitation, the study sites were
62 categorized into High (3000 mm Mean Annual precipitation; MAP), Medium (1500 mm
63 average annual rainfall), and Low (1000 mm MAP) rainfall zones (Table 1). To assess the
64 growth parameters of each species under each rainfall regime, five sample plots of 20 m x
65 20 m were randomly laid out. Observations on the following parameters were recorded and
66 used for the carbon stock estimation. Estimation of the total carbon storage under varied
67 rainfall regimes (above and below ground biomass) in each plot was estimated using the
68 following formula [9]:

69 **2.1 Above ground carbon Stock**

70 **Total above-ground biomass (Mg ha⁻¹; AGB)** = Plot volume x Wood basic density x
71 Biomass expansion factor (1.58).

72 **Below ground biomass (Mg ha⁻¹; BGB)** = Above ground biomass x 0.26

73 **Total biomass (Mg ha⁻¹)** = AGB+ BGB

74 **Total carbon stock (Mg ha⁻¹)** =Total biomass x 0.47

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76 **2.2 Soil organic Carbon Stock**

77 To study the soil parameters three soil samples were taken at five different depths (0–20 cm,
78 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm) at each location. These soil samples were
79 analyzed for soil organic carbon by placing 0.5 g of soil in a flask with 10 ml of potassium
80 dichromate solution (K₂Cr₂O₇), adding 20 ml of concentrated sulfuric acid (H₂SO₄), and
81 mixing, the organic carbon content of the soil was ascertained. 200 cc of distilled water was
82 gently added and well shaken after about 30 minutes. One millilitre of ferroin indicator was

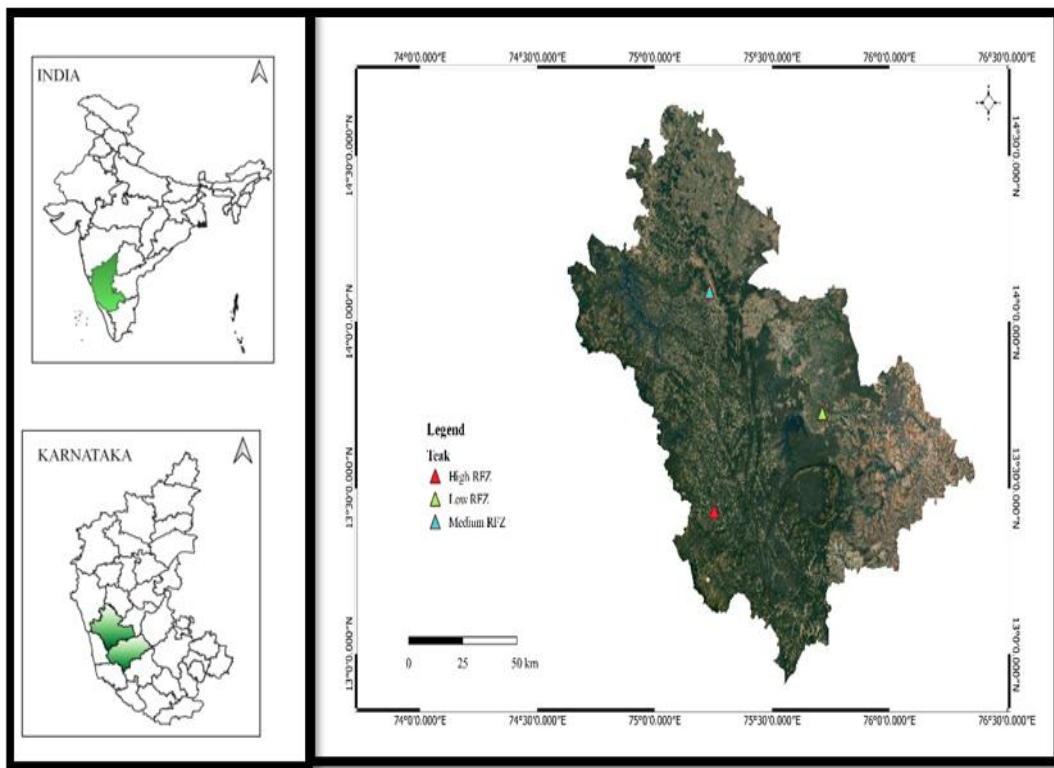
83 added just before titration. 0.5 N ferrous ammonium sulfates were used to titrate the excess
84 $K_2Cr_2O_7$ till the color eventually changed to brownish red at the endpoint [10]. The organic
85 carbon concentration in the soil was converted to total SOC pool as per [11] as follows:

