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Influence of Spacing on Tree Carbon Sequestration in Teak (*Tectona grandis*) based Agroforestry System

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ABSTRACT: Tree carbon sequestration is the process by which atmospheric carbon dioxide is taken up by trees, grasses, and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliage, and roots) and soils. Even though, the earth naturally stores carbon in forest, oceans, and soil, these carbon sinks are unable to excessive and increasing amount of carbon dioxide humans continue to emit. The experiment was carried at University of Agricultural Sciences, GKVK, Bengaluru to know optimum spacing for maximum wood volume production and higher tree carbon sequestered in teak plantation through agroforestry system. In seven years old teak plantation maximum tree height (7.93 m), girth at breast height (GBH) (52.67 cm), wood volume (15.8523 m^3 ha^{-1}), total tree biomass (45.94 t ha^{-1}) and tree carbon sequestered (22.97 t ha^{-1}) was recorded with a spacing of 12 m × 3 m followed by 10 m × 3 m and 8 m × 3 m. The objective of the study was to improvise the carbon sequestration along with tree pulp yield.

Keywords: Teak, wood volume, Total biomass, Carbon sequestration.

INTRODUCTION

Teak (*Tectona grandis*) is the economical tree species commonly recommended for plantation programmes in dry tropical regions for timber production. The durability and workability of teak were recognized in our country, due to its widespread distribution and cultivation. Teak among the top five tropical hardwood species established worldwide relatively easy to established by plantations and global demand for its products with good prospects. Teak species indigenous to India, Myanmar and Thailand but also grows in seasonal dry tropical areas in Asia (Bunyavejchewin, 1983). It is highly rated among hardwood plantations due to its durability, mellow colour, and long straight cylindrical bole. The wood of teak is used for furniture, flooring, joinery, trim, doors, wooden panels, carving, musical instruments, turnery, vats, boat masts and decks, railway sleepers, mine props, fuel, and fence posts (Nair and Chavan 1985; Tiwari 1992; Bhat, 2000; Bailleres and Durand 2000; Kokutze *et al.*, 2004). The heartwood of teak is golden brown with a distinct grain and has a specific gravity of 0.55 (Longwood, 1961). It can be grown in a wide variety of soils, tolerate a wide range of climates, and have best growth under the conditions that the minimum monthly temperature is above13°C and the maximum monthly temperature is below 40°C. Optimal rainfall for teak ranges between 1250 and 3750 mm per year, however, for the production of good-quality timber the species requires a dry season of at least four months with less than 60 mm precipitation. It usually grown on the soils with a pH range of 6.5 to 7.5. Normally teak does not grow at altitude of over 900 m and the plant vigour decreases over 750 m (Takle and Mujumdar 1956). Similarly, aspects of the locality also affect the plant's growth and the plants grow better on the cooler northern and eastern aspects than on the hotter southern and western ones (Seth and Yadav 1957). Teak is one of the most extensively planted tree species in the tropics, constituting about 6.0 million ha plantation area worldwide (Bhat and Hwan Ok Ma 2004). Approximately 94% plantations of this net area are located in Tropical Asia, with 44% in India and 31% in Indonesia. The plantations of other countries in the region contribute significantly with 7% in Thailand, 6% Myanmar, 3.2% Bangladesh and 1.7% Sri Lanka. Several studies on carbon and biomass distribution in teak plantation in many countries, the carbon cycling of teak plantation has rarely been reported (Khanduri *et al.*, 2008; Kraenzel *et al.*, 2003; Viriyabuncha *et al.*, 2002; Pande, 2005). Teak plantation production varies widely among countries and depending on soil conditions (Enters, 2000). For example, the mean annual increment ranged from 2.0 m^3 ha^{-1} $year^{-1}$ in poor sites in India to 17.6 m^3 ha^{-1} $year^{-1}$ in prime sites in Indonesia with 50 year rotation periods (Pandey and Brown 2000). Thus, the quantitative illustration of carbon cycling in teak plantations is useful for understanding the key carbon sequestration channels, which may serve as the basis for improving forest management. Although forest tree plantations have only had a small contribution to the total balance of terrestrial carbon (3.8% or 140 million ha of the world's total forest area; FAO 2016) but their potential to absorb and store carbon has been recognized to play a more important role in the future mitigation of climate change (Canadell *et al.,* 2007). Soil carbon sequestration can be accomplished by management systems that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil fauna activity.

