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Studies on Sandalwood Tree (*Santalum album* L.) Based Agroforestry System in Haveri District of Karnataka, India

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***Abstract*:** Study was conducted during the year 2018-2021 at College of Forestry, Sirsi for studied on sandalwood tree (*Santalum album. L.*) based Agroforestry systems in Karnataka. The important objectives of this study were screening of secondary host plants on heartwood, oil content and carbon sequestration potential of sandalwood tree in different agroforestry systems of Karnataka in Haveri district and revealed that 47.32 per cent in clear bole height of sandalwood trees with *Swietenia mahogany* and 42.43 per cent with *Calliandra haematocephala* as compared to other secondary hosts. The volume of the main stem of sandalwood was increased by 85.08 per cent with *Moringa oleifera* and 83.37 per cent with *Casuarina equisetifolia* as secondary host for sandalwood trees. The heartwood content of sandalwood tree increased by 68.75 per cent with *Casuarina equisetifolia* and 64.36 per cent in *Sesbania grandiflora.* The per cent oil content of sandalwood tree was increased by 95.20 per cent with *Casuarina equisetifolia* and 92.75 per cent with *Swietenia mahogani* as secondary host of sandalwood tree. Carrbon sequestration potential of different host based sandalwood planation was highest capacity with the host of *Murraya koenigii* (21.05 tha^{1}) and *Moringa oliefera* (20.19 tha^{1}).

Keywords: Sandalwood, Heartwood and path coefficient analysis

Indian sandalwood tree (*Santalum album* L.) one of the world's most valuable commercial timbers and is currently valued globally for its heartwood and oil. According to the predictions of Thomson(2020) the local demand for sandalwood oil in India will rise to a minimum of 250 tons in 2040. Wild sandalwood might yield ~100 tons of oil in 2040 and based on recent data Sandalwood plantations were taken up in a massive scale at around 2019 (~30000 ha) in India. High economic worth of Indian sandalwood is due to its heartwood and oil content. Heartwood is defined as inner rings of xylem deposited with metabolic byproducts that is hard and nonliving, which is usually dark in color. Initiation and heartwood formation in Indian sandalwood usually begins from the age of 6-7 years and the best quality heartwood is observed at the age of 30 years whose girth may be around 50 to 60 cm. Karnataka once was famous for sandalwood trees in the world. Sandal trees are necessarily grown with other plants, preferably leguminous plants for providing nutrients and water for Sandal trees (Rocha et al 2017). The semi-parasitic nature of the tree, its adaptability to grow in semiarid tracts and its potential to grow in combination with horticultural species as secondary hosts make it a potent agroforestry species.

Carbon conservation and carbon sequestration require the support of socio-economic improvements in numerous developing nations. Tree crop plantations offer the potential to combine climate change mitigation with economic growth, as they can sequester carbon while providing wood and non-wood products to meet domestic and global market demands. Financial compensation for such plantations may be eligible under the Clean Development Mechanism of the United Nations Framework Convention on Climate Change (UNFCCC) Kyoto Protocol. It has also been proposed for inclusion in REDD+ (reducing emissions from deforestation, forest degradation, and enhancement of forest carbon stocks), which is under negotiation within the United Nations FCCC (Kongsager et al 2013). The carbon sequestration potential (CSP) of agroforestry has been estimated in numerous studies. Globally, carbon accumulation in agroforestry ranges from 0.29 to 15.2 Mg C ha^{1} year^{1} aboveground and 30 to 300 Mg C ha^{1} year^{1} for soils down to 1 m depth (Albrecht and Kandji 2003). However, carbon stocks in agroforestry vary based on geographical location and climatic zone (Basu 2014). In India, the biomass, carbon stock, and carbon sequestration potential of different agroforestry systems also vary across regions (Rai et al 2009, Kumar 2010, Koul and Panwar, 2012, Devagiri et al 2013). These differences in carbon density and carbon sequestration potential among AFS are primarily attributed to climatic conditions and other site-specific factors due to India's diverse geography and climate. Furthermore, variations in methodological approaches, such as biomass assessments based on standing tree volume, destructive sampling, allometry, and spectral modeling using remote-sensing data, can lead to differences in estimated biomass carbon values. Quantifying carbon stocks associated with tree growth at different spatial and temporal scales is a complex task, influenced by factors like planting geometry on farmlands, soil conditions, local climate, tree management practices, and genetic parameters. For instance, trees growing in natural or wild conditions tend to have greater height, larger trunk diameter, and stronger physical and mechanical properties than trees growing in an agricultural landscape (Kozakiewicz et al 2021, McKinney and Kozakiewicz 2021). According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, there is limited information available regarding the biomass, carbon stock, and sequestration potential of both natural forests and trees outside forests at the national and regional levels. Present study effort was made to estimate the total biomass and carbon sequestration potential of different age and different agro climatic zones of Karnataka state Sandalwood plantations.

