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GROWTH PERFORMANCE ANALYSIS OF SEVEN AGROFORESTRY TREE SPECIES IN TWO AGRO-CLIMATIC ZONE OF KARNATAKA, INDIA

B. Tambat[1]*, Deekhsa Raj N.[1], Yash Khot[1] and R. Ravishanker[2]
[1]Department of Forestry and Environmental Sciences, UAS, GKVK, Banaglore-65
[2]Chief Conservator of Forests, Karnataka Forest Department, Bangalore
*Corresponding author E-mail: btambat@gmail.com
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ABSTRACT

Agroforestry refers to growing of woody perennials along with the agricultural crops on the same piece of land. In India several agroforestry models exist with different species composition and architecture. However, the tree species suitability and performance in a given area is not well studied. The Karnataka, a state in south India having more than 8 % area under agroforestry. The entire state is divide into 10 agroclimatic zones based on the climatic, edaphic and cropping pattern. Tree species are being recommended for the agroforestry considering their specific characters and usefulness. However, tree species suitability and performance for the given agroclimatic zones is not being well evaluated. The study aims to analyze growth performance of seven tree species in two agroclimatic zones, namely central dry zones (Zone 4) and eastern dry zones (Zone 5) of Karnataka. Overall, more than 1,400 trees were enumerated from the 73 farmers filed. Growth parameters such as total height (m) and girth at breast height (GBH) were recorded and merchantable wood volume (m^3) was estimated. Results revealed the existence of marked interspecies and interzonal variations. In the Eastern Dry Zone, *Melia dubia, Swietenia mahagoni, Santalum album, Grevillea robusta*, and *Artocarpus heterophyllus* exhibited superior growth performance, whereas *Tectona grandis* and *Syzygium cumini* performed better in the Central Dry Zone. The results of the study are useful in developing zone-specific agroforestry strategies and species selection guidelines to enhance the productivity and farm income in dryland regions of Karnataka.
***Keywords* :** Agroforestry, Agroclimatic zones, Karnataka, Tree species, growth performance.

Introduction

Agroforestry is considered to be promising alternative to conventional agriculture that can conserve biodiversity and support local livelihood, and also sequester atmospheric carbon (Patil, 2022). In agroforestry trees are grown on the same piece of land along with the crops (Deeksha Raj *et al*., 2025). Further, growing trees helps to maintain the ecological balance such as conservation of soil, water, enhances the forest cover, biodiversity and carbon sequestration also supports the farmers in earning additional income in field by adopting intercropping and mixed cropping system (Chittpur and Murthy, 2018). In India many agroforestry systems have been identified considering the component it involved (Dhyani, 2018). Further, cultivation of trees in agroforestry systems indirectly reduce the pressure on forests and helps to cope-up with climate variability. Alternative land use systems are playing a major role in sustaining the resource base and increasing overall productivity in the rainfed areas that too in arid and semi-arid regions in particular. Agroforestry land use increases livelihood security and reduces susceptibility to climate and environmental change.

Timber is a crucial input in paper industry, needed for construction, furniture making, packaging goods, etc. India's need for timber is high, and domestic supply falls short, making the country heavily dependent on imports to meet growing demand. The productivity of timber in India is only 0.7 cu.m/ha/year whereas, the world average is 2.1 cu.m/ha/year (Lal, 2011). This intern increased the nation's forest footprint, particularly in South-East Asia. In order to minimize the forest footprint, we need to encourage sustainable utilization of timber and also by promoting growing of trees outside the forest in the form of farm forestry and agroforestry. India's domestic timber supply is about 85–95 million m³ per year, mostly from agroforestry, while demand exceeds 150 million m³, creating a large gap met through imports. India's annual timber demand has been estimated at around 63 million m³, with domestic production meeting about half and the rest met through imports (FSI).

In the recent times, incorporation of fast-growing tree species into the agroforestry systems has received more attention among farmers in India due to its diversified outputs and sustained agricultural productivity (Akhilraj *et al.*, 2023). However, there are only few studies suggesting the most operative and productive tree species in agroforestry that are best suited to a given agroclimatic zone (Deeksha Raj *et al.*, 2025). The fact that growth performance and timber yield of specific known to vary with the agroclimatic conditions apart from the genetic factor (Chethan *et al.*, 2019). Analysing growth performance of tree species across the agroclimatic zone would be useful, particularly in estimating economic returns and total productivity of the land. It also helps to select a tree species for a given agroclimatic zone. In this study growth performance and merchantable yield of seven agroforestry tree species in two agroclimatic zones of Karnataka, South India was analyzed.

Material and Methods

Study Area: The study was carryout in Karnataka state, South India, which encompasses ten agroclimatic zones differentiated by rainfall, soil type, topography, elevation, and cropping patterns. The two zones namely central dry zones (Zone-4) and eastern dry zones (Zone-5) were selected for the study. The study locations are mapped and are given in the figure 1.