The carbon sequestration potential in the trees and soil increased in the agroforestry. Thus agroforestry was found to be a sustainable land use system for improving biological productivity and carbon sequestration (Kumar, 2017). Study indicates that variability of C stock is influenced by species composition and altitude and BU forest type is more significant for carbon sequestration (Dar & Sahu 2018). It is a crucial need of the hour to conduct accurate, regional based investigations of SOC and TN storage in order to detect variations in carbon and nitrogen sequestration capacity caused by land use pattern changes associated with modern agriculture practices (Pathak and Reddy 2021).

Carbon sequestration potential of tree species becomes relevant in this respect. It varies with species, climate, soil and management. Forest plantations have significant impact as a global carbon sink. Young plantations can sequester relatively larger quantities of carbon while a mature plantation can act as a reservoir. Long rotation species such as teak (*Tectona grandis*) has long carbon locking period compared to short duration species and has the added advantage that most of the teak wood is used indoors extending the locking period further.

MATERIALS AND METHODS

The experiment was conducted at agroforestry unit, ZARS, Gandhi Krishi Vignana Kendra, University of Agricultural Sciences, Bengaluru situated in the Eastern Dry Zone (Zone – 5) of Karnataka. The experimental site is located between 12º 51' N Latitude and 77º 35' E Longitude at an altitude of 930 m above mean sea level (MSL). The soil of the experimental site was red sandy clay loam with coarse sand (33.2%), fine sand (36.4 %), Silt (7.4 %) and Clay (23 %) as soil components. Composite samples were drawn from the experimental site. Samples were air dried, powdered, sieved and stored in plastic container for further chemical analysis. The chemical properties of the soil in experimental site and the standard methods followed for further chemical analysis. Soils are neutral in pH (6.9), organic matter content (0.79), medium in available nitrogen (326 kg ha^{-1}), phosphorus (25kg ha^{-1}) and potash (266kg ha^{-1}). The experiment was laid out in block plantation with three different spacings *i.e.,* 12 m × 3 m, 10 m × 3 m and 8 m × 3 m. Planting of teak saplings was done by opening pits of 30 cm width 30 cm depth. Planting of teak was done during July 2010.

Measurements of different tree parameters. The total height of the tree was measured using altimeter and it was expressed in meter (m). The girth at breast height (GBH) was measured with steel calliper at 1.37 m above the base of the tree and it was expressed in centimetre (cm). Canopy spread was measured at east – west and north – south directions using measuring tape and expressed in meter (m).

Total tree volume (m^3): The total wood volume was determined by using quarter girth formula.

Volume= (Girth of log at the middle/4)^2 × length of log

Quantifying the amount of carbon sequestration (t ha^{-1})

1. Biomass of tree (t ha^{-1}): To estimate the biomass of the tree, it is not advisable to cut them. Hence, the total biomass of the tree was determined by non-destructive method using mathematical models by measuring DBH and height (Chavan *et al*., 2010).

2. Above ground biomass of tree (t ha^{-1}): The aboveground biomass (AGB) of tree was calculated by multiplying volume of biomass of each tree species with its respective wood density and the volume was calculated based on diameter and height (Pandya *et al*., 2013). It was expressed in tonnes per hectare. Wood density is used from Global wood density database (Zanne *et al*., 2009).

Above ground biomass (t ha^{-1}) = volume of biomass ($m^3\ ha^{-1}$) × wood density (g cm^{-3})

3. Below ground biomass of tree (t ha^{-1}): The below ground biomass (BGB) was calculated by multiplying above ground biomass taking 0.26 as the root: shoot ratio (Chavan and Rasal 2011; Hangarge *et al.,* 2012) and was expressed in tonnes per hectare.

Below ground biomass (t ha^{-1}) = Above ground biomass (t ha^{-1}) × 0.26.

4. Total biomass of tree (t ha^{-1}): Total biomass of tree is the sum of the above and below ground biomass (Sheikh *et al*., 2011) and was expressed in tonnes per hectare.

5. Tree carbon stock (t ha^{-1}): The amount of carbon sequestered by the tree was estimated by reducing the total biomass of the tree to 50 percent (Pearson *et al*., 2005) or by multiplying the total biomass of tree with 0.5 (Mac Dicken, 1997) and was expressed in tonnes per hectare.

Tree carbon sequestration (t ha^{-1}) = Total biomass ÷ 2

The experimental data gathered on tree growth parameters, soil parameters and amount of carbon sequestered were subjected to Fisher's method of "Analysis of Variance" (ANOVA) as outlined by Panse and Sukhatme (1954). For comparison between the treatment means, an appropriate value of critical difference (C.D.) was worked out wherever F- test was significant. All the data were analysed and the results are presented and discussed at a probability level of 5 %.

