Indian Journal of Ecology (2023) 50(5): 1338-1342
DOI: https://doi.org/10.55362/IJE/2023/4057

Manuscript Number: 4057
NAAS Rating: 5.79

Environmental and Economic Role of *Tectona grandis*: A Case Study

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Abstract: As a mitigation strategy to lower atmospheric carbon dioxide and boost farmers' net income, tree plantations are advocated as one of the biological tools to sequester carbon. Many tropical nations are implementing agroforestry-based carbon storage programmes; however, it is challenging to quantify the potential for carbon storage. The amount of carbon stored in the plantation, the potential to mitigate carbon from the atmosphere and the market value of 4 and 6-year-old *Tectona grandis* plantation in Chhattisgarh, India, was estimated. In the present study, the result indicated that the six-year-old plantation has the potential to produce 1650.90 ft^3 of the merchantable volume of timber with a market value of Rs. 20,63,621-1,15,57,929/- per hectare and the merchantable volume and market value produced in the plantation was 1097.87 ft^3 and Rs. 15,83,218-76,44,215/-. Similarly, the biomass and carbon stored in a six-year-old plantation was 309.00 t ha^{-1} and 127.36 t C ha^{-1} and in the four-year-old plantation it was 221.99 t ha^{-1} and 91.29 t C ha^{-1}. The CO_2 mitigation potential was 335.04 t $CO_2 ha^{-1}$ in a four-year-old plantation and 467.40 t $CO_2 ha^{-1}$ in a six-year-old plantation. The response in the India has been shown to be superior since teak is native to the forests of India and is produced on a modest to moderate scale. The results revealed that, with the increase in the age of teak plantations, there is an increase in carbon sequestration in plantations with a higher economic and ecological return.

Keywords: Teak, Economics, Carbon storage, CO_2 mitigation

Since the pre-industrial period, anthropogenic greenhouse gas emissions have risen significantly, mostly due to population expansion and industrialisation. Agroforestry is being investigated to mitigate increases in atmospheric carbon dioxide and projected climate change (Bhusara et al 2016). Many tropical nations are implementing forest carbon sequestration programmes; however, assessing carbon sequestration capacity is hindered by a lack of species-level data. Farmers may diversify their produce, decrease agricultural risk, contribute to food security, and earn much-needed revenue using these solutions. They also fulfil commercial timber needs while improving environmental values and services. Research on different tree species to evaluate their potential for carbon sequestration could help prioritise the best land use practices to ensure sustainability and benefit sharing among countries. The Kyoto Protocol recognises forests as one of the important carbon sinks. Research suggests that trees and other forest components sequester carbon within their bole, bark, branches, foliage, and roots for decades (Thakur et al 2011, Nizami 2012, Adnan and Nizmai 2014). The ability of various tree species to store carbon is mainly governed by the rotation of tree types and the age of plantations. With the additional benefit of being utilised mostly indoors, long-rotation species like teak (*T. grandis*) have a longer carbon locking time than short-rotation species (Sreejesh et al 2013). Teakwood trade has grown dramatically during the past few years. As long as its legal and sustainable farming has been established, teak is still highly valued and in great demand worldwide. Due to the growing volume of teakwood commerce, a systematic strategy to supply chain monitoring is required. As a result, starting on January 1, 2022, the Harmonized System nomenclature 2022 (HS 2022) Edition is bieng used to track the global trade in teakwood. The consistent classification of commodities traded worldwide are done using HS 2022. Togo's smallholder farmers cultivate teak on their properties to enhance household income. Food security is crucial since agricultural land and workers are in short supply. Despite this, farmers are eager to grow teak since the 15-year rotations offer the greatest yields for subsistence farmers (Kenny 2007). For similar reasons, smallholder farmers in southern Benin cultivate teak on short rotation to produce poles 5 to 15 cm long (Aoudji et al 2011). Farmers in Nigeria, under national afforestation initiatives and advancing national environmental goals, teak lengthens the time spent in a fallow state, improves soil fertility, diversifies agricultural output, and raises household income (Osemeobo 1989). However, access to land, technical knowledge, market expertise, and high-quality germplasm are necessary for farmers for such systems to perform to their full potential (Zanin 2005).