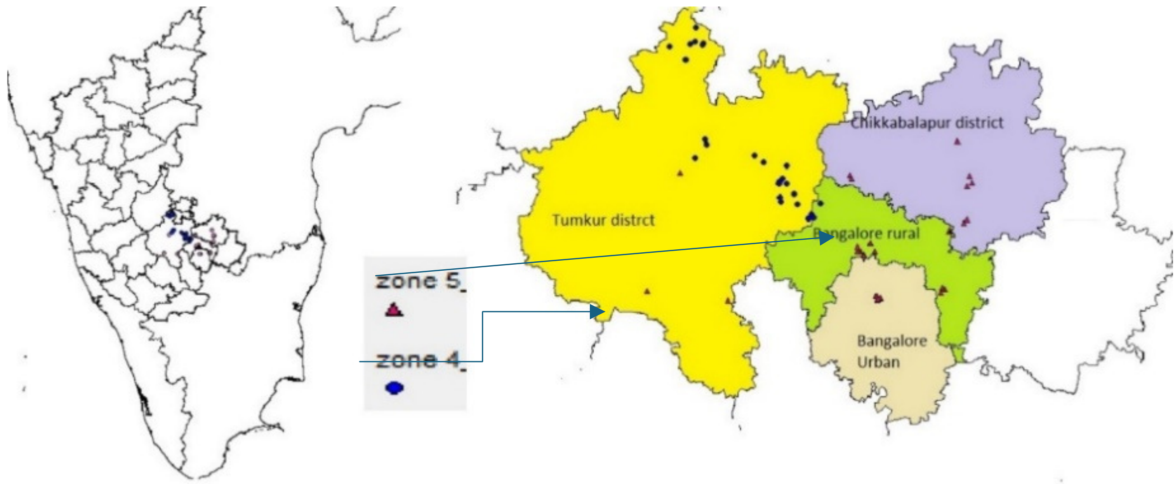


Fig. 1: Map depicting the geographical locations of study sites in Central Dry Zone (Zone 4) and Eastern Dry Zone (Zone 5) of Karnataka, south India (colour depict the district)

Central dry zone (Zone-4): The Central Dry Zone covers approximately 2.0 million hectares' area. Annual rainfall ranges between 450 and 720 mm and elevations ranging from 450 to 900 m above mean sea level. Soils are predominantly red sandy loams and medium to deep black soils. The study sites in this zone were located in Tumkur district, covering villages across the taluks of Koratagere, Sira, Kunigal, and Madhugiri.

Eastern dry zone (Zone-5): The Eastern Dry Zone extends over about 1.85 million hectares, with elevations between 800 and 1,500 m above mean sea level and annual rainfall ranging from 680 to 890 mm. The climate is semi-arid with tropical monsoon influence, and soils are mainly clayey lateritic in nature. Field observations were conducted in selected taluks of Chikkaballapur, Bengaluru Rural, and Bengaluru Urban districts.

Selection of Tree Species and Sampling

The information on agroforestry tree species planted by the farmers and the year of planting was obtained from Karnataka Forest Department (KFD) divisional office. The species common to both the zones, and sites representing different aged plants (1 to 15 years) were shortlisted and selected. Based on the above criteria, seven species were selected namely; *Melia dubia* (Melia), *Swietenia mahagoni* (Mahagony), *Santalum album* (Sandalwood), *Tectona grandis* (Teak), *Grevillea robusta* (Silver oak), *Syzygium* *cumini* L. (Jamun) and *Artocarpus heterophyllus* Lam. (Jack). Through preliminary field surveys a few stratified regions were identified. Finally, data from 73 sites was collected across the two zones. For selected tree species age was determined by subtracting year of planting from the current Calendar year (2023). Purposive sampling method was adopted for the study. At the field sites for each species biometric data was recorded on at least 10 randomly selected trees and average values were computed and used for the analysis.

Data Collection and Analysis

The biometric observations included measurements of tree height, bole height, and girth at breast height (GBH). Tree height (m) was measured from ground level to the terminal apex using Ravi's altimeter and recorded in meters. Bole height, defined as the distance from the ground to the lowest branch of the crown, was also measured with Ravi's altimeter and expressed in meters. Girth at breast height was measured at 1.37 m above ground level using a measuring tape and recorded in meters. For each species, mean values were calculated for each age group at every study site and used for subsequent analysis. The volume of individual trees was estimated using the following formula;

Volume (m^3) = Basal area (BA) x height (H) x farm factor (FF)

Where Basal area (BA) was computed using the formula

$$BA = G^2 / 4\pi, \; G = \text{Girth at Breast height}$$

The average value for a given age was then computed and used for further analysis. The Merchantable volume was measured as the portion of a tree's height that can be used as timber, typically measured from the base of the tree, upto the point where first branching starts (excluding the stump, which is generally about one foot high). Farm factor (FF) used for the analysis differ across the species; thus, species specific FF values used for the analysis (table 1). However, form factor 0.33 is used when species-specific or site-specific form factors are not developed or when a quick estimate is needed (Evert, 1969). Relationship of tree height, girth and volume (dependent variable) with the age (independent variable) was verified with regression analysis using software (STATISTICA).