RESULTS AND DISCUSSION

A. Tree height, girth and canopy spread

In seven year old teak plantation studied for tree carbon sequestration in teak based agroforestry system the tree growth parameters such as tree height, girth at breast height (GBH) and canopy spread towards North-South and East-West direction varied significantly. Effect of different spacing on teak as influenced on growth parameters is shown in Table 1 & 2. Maximum tree height, GBH and canopy spread was recorded with spacing of 12 m × 3 m (7.93m, 52.67cm, 3.75 m towards North-South and 3.97 m towards East-West direction, respectively) followed by 10 m × 3 m (7.42 m, 42 cm, 3.17 m towards North-South and 3.33 m towards East- West direction, respectively) and 8 m × 3 m (7.17 m, 40.83 cm, 4.51 m towards North-South and 4.85 m towards East- West direction, respectively) during 2021 and similar trend was observed during 2017, 2018, 2019 and 2020. The significant difference observed in tree height, GBH and canopy spread of teak was ascribed to growth habit and its aptness to local agro-ecological conditions and the results are in accordance with the findings of Kaushik *et al*. (2015); Vaidya and Naik (2018).

Table 1: Influence of spacing on tree height and girth at breast height of teak plantation.

Spacing (m)	Height (m)					Girth at breast height (GBH) (cm)				
	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
12 ×3	4.54	4.65	6.79	7.81	7.93	20.89	21.00	32.33	36.13	52.67
10 × 3	4.42	4.60	5.88	6.76	7.42	18.00	18.24	23.33	27.06	42.00
8 × 3	4.24	4.39	5.03	6.10	7.17	18.20	18.21	19.67	22.82	40.83
S.Em±	0.15	0.03	0.08	0.08	0.06	1.77	0.34	0.88	0.88	1.93
CD (P=0.05)	0.47	0.12	0.33	0.26	0.21	5.45	1.32	3.46	3.46	5.79

Table 2: Influence of spacing on canopy spread of teak plantation.

Spacing (m)	Canopy Spread									
	North-West (m)					East-West (m)				
	2017	2018	2019	2020	2021	2017	2018	2019	2020	2021
10 × 3	1.24	1.42	2.44	3.16	3.75	1.39	1.75	3.97	3.20	3.97
8 × 3	1.13	1.33	2.35	2.51	3.17	1.37	1.59	2.70	2.68	3.33
12 × 3	1.34	1.90	2.73	4.06	4.51	1.43	1.78	2.90	4.37	4.85
S.Em±	0.12	0.01	0.18	0.04	0.41	0.13	0.01	0.05	0.05	0.39
CD (P=0.05)	0.36	0.05	3.69	0.13	1.23	0.40	0.03	0.18	0.18	1.19

Tree Wood Volume

Teak wood volume of teak has significantly influenced by different tree spacing (Table 3). Maximum tree wood volume was recorded with spacing of 12 m × 3 m during 2018 (8.2697 m^3 ha^{-1}), 2016 (12.6556 m^3 ha^{-1}) and 2017 (15.8523 m^3 ha^{-1}), which was followed by 10 m × 3m (6.5855m^3 ha^{-1}, 8.8331m^3 ha^{-1} and 9.5876m^3 ha^{-1}, respectively) and 8 m × 3 m (4.6105 m^3 ha^{-1}, 7.4370m^3 ha^{-1} and 8.1905m^3 ha^{-1}, respectively) during 2019, 2020 and 2021, respectively. The difference observed in tree volume of teak tree with different spacing is due to their different growth habit and the prevailing agro-ecological conditions. The higher tree volume in 12 m × 3 m attributed to significantly higher GBH and vigorous growth.

Tree biomass. Tree spacing has variedly influenced upon the biomass growth of teak plantation. Maximum above ground, below ground and total biomass of teak was recorded with a spacing of 12 m × 3m during 2018 (19.02 t ha^{-1}, 4.95t ha^{-1} and 23.97t ha^{-1}, respectively), 2019 (29.11 t ha^{-1}, 47.57t ha^{-1} and 36.68t ha^{-1}, respectively) and 2020 (36.46 t ha^{-1}, 9.48t ha^{-1} and 45.94 t ha^{-1}, respectively) followed by 10 m × 3 m and 8 m × 3 m Table 3 & 4. There is increase in tree biomass with wider spacing mainly attributes to increased tree canopy. Similar results were found with work carried by Sreejesh *et al*. (2013).

Table 3: Tree volume of teak as influenced by different tree spacing's.