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$$\text{Total SOC Pool} = \frac{\% \text{ of SOC}}{100} \times \text{BD} \times 2000$$

87 where total SOC pool is the weight of soil organic carbon ($Mg\ ha^{-1}$), SOC is soil organic
88 carbon (%), BD is soil bulk density and 2000 is the volume of 1 ha furrow slice ($0.20\ m$) (m^3).
89 The **Total Ecosystem Carbon Stock (TECS)** was obtained by summing the quantities of
90 carbon stored in the biomass and in the soil.

91 2.2 Statistical analysis

92 Observations recorded were analyzed as per the standard statistical procedure. The data
93 were subjected to a one-way analysis of variance (ANOVA) using Origin (Pro), 2022b.



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95 **Fig. 1: Overview of the Study area indicating the locations selected for the high RFZ,**
96 **Medium RFZ and Low RFZ**

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99 **Table 1. Geo coordinates and weather parameters of the study locations**

100 **MAP: Mean Annual precipitation; Max Temp: Average annual maximum temperature;**
101 **Min Temp: Average annual minimum temperature; Max RH: Average annual maximum**
102 **Relative Humidity; Min RH: Average annual minimum Relative Humidity**

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Rainfall Zone	Latitude	Longitude	Altitude (MSL)	MAP (mm)	Max Temp (°C)	Min Temp (°C)	Max RH (%)	Min RH (%)
High RFZ	13° 25' 49.80" N	75° 15' 10.44" E	725 m	3500	31.42	18.98	95.90	55.62
Medium RFZ	14° 5' 30.66" N	75° 13' 59.59" E	663 m	1500	30.86	19.25	98.66	57.58
Low RFZ	13° 43' 33.24" N	75° 42' 49.78" E	660 m	1000	30.81	19.26	95.88	56.32

106 3. RESULTS AND DISCUSSION

107 An attempt to understand the variations in carbon stock under teak plantations at varied
108 rainfall regimes was made in the study and the results depicted in Table 2 revealed that, the
109 significant influence of rainfall on above-ground ($p=0.014$) and below-ground biomass
110 ($p=0.013$). The teak plantations under high RFZ accumulated maximum above-ground
111 biomass revealing the positive effect of rainfall the productivity. The carbon (C) stored in
112 forest ecosystems serves as a key indicator of the global C balance. C is mostly stored in
113 soils and living biomass, with some amount being present in coarse woody detritus [12].
114 While forest soils are supposed to possess roughly 73 per cent of the world's SOC stock,
115 standing biomass C stock makes for 82–86 percent of the aboveground C stock [13].
116 Following the absorption of atmospheric CO_2 by forests through photosynthesis, plant debris
117 (litter and roots) decomposes to contribute carbon to the soil's carbon pool [14]. Changes in
118 land use have a substantial effect on the global carbon cycle by altering the rate of soil
119 carbon accumulation and fine root turnover [15]. Thus, the distribution of vegetative biomass
120 and carbon stores may change [16]. Due to deforestation and the breakdown of soil organic
121 matter, a shift in land use typically results in higher CO_2 emissions [17]. Furthermore,
122 because the majority of carbon in semiarid and arid ecosystems is found underground [18],
123 fluctuations in soil CO_2 brought on by infrequent precipitation events may have significant
124 effects on soil carbon stocks. Therefore, it is crucial to precisely measure soil CO_2 in
125 connection to rainfall events to comprehend the dynamics of the carbon balance in these
126 ecosystems that are primarily underground. Rainfall surges may become even more
127 significant in the near future since precipitation frequency and intensity are expected to rise
128 [19]. The interannual fluctuation in the terrestrial carbon sink is determined by semiarid
129 habitats, which are now known to be significantly more significant in the global terrestrial
130 carbon balance than previously believed [20]. Teak is a long rotation crop (50 to 80 years).
131 However, the rotation period may be reduced by suitable silvicultural practices [21]. The
132 productivity of short rotation teak is high with a mean annual increment range of $10\text{--}20\text{ m}^3\text{ ha}^{-1}$
133 yr^{-1} [22]. Further, this was reflected in the total above-ground carbon sequestration of the
134 plantations leading to maximum carbon storage under the high RFZ followed by medium and
135 low RFZ. In the recent past decade, the country has become the net importer of teak wood
136 to meet its requirements [23]. To reduce the import duty of teak there is great enthusiasm
137 among farmers to grow teak outside the forest area which is also appropriately supported by
138 different government programmes. In the present study, however, the productivity was much
139 lower than the values reported by the literature. Further, the carbon sequestration of the
140 trees under high RFZ was higher than that of low RFZ. The research by [24] on the above-
141 ground biomass of teak plantations on farmlands showed substantial differences concerning
142 agro-climatic zones and age, which supported these findings. At all three age gradations,