Table 1: Tree species (scientific and common name) and form factor (FF) values used for the analysis

Sl No	Species	Common name	FF	References
1	*Melia dubia* Cav.	Melia	0.70	Chandana *et al.,* 2020
2	*Swietenia mahagoni* (L.) Jacq.	Mahagony	0.70	dos Reis *et al.,* 2019
3	*Santalum album* L.	Sandalwood	0.40	Tewari *et al.,* 2014
4	*Tectona grandis* L.f.	Teak	0.47	Felipe *et al.,* 2016
5	*Grevillea robusta* A. Cunn.ex.R.Br.	Silver oak	0.55	Sanjith *et al.,* 2020
6	*Syzygium cumini* L.	Jamun	0.33	Evert, 1969
7	*Artocarpus heterophyllus* Lam.	Jack	0.33	Evert, 1969

Results and Discussion

Results pertaining to the growth performance of different agroforestry tree species in central and eastern dry zones of Karnataka was furnished here. In the present study, total height was recorded up to 15 years. The results revealed that the growth performance varied across the two zones in all the seven-tree species studied.

Tree Height: The **t**ree height exhibited significant variation among species as well as between the two agroclimatic zones. In the Eastern Dry Zone, *Grevillea robusta* attained the greatest mean height (15.45 m at 15 years), followed by *Melia dubia* (15.10 m at 12–13 years), *Tectona grandis* (12.05 m at 14 years), and *Swietenia mahagoni* (10.60 m at 13 years). In contrast, relatively lower height growth was observed in *Santalum album* (6.95 m at 10 years), Artocarpus *heterophyllus* (7.83 m at 14 years), and *Syzygium cumini* (4.59 m 15 years), indicating slower vertical growth under prevailing field conditions.

In the Central Dry Zone, the maximum tree height was recorded in *Tectona grandis* (13.70 m at 14 years), followed by *Grevillea robusta* (13.25 m at 15 years) and *Melia dubia* (10.35 m at 9–10 years), *Swietenia mahagoni* (9.55 m at 7 years) and *Syzygium cumini* (7.90 at 10 years). Species such as *Santalum album* (5.40 m at 10 years) and *Artocarpus heterophyllus* (3.59 m at 7 year) exhibited comparatively reduced height growth. These results are in conformity with the findings of Akhilraj *et al.* (2023) and similar studies were conducted by Sharma *et al.,* (2019) they found significant variation in height growth in *Melia dubia* in Forest Research Institute, Dehradun. Srivastav *et al.,* (2018) conducted a study on the early performance of 19 *Eucalyptus* clones in Uttar Pradesh, significant variation in height growth was recorded which is comparable to present study. The results revealed that, observed interzonal differences in height growth suggest a strong influence of rainfall regime, soil type, and microclimatic conditions on species-specific growth responses.

Girth at Breast Height (GBH): Girth at breast height (GBH) increased progressively with tree age across all species and both agroclimatic zones, demonstrating a strong age-dependent growth pattern. In the Eastern Dry Zone, *Melia dubia* recorded the highest mean GBH (1.41 m at 12–13 years), followed by *Grevillea robusta* (1.24 m at 15 years), *Swietenia mahagoni* (0.96 m at 13 years) *Tectona grandis* (0.92 m at 14 years) and *Artocarpus heterophyllus* (0.80 m at 15 years). Lower GBH values were observed in *Santalum* (0.41 m at 10 years) and *Syzygium cumini* (0.76 m at 15 years), reflecting comparatively slower radial growth.

In the Central Dry Zone, the highest GBH was observed in *Grevillea robusta* and *Tectona grandis* (1.09 m at 15 and 14 years), followed by *Syzygium cumini* (0.76 m at 10 years) and *Melia dubia* (0.63 m at 10 years respectively). Species such as *Swietenia mahagoni* (0.38 m at 7 years), *Santalum album* (0.33m at 10 years), and *Artocarpus heterophyllus* (0.24 m 7 years) recorded lower girth increments. Supporting the present study, a similar increment in the plant height and DBH of *Ailanthus excelsa* at different field conditions were observed by Deswal *et al*., 2021. Diameter at breast height showed the most significant values in *Grevillea robusta* tree species in eastern dry zone of Karnataka, indicated that GBH increasing with increasing with age of the tree. Similar results have been reported by the Chaturvedi, 1992, Bisaria *et al*., 1999 and Khan & Chaudhry, 2007.These results clearly indicate that GBH is strongly influenced by species characteristics and site-specific conditions, and that radial growth responds more sensitively to agroclimatic variation than height growth.