MATERIAL AND METHODS

The comprehensive survey was conducted across various locations within the Haveri district, gathering essential data through meticulously designed questionnaires. Within each location, an unbiased selection process was implemented, randomly choosing five trees for a detailed assessment of their heartwood and oil content. The study recorded vital observations, including the location's name, the age of each tree in years, the introduction of secondary host species (Table 1, 2), method of planting, adopted spacing (measured in meters), various growth parameters, the percentage of heartwood formation, and the percentage of oil content in each tree. Furthermore, the study area and survey encompassed an assessment of site characteristics such as location coordinates (latitude and longitude), altitude in meters, rainfall measurements in millimeters, temperature data, soil types and management practices (Table 3). For calculation of canopy volume the study area was comprised 4 locations of Northern Transitional agroclimatic zone of Karnataka. The estimation of canopy volume was conducted using a specific formula, as outlined by Thorne et al (2002). This comprehensive survey aims to provide valuable insights into the cultivation and characteristics of trees in the Northern Transition zone.

$$V = \frac{2}{3} \pi h \left(\frac{a}{2} \times \frac{b}{2}\right)$$

Where, h is the height of the canopy; a and b are spread of mid canopy at perpendicular axes.

Volume of the main stem: The main stem volume indicates the dry matter accumulation in the sandalwood tree and marketable yield. It was calculated considering the main stem as cylinder using the formula as a non-destructive observation. $V = \pi r2h$, where h is clear bole height and r is radius derived from tree girth.

Table 2. Predominant secondary hosts identified and sample size

Secondary host plants	Common name	Age (Yrs)	Sample size
Melia dubia	Hebbevu	8.5	5
Sesbania grandiflora	Agase	5.5	4
Tectona grandis	Teak	9	3
Mangifera indica	Mango	8.5	6
Swietenia mahogani	Mahogany	8.0	3
Emblica officinalis	Amla	8.5	3
Punica granatum	Pomegranate	9.0	4
Murraya koenigii	Curry leaf	6.5	3
Manilkara zapota	Sapota	7.0	4
Moringa oleifera	Drumstick	5.5	3
Pongamia pinnata	Karanj	7.5	3
Casuarina equisetifolia	Beef wood	8.0	2
Dalbergia latifolia	Rose wood	7.5	2
Calliandra haematocephala	Calliandra	6.5	3

Table 1. Location and annual rainfall of study area

Location	Latitude (North)	Longitude (East)	Elevation (m)	Mean annual rainfall (mm)	Mean annual temperature (°C)	
					Maximum	Minimum
Kudapalli	14.46	75.56	571.36	753	34.50	26.50
Hirekerur	14.45	75.39	608.15	718	34.00	26.20
Nandihalli	14.50	75.63	541.19	695	33.80	26.90
Byadagi	14.67	75.48	601.33	710	33.50	26.50
Hiremaranahalli	14.92	75.48	531.30	735	34.10	27.15
Savanur	14.97	75.33	592.98	724	33.00	26.50

Estimation of heart wood formation and oil content in *Santalum album* wood: Data were collected from three replicates/sample trees within each girth class, with recorded measurements including girth at breast height (GBH) and tree height. To extract core samples from each tree, a Haglof increment borer was employed, encompassing the bark, sapwood, transition region, and heartwood portions. The heartwood section of the core sample was used for oil content estimation, and these core samples were collected at breast height level, wrapped in blotting paper, and placed in desiccators. From these core samples, parameters such as bark thickness, sapwood radius, transition region, and heartwood radius were estimated by converting tree girth to tree diameter, facilitating the calculation of heartwood percentage. Sandalwood oil content was assessed using the method developed by non-destructive and convenient approach for quickly screening oil content in standing trees. Subsequently, the heartwood portion was finely sliced using a blade. A sample weighing 100 mg was measured on a precision balance, followed by the addition of 100 ml of hexane (boiling point range of 60-70°C) in a 100 ml standard flask. These samples were left undisturbed for 18 hours with periodic agitation. The resulting supernatant was collected in a quartz cell, and its optical density was measured at 219 nm (maximum) using a UV Spectrophotometer (Shimadzu-240). The statistical significance was determined using a student t-test in Microsoft Excel 2010 at a 95 percent probability level.

RESULTS AND DISCUSSION

Influence of host trees on growth, heart wood initiation and oil content on nine year old sandalwood trees at Haveri district: Sandal wood clear bole height under different hosts showed significant difference. The significantly higher clear bole height was with *Swietenia mahogani* (2.24 m) followed by *Calliandra haematocephala* and *Dalbergia latifolia.* The lowest sandal wood clear bole height was with *Emblica officinalis* (1.18 m) which is on par with the host of *Melia dubia.* Among 14 secondary hosts for sandalwood tree significantly higher tree girth was with *Mangifera indica* (32.63 cm) which was on par with the other host *C. equisetifolia*, *S.grandiflora*, *P/ pinnata* followed by *E. officinalis*, *D. latifolia* and *Melia dubia*. The lowest tree girth was noticed in *Manilkara zapota* (13.17 cm) which was on par with host *T. grandis*, *S.mahogany, M. koenigii* and *C.haematocephala*. The significantly higher volume of main stem was with *M. indica* (12.27 dm^3) which was on par with T.*grandiflora*, *C.equisetifolia*, *