India's economic growth and rapid urbanisation are transforming the country's lifestyles and spending habits. The historic allure of wood and wood products in the nation is growing. An estimated 438.14 million m^3 of wood (including bamboo) is produced annually in India. India produces the most fuelwood (304 million m^3) (FAO 2021). *Tectona grandis* L.f., a large deciduous tree with a height of up to 40 m, is a member of the Lamiaceae family. Due to its stunning look and durable qualities, teak is one of the most expensive wood species. Despite being native to South and Southeast Asia, teak wood was imported into the agroforestry systems of several nations throughout tropical Asia, Africa, and Central and South America due to its tremendous economic potential (Nidavani and Mahalakshmi 2014, Udayana et al 2020). Farmers and foresters have recognised teak as a plant they like to domesticate (Thakur et al 2016, Kumar et al 2017, Pachas et al 2019). In India, the production of teak as a forestry business was a turning point in the development of forestry from a mainly extractive and regulating profession to one that involved resource creation. Teak was promoted with other main crops by the taungya systems in Myanmar (Blanford 1958), Java (Weersum 1982), and Africa (Oduol 1986). Since the introduction of clonal forestry, most teak plantations in tropical and subtropical nations have been grown from rooted cuttings and planting material obtained from tissue culture (Monteuuis and Maître 2007, Monteuuis and Goh 2017). Smallholder teak plantation refers to farmers with an average holding size of 0.5 to 1.0 ha and prefers agricultural systems incorporating teak trees, annual crops, and animals. Around 0.92 million acres of teak are grown by smallholders worldwide, with just 19% of the area being in Asia (Kollert and Cherubini 2012). In the 1960s, Indonesia developed the idea of contemporary smallholder agroforestry, primarily to produce teak wood. Later, it became a cutting-edge agroforestry model. Teak from small-scale plantations became a popular timber supply, producing more than large-scale plantations (Halladay and Gilmour 1995). Teak demand in and around the world exceeds the sustainable production from natural forests and plantations. The growing demand provides the opportunity for enterprising farmers. Teak is being farmed in smallholder agroforestry systems in several tropical nations. This research examines the role of teak systems in smallholder livelihoods and the C mitigation potential through block plantation.

MATERIAL AND METHODS

Study area: At a farmer's field in Bilaspur, Chhattisgarh, India, a 6 and 4-year-old clonal teak plantation were selected for the experiment. The site is located at 280 m above mean sea level, between 22°12' 05.21" N latitude and 82°05' 04.27" E longitude. The number of plants per hectare (2196) were higher in block plantations because they were planted in close spacing (2x2 m) to avoid deformation at early age.

Environment function: Allometric equations (Singh and Mishra 1979) linking tree circumference to biomass were utilised to assess tree biomass. Prior measurement of the carbon concentration (bole 43.50%, branch 45.67%, leaf 46.67%, and coarse root 35.73%) by Singh (2010) for the tropical dry deciduous forest of Chhattisgarh was utilised to estimate carbon stock. The carbon storage for vegetative components was determined by multiplying the dry weight of the components by their mean carbon content.

Economic function: By adhering to the prescribed protocols, field observations on significant growth factors, such as diameter at breast height (DBH) and individual trees height was recorded as per standard procedures. Tree stem volume was estimated using equation (FSI 1996): VUB (m^3) = $-0.0645 + 0.2322D^2H$, Where VUB is volume under bark, D is DBH over bark, and H is tree height. The average stem volume per tree was multiplied by the number of plants per hectare to determine the volume of stems per hectare in m^3/ha. In order to calculate the marketable value, it was converted to ft^3/ha. The market value of the standing crop was calculated using two market values (upper and lower limits) from the official website of India Mart.