Relationship Between Tree Age and Growth Parameters

Simple linear regression analysis indicted that statistically strong and positive relationships exist between tree age (independent variable) and growth parameters such as tree height, GBH, and merchantable wood volume (dependent variables) for all seven species in both agroclimatic zones. The regression coefficients indicated consistent incremental growth with increasing age, confirming that tree growth follows a predictable path over a time are presented in Fig. 2, 3 4, 5, 6, 7 and 8. These results are in line with Nissen *et al*., 2001 implying biometric parameters like height (m), girth (m) and volume (m^3) increases significantly with age of the tree. There exists large variation in the growth parameters of different agroforestry tree species due to its soil and climatic factors (Srimathi and Kulkarni, 1979).

The regression analysis indicated that a substantial proportion of the variability in height and girth was explained by tree age alone, particularly in fast-growing species such as *Melia dubia*, *Grevillea robusta*, and *Tectona grandis*. This suggests that age is a reliable predictor of biometric growth parameters in agroforestry systems. However, residual variation observed in the models highlights the influence of additional factors such as soil fertility, moisture availability, and management practices.

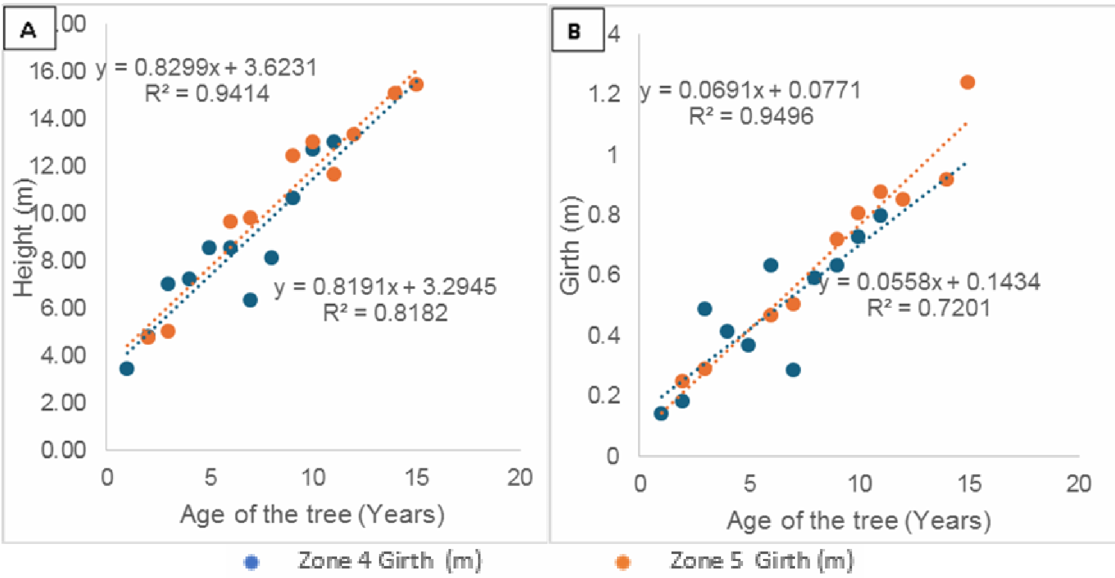


Fig. 2 : Relationships between Age A. Tree height (m) and B. Girth (m) of *Grevillea robusta* (Silver oak) in Central (Zone-4) and Eastern (Zone-5) Dry Zones of Karnataka