143 teak plantations grown on farmlands in the Northern Transition Zone had considerably
 144 higher above-ground biomass than those in the Northern Dry Zone and Hilly Zone. As a
 145 result, the amount of total above-ground carbon sequestered in the Northern Transition
 146 Zone's teak plantations was much higher than in the Northern Hilly Zone and Northern Dry
 147 Zone. The authors hypothesize that changes in soil fertility, rainfall, temperature, and other
 148 environmental variables may be to blame for the discrepancies in above-ground biomass
 149 and carbon sequestration capability between the various agro-climatic zones.

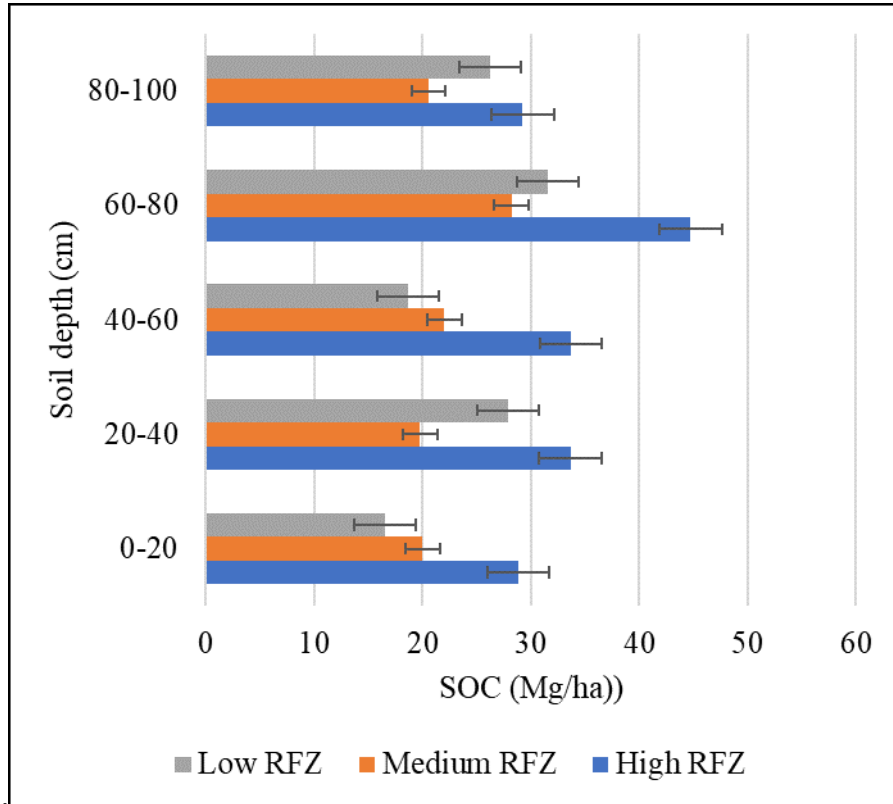
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 151 Soil organic matter (SOM) is one of the largest and most dynamic reservoirs of carbon (C) in
 152 the global C cycle. The amount of C stored in SOM is about twice that stored in the
 153 biosphere and atmosphere combined [25]. Hence an assessment of SOC revealed the
 154 nonexistence of significant differences among the locations of SOC. This might be due to the
 155 early age of the teak plantations which had resulted in the too little leaf fall to have significant
 156 variations among the locations. [26] stated that the level of plant material incorporated into
 157 the soil improves soil mineral status and opined that organic carbon content in soil
 158 accounted for the rate of the quantity of litterfall and the rate of their decomposition.
 159 Variations in organic carbon content in soils under various tree sp. are attributed to the age
 160 of the plantation and the amount of litterfall, their biochemical composition, and the rate of
 161 their decomposition. Further, [27] also observed that the SOC under the teak plantation will
 162 be higher due to the relatively high amount of organic materials that might have resulted
 163 from litter falling from the trees in the teak plantation. [28] recorded an increase in soil
 164 organic matter in afforested areas under Teak. The data on the Total ecosystem carbon
 165 echoed the same trend as that of the total above-ground carbon revealing the maximum
 166 potential of plantations under high RFZ to sequester carbon compared to other rainfall
 167 zones. However, significant variations in the SOC along the soil depth under varied rainfall
 168 regimes were observed (Fig 2). The data reveals that, the higher amount of SOC in the
 169 upper 0-20 cm layer and at the 60-80 cm layer irrespective of the locations. This may be due
 170 to deeper root activities of trees which can add to the SOC. When deeper soil profiles were
 171 examined, soil C variations between rainfall classes increased even more because rainfall
 172 can impact the vertical distribution of roots and the stability of C in deep mineral layers [29].
 173 In general, moister and cooler areas retained more soil carbon than drier and hotter sites
 174 (Table 2). Variations in oxygen levels can cause microbial metabolism in tropical forests with
 175 heavy rainfall to switch to less productive pathways [30], which slows microbial breakdown
 176 rates and increases soil carbon storage. The highest SOC levels in these soil layers were
 177 found in areas with high RFZ. The research [31], which found that rainfall and temperature
 178 were the two most crucial factors affecting soil C stores at all depths, validated this.
 179 Interactions between climate, other environmental factors, and historical circumstances
 180 become significant over the whole temperature gradient when deeper soil profiles are taken
 181 into consideration. Furthermore, it was suggested by [32] that the change in carbon release
 182 throughout seasonal fluctuations was caused by the cumulative rainfall amounts of the
 183 several seasons, and that soil carbon release is particularly sensitive to total rainfall
 184 amounts.

185 **Table 2: Above-ground and SOC sequestration of Teak plantation under varied rainfall**
 186 **regimes**

	AGB (Mg/ha)	BGB (Mg/ha)	TB (Mg/ha)	TBC (Mg C/ha)	SOC (Mg/ha)	TECS (Mg C/ha)
High RFZ	35.84	9.31	45.16	21.22	170.19	188.48
Medium RFZ	30.89	8.03	38.92	18.29	110.61	131.83

Low RFZ	20.33	5.28	25.62	12.04	120.83	132.87
p value	0.014	0.013	0.013	0.014	NS	<0.001

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Fig. 2: Variation in SOC under varied RFZ and soil depths

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4. CONCLUSION

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The influence of rainfall on the above-ground and soil carbon stocks was evident in the present study. Although the study was conducted at the early ages of Teak plantations, it's imperative to understand the above-ground and below-ground carbon stock of teak plantations owing to their long rotation and deciduous nature. Variations in the SOC along the soil depth were interesting and need to be explored more with the fine root activities and microbial abundance. The climatic controls suggest the sensitivity of above ground and soil C stocks in plantation forests to future climate change.

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AUTHORS' CONTRIBUTIONS

Author 1: Carried out the fieldwork and laboratory analysis and prepared the manuscript

Author 2: Conceptualized and designed the study

Author 3: Reviewed the manuscript

212 Author 4: Reviewed the manuscript
213 All authors read and approved the final manuscript

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