RESULTS AND DISCUSSION

Economic function: The result showed that the average height of the four-year-old plantation was 3.04 m and that of six-year-old plantation was 4.11 m, and the merchantable height was 2.95 m and 3.36 m, respectively, for both plantations (Table 1). The diameter above the bark ranged between 32.30 and 56.00 cm at in four-year-old plantation and 40.90 and 60.90 cm of the six-year-old plantation. The

Table 1. Merchantable volume and market value of teak plantation

Plantation	Avg DBH (cm±SE)	Avg ht (m±SE)	Merchantable volume		Market value/ tree* (INR) (n=15)		Market value/ha* (10^6 INR)	
			m^3/ha±SE	ft^3/ha±SE	1450 ru/ft^3	7001 ru/ft^3	1450 ru/ft^3	7001 ru/ft^3
4-yr-old	45.01±1.65	2.95±0.07	30.92±2.14	1091.87±75.57	720.96	3480.97	1.58	7.64
6-yr-old	52.00±1.40	3.36±0.07	46.75±2.55	1650.90±90.15	939.72	5263.17	2.06	11.56

Source of market price per cubic feet- India Mart merchantable volume of the four-year-old plantation was 30.92±2.14 m^3, and 46.75±2.55 m^3 of the six-year-old plantation. It could provide an additional income of 720 to 3,480 rupees per plant and around 1.58 to 7.64 million rupees per hectare in a 4-year-old plantation and 939-5,263 rupees per plant and around 2.06 to 11.56 million rupees per hectare in the six-year-old plantation. If the farmer uses the systemic thinning process to encourage higher per-hectare volume growth and removes only 1312 to 1625 plants per hectare, the plantation will generate an additional intermediate income of Rs 9,44,640-56,55,000 from 4 years and Rs 12,31,968 - 85,52,375 through 6-year-old plantation. Also, the increased gap between the row and column will also increase the space for short-term crops.

According to reports (ISFR 2019), the demand for sawn wood is now rapidly rising, and outside of forests, trees contribute the most to the production of wood (84%). In Gunungkidul village of Java, smallholders use teak plantations as their living saving account and harvest them only in significant need of money (Roshetko et al 2013). Also, the farmers in Luang Prabang sell their trees for cash in an instant need to cover unforeseen needs and significant annual bills like tuition (Antilla 2016). According to Monteuuis and Goh (2015), clonal plants with 3x3 m spacing at 5 years had an average output of roughly 25 cum per hectare yearly. After 50% of the trees were cut down systematically, 48.8 cum per hectare per year was recorded (Monteuuis and Goh 2018). Also, Mevada et al (2022), Kumar et al (2016) and Thakur et al (2016) observed that comparing the single crop net realisation and benefit cost ratio from teak-based agri-silviculture was greater.

Environmental function: The results (Table 2) of biomass and carbon stored in different plantations and their potential to mitigate the CO_2 from the atmosphere indicate that the biomass stored in the four-year-old plantation was 309.00±26.86 t/ha, with carbon stock 127.36±11.15 t C/ha, and it had the potential to eradicate the 467.40±40.91 t CO_2 per hectare. The bole contributed 91.98 t/ha and 40.01 t C/ha to biomass and carbon storage; the branch contributed 86.96 t/ha and 39.72 t C/ha; the foliage contributed 10.61 t/ha and 4.95 t C/ha; and the root component contributed the most (119.45 t/ha and 42.68 t C/ha). Similarly, the biomass storage capacity of the six-year-old plantation was 434.67 t/ha, with 179.59 t C/ha of carbon stored in it and the ability to absorb 659.08 t CO2 per hectare.