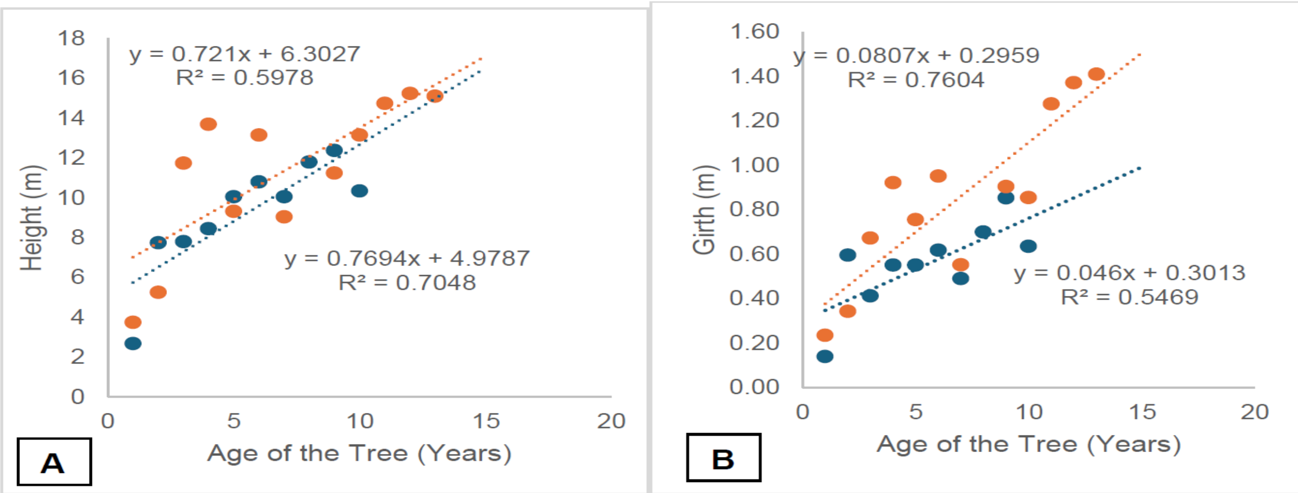


Fig. 3 : Relationships between Age, A. Tree height (m) and B. Girth (m) of *Melia dubia* in Central (Zone-4) and Eastern (Zone-5) Dry Zones of Karnataka

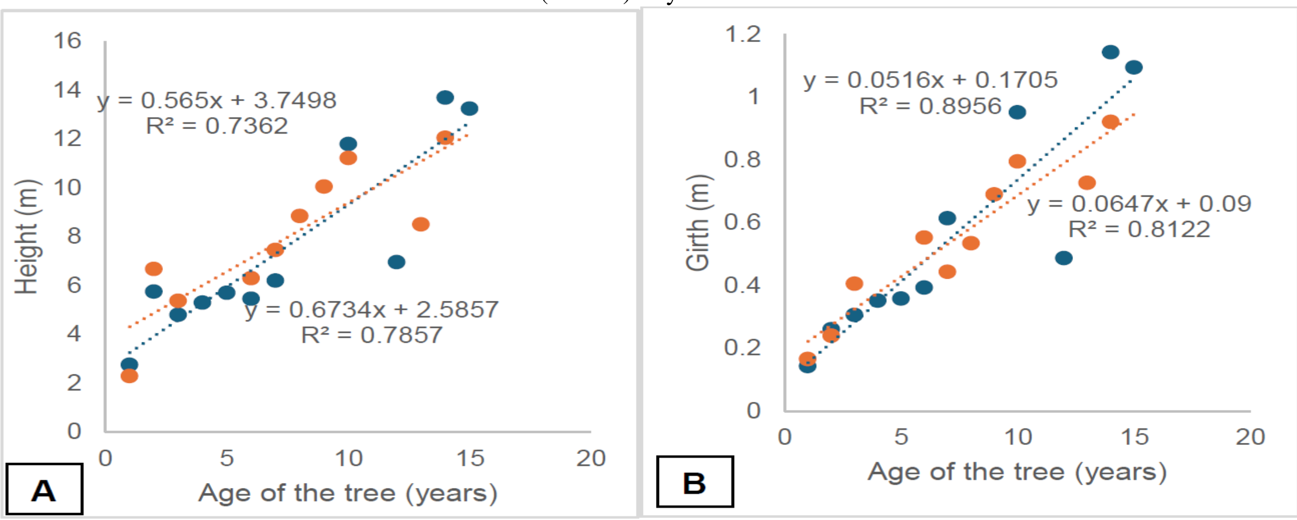
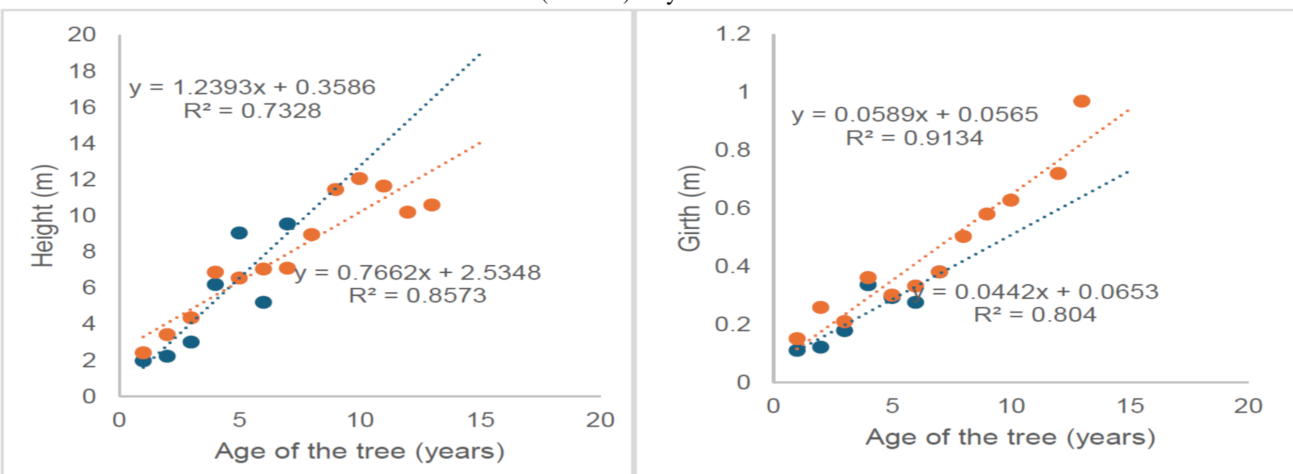
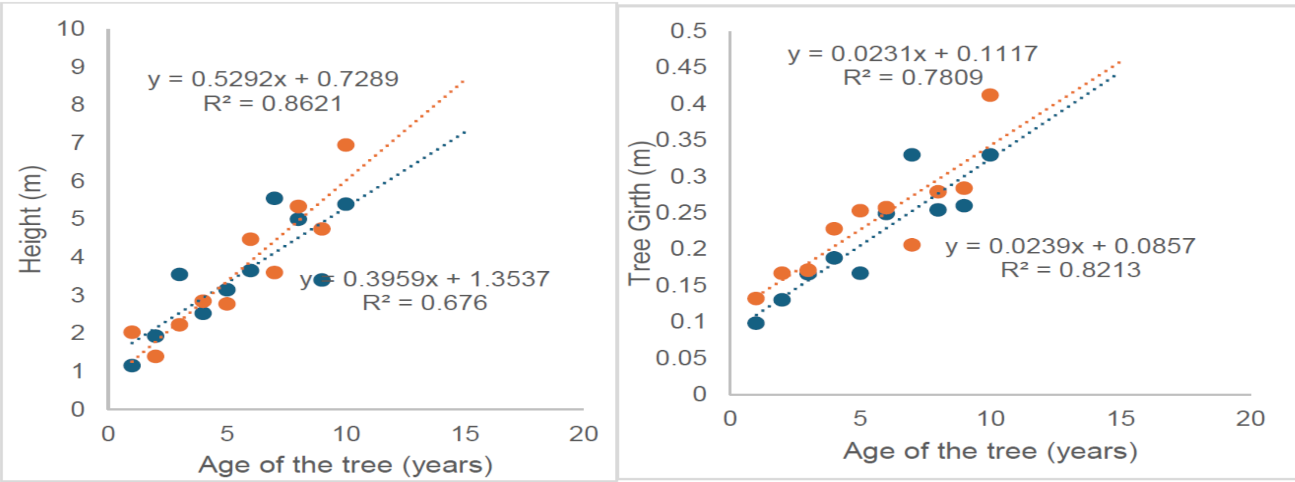


Fig. 4 : Relationships between Age, A. Tree height (m) and B. Girth (m) of *Tectona grandis* (Teak)in Central (Zone-4) and Eastern (Zone-5) Dry Zones of Karnataka



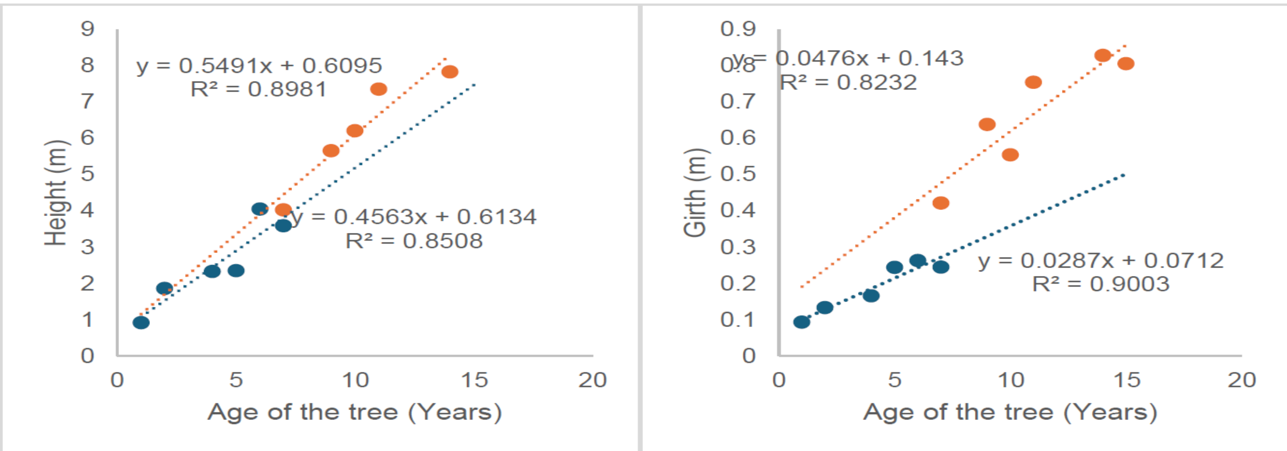
A **B**

Fig. 5 : Relationships between Age, A. Tree height (m) and B. Girth (m) in *Swietenia mahagoni* (Mahagony) Central (Zone-4) and Eastern (Zone-5) Dry Zones of Karnataka



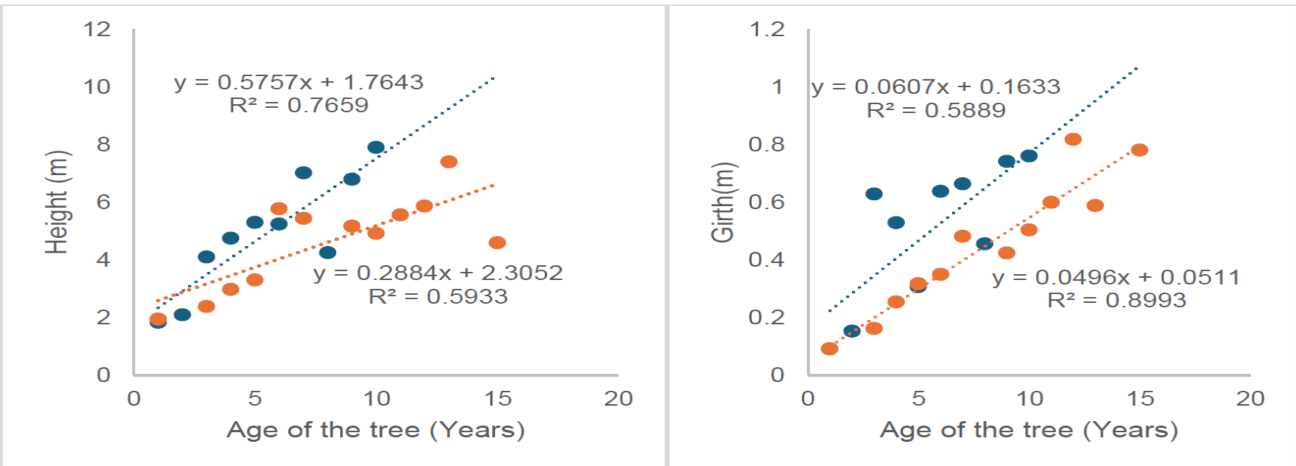
A **B**

Fig. 6 : Relationships between Age, A. Tree height (m) and B. Girth (m) of *Santalum album* (Sandalwood)in Central (Zone-4) and Eastern (Zone-5) Dry Zones of Karnataka.



A **B**

Fig. 7 : Relationships between age, A. Tree height (m) and B. Girth (m) of *Artocarpus heterophyllus Lam.* (Jack)in Central (Zone-4) and Eastern (Zone-5) Dry Zones of Karnataka



A **B**

Fig. 8 : Relationships between Age, A. Tree height (m) and B. Girth (m) *Syzygium cumini* L. (Jamun) in Central (Zone-4) and Eastern (Zone-5) Dry Zones of Karnataka

To further elucidate the reasons for the distribution of tree growth across different agroclimatic zones, it is noteworthy that wide variations were observed in both girth distribution and tree age. However, during the initial years, variations in height may be attributed to environmental influences on tree growth (Thakur *et al.*, 2019). The results clearly indicate that the growth performance of different agroforestry tree species in the Central and Eastern Dry Zones of Karnataka, in terms of height, girth at breast height, and volume increment, is strongly influenced by climatic and soil factors, as well as farmers' management practices. These factors collectively exert a cumulative effect on tree growth as the trees age.

Merchantable Wood Volume

The wood volume of selected agroforestry tree species in the Central and Eastern Dry Zones of Karnataka is presented in Tables 2 and 3. Wood volume was assessed after three years of planting and estimated using standard volume equations and regression models as described by Tambat *et al.* (2025). Among the species evaluated, *Melia* recorded the highest merchantable wood volume in the Eastern Dry Zone (0.856 m³), compared to Central Dry Zone (0.331 m³) at 15 years after planting. In contrast, *Teak* exhibited greater volume accumulation in the Central Dry Zone (0.399 m³) compared to the Eastern Dry Zone (0.215 m³) at 14 years. Similarly, *Mahogany* and *Silver oak* showed significantly higher wood volumes in the Eastern Dry Zone, recording 0.210 m³ and 0.534 m³, respectively, compared to 0.104 m³ and 0.240 m³ in the Central Dry Zone at 15 years.

Jack and *Sandalwood* also exhibited higher wood volumes in the Eastern Dry Zone, with values of 0.065 m³ (11 years) and 0.015 m³ (15 years), respectively, whereas comparatively lower volumes were observed in the Central Dry Zone. Conversely, *Jamun* performed better in the Central Dry Zone, recording a higher wood volume (0.086 m³) than in the Eastern Dry Zone (0.034 m³) at 15 years.

Overall, Melia, Teak, Silver oak, and Mahogany demonstrated superior merchantable wood volume across both zones, whereas Sandalwood, Jack, and Jamun recorded comparatively lower volumes. Among all species, Sandalwood consistently exhibited the lowest wood volume in both zones. Zone-wise comparison revealed that Melia, Mahogany, Jack, Silver oak, and Sandalwood performed better in the Eastern Dry Zone (Zone 5), while Teak and Jamun showed relatively higher productivity in the Central Dry Zone (Zone 4).

The results indicate a positive relationship between merchantable wood volume, tree age, and girth at breast height (GBH). Merchantable volume increased steadily with increasing girth and age, confirming that tree growth is primarily age-dependent, as reported by Nissen *et al.* (2001). These findings reiterate the earlier finding by Sandeep *et al.* (2016), Perez and Kanninen (2003), and Tewari and Mariswamy (2013).

Table 2 : Merchantable volume of different agroforestry tree species in central dry zone (Zone 4) of Karnataka

Age of the tree	Melia	Mahagony	Teak	Sandalwood	Jack	Jamun	Silver oak
4	0.087	0.018	0.017	0.002	0.001	**0.007**	**0.026**
5	0.119	0.027	0.013	0.002	0.002	**0.006**	**0.032**
6	0.140	0.029	0.017	0.003	0.004	**0.020**	**0.079**
7	0.072	0.048	0.049	0.009	0.003	**0.044**	**0.012**
8	0.189	**0.049**	**0.123**	0.005	**0.003**	**0.010**	**0.075**
9	0.287	**0.057**	**0.149**	0.003	**0.004**	**0.051**	**0.108**
10	0.148	**0.065**	0.216	0.009	**0.004**	**0.073**	**0.166**
11	**0.227**	**0.073**	**0.200**	**0.009**	**0.005**	0.060	**0.226**
12	**0.248**	**0.081**	0.033	**0.010**	**0.005**	0.066	**0.183**
13	**0.269**	**0.088**	**0.251**	**0.010**	**0.006**	0.073	**0.202**
14	**0.290**	**0.096**	0.399	**0.011**	**0.006**	0.080	**0.221**
15	**0.311**	**0.104**	0.360	**0.012**	**0.007**	0.086	**0.240**

Table 3 : Merchantable volume of different agroforestry tree species in eastern dry zone (Zone-5) of Karnataka

Age of the tree	Melia	Mahagony	Teak	Sandalwood	Jack	Jamun	Silver oak
4	0.313	0.028	**0.023**	0.001	**0.008**	**0.002**	**0.006**
5	0.088	0.019	**0.037**	0.001	**0.013**	**0.005**	**0.039**
6	0.257	0.023	0.035	0.002	**0.017**	**0.007**	**0.051**

7	0.094	0.028	0.030	0.002	0.006	**0.014**	**0.061**
8	**0.392**	0.063	0.049	0.003	**0.026**	**0.014**	**0.137**
9	0.264	0.119	0.092	0.003	0.030	**0.011**	**0.144**
10	0.291	0.144	0.151	0.019	0.023	**0.018**	**0.179**
11	0.703	0.084	**0.121**	**0.010**	0.065	**0.023**	**0.180**
12	0.821	0.146	**0.135**	**0.011**	**0.044**	**0.033**	**0.210**
13	0.880	0.258	0.098	**0.012**	**0.048**	**0.028**	**0.300**
14	**0.789**	**0.193**	0.215	**0.013**	0.055	**0.031**	**0.294**
15	**0.856**	**0.210**	**0.177**	**0.015**	0.048	**0.034**	**0.534**

Conclusion

The study provides a comprehensive evaluation of growth performance and merchantable wood volume of seven agroforestry tree species across the Central and Eastern Dry Zones of Karnataka. Significant interspecific and interzonal variations were observed in height, girth, and wood volume, underscoring the influence of agroclimatic conditions on tree growth. Species such as *Melia dubia*, *Grevillea robusta*, *Tectona grandis*, and *Swietenia mahagoni* emerged as promising candidates for enhancing productivity and profitability in dryland agroforestry systems. The findings highlight the need for zone-specific species selection to optimize agroforestry outcomes and support sustainable land-use planning in Karnataka.

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Authors Contribution:

B. Tambat - Conceptualization, investigation, data analysis and draft correction

Deekhsa Raj N. - Data collection and preliminary analysis, draft preparation

Yash Khot. - Data collection and preliminary analysis

R. Ravishanker - Draft correction and reviewing

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