Treatments	Tree wood volume m^3 ha^{-1}		
	2018	2019	2020
8 m × 3 m	4.6105	7.4370	8.1905
10 m × 3 m	6.5855	8.8331	9.5876
12 m × 3 m	8.2697	12.6556	15.8523

Tree carbon sequestration. The total amount of tree carbon sequestered has varied with different teak spacing in five to seven years old teak plantation (Table 4). Higher tree carbon sequestered was recorded with a spacing of 12 m × 3 m during 2018 (11.98 t ha^{-1}), 2019 (18.34 t ha^{-1}) and 2020 (22.97 t ha^{-1}). This was followed by 10 m × 3 m and 8 m and 3 m during 2018 (9.54 t ha^{-1} and 6.68 t ha^{-1}, respectively), 2019 (12.80 t ha^{-1} and 10.78 t ha^{-1}, respectively) and 2020(13.89 t ha^{-1} and 11.87 t ha^{-1}, respectively). Carbon sequestration will increase with increase in spacing which is contributed mainly by increased tree biomass and growth parameters of trees (Sreejesh *et al*., 2013).

Table 3: Above ground and below ground biomass influenced by different tree spacing's.

Treatments	Above ground biomass (t ha^{-1})			Below ground biomass (t ha^{-1})		
	2018	2019	2020	2018	2019	2020
8 m × 3 m	10.60	17.11	18.84	2.76	4.45	4.90
10 m × 3 m	15.15	20.32	22.05	3.94	5.28	5.73
12 m × 3 m	19.02	29.11	36.46	4.95	7.57	9.48

Table 4: Total biomass of tree and tree carbon stock influenced by different spacings.

Treatments	Total biomass of tree (t ha^{-1})			Tree carbon stock (t ha^{-1})		
	2018	2019	2020	2018	2019	2020
8 m × 3 m	19.08	25.60	27.78	9.54	12.80	13.89
10 m × 3 m	13.36	21.55	23.74	6.68	10.78	11.87
12 m × 3 m	23.97	36.68	45.94	11.98	18.34	22.97

Performance of finger millet in Teak plantation. Finger millet was taken as intercrop with teak plantation during 2017 and 2020 (Table 5). Significantly higher grain yield 26.78 q ha^{-1}, 25.49q ha^{-1}, 21.44q ha^{-1} and 18.94 q ha^{-1} was recorded with a spacing of 12 m × 3 m during 2017, 2018, 2019 and 2020 with yield reduction of 8.97 per cent, 18.97 per cent, 25.45 per cent and 36.19 per cent respectively when compared to sole crop. Further higher finger millet yield was recorded with a spacing of 10 m × 3 m and 8 m × 3 m. As the age of the tree increases there will be increase in canopy spread and decreases in light intensity for the intercrop associated henceforth intercrops which do shade love are preferred over cereals (Nagarajaiah *et al.*, 2012).

Table 5: Effect of *Tectona grandis* trees on grain yield of finger millet.

Treatments (m)	Finger millet							
	2017		2018		2019		2020	
	(q ha^{-1})	Reduction (%)	(q ha^{-1})	Reduction (%)	(q ha^{-1})	Reduction (%)	(q ha^{-1})	Reduction (%)
12m ×3 m	26.78	8.97	25.49	18.97	21.44	25.45	18.94	36.19
10 m × 3 m	25.97	11.72	22.63	28.06	20.59	28.41	16.89	43.09
8 m × 3 m	23.65	19.61	21.55	31.50	18.74	34.84	15.24	48.65
Pure crop	29.42	0.00	31.46	0.00	28.76	0.00	29.68	0.00
S.Em±	0.03	0.05	0.15	0.26	0.25	0.31	0.19	0.27
CD (P=0.05)	0.08	0.14	0.42	0.67	0.72	0.88	0.53	0.81

CONCLUSIONS

Carbon sequestration in teak plantation increases with increase in spacing and age of the tree. In seven years old teak plantation maximum tree carbon sequestered was 22.97 t ha^{-1}. Intercrops such as cereals and pulses can be taken till seven years of plantation and then shade loving crops are preferred for economical yield.

FUTURE SCOPE

Teak plantation have very good carbon sequestration potentiality depends upon the species, plantation techniques, agronomical practices followed for the maintenance with after care. Moreover, teak plants also help in climate change mitigation measures through absorbing many green gaseous converting them and fixing in biomass and giving back oxygen to atmosphere. Apart from this have great potentiality in enriching forest floor to support the growth and biomass.

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