Here also, root component contributed the most to biomass and carbon storage (164.24 t/ha and 58.68 t C/ha, respectively), followed by bole (126.41 t/ha and 54.99 t C/ha), branch (129.90 t/ha and 59.33 t C/ha), and minimum by foliage component (14.12 t/ha and 6.59 t C/ha, respectively). Estimation of biomass is crucial for understanding carbon stocks (Ketterings et al 2001). Tree absorb carbon dioxide during photosynthesis and is fixed in their body biomass, and as a tree's biomass expands, its diameter likewise rises, increasing the tree's capacity to sequester carbon dioxide from the atmosphere (Pandya et al 2013). High biomass and carbon sequestration are substantially associated with the basal area and tree size (Vilanova et al 2018). Many times, teak plantations are selected since it is a species with significant commercial value. Teak is more effective at storing more carbon in its tissue for longer periods and emitting less carbon dioxide into the environment (Sreejesh et al 2013).

Although the contribution of root components in biomass and carbon storage is highest, with an increase in age, the contribution of wood components (bole and branch) increases. The contribution of short-lived components (foliage) in biomass and carbon storage is minimum, and they play an active role in carbon sequestration and the

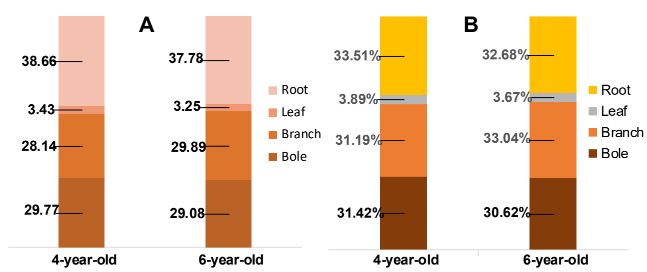

Fig. 1. Contribution of components a) stand biomass and b) stand carbon storage and CO^2 mitigation potential

Table 2. Biomass, carbon storage, and carbon mitigation potential of teak plantation

Plantation	Parameter	Bole	Branch	Leaf	Root	Total
4-year-old plantation	Biomass (t/ha±SE)	91.98±7.45	86.96±8.95	10.61±0.77	119.45±9.69	309.00±26.86
	Carbon storage (t C/ha±SE)	40.01±3.24	39.72±4.09	4.95±0.36	42.68±3.46	127.36±11.15
	CO_2 mitigation potential (t CO_2/ha±SE)	146.84±11.90	145.76±15.00	18.17±1.32	156.63±12.71	467.40±40.91
6-year-old plantation	Biomass (t/ha)	126.41±7.57	129.90±9.88	14.12±0.76	164.24±9.85	434.67±28.05
	Carbon storage (t C/ha)	54.99±3.29	59.33±4.51	6.59±0.35	58.68±3.52	179.59±11.67
	CO_2 mitigation potential (t CO_2/ha)	201.81±12.08	217.73±16.56	24.18±1.30	215.36±12.91	659.08±42.84

nutrient cycle (Singh and Singh 1991, Singh and Singh 1993). In the present study, the results favoured the results obtained by Singh and Singh (1991). The different studies conducted in the Chhattisgarh region supported the contribution of foliage in biomass and carbon storage (Singh 2010, Pawar 2014, Samal et al 2022, Thakrey et al 2022). Whereas the study by Shukla and Viswanath (2014) reported that the contribution of the bole component was highest.

CONCLUSION

The physical productivity and economic viability of an agroforestry system are significantly influenced by its woody components' temporal and spatial arrangements. The relative virtues of teak block plantings have been shown by data from this study's investigation of the economic and environmental benefits. Smallholder teak systems are a low-input alternative strategy for improving livelihoods. The techniques increase income and provide the option of redirecting family labour to non-farm pursuits. The system's fundamental element, the classic intercropping approach, enables the production of short-term and long-term profits. Smallholder teak systems have developed into a substantial source of raw materials for the furniture industry and have assisted in ecosystem restoration. In addition to the potential benefits and ongoing significance of smallholder teak systems, a teak block plantation may theoretically eliminate atmospheric CO_2 and store it in biomass that can be used to produce furniture and kept for a long time, which can assist in slowing down climate change.

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Received 16 April, 2023; Accepted 22 August, 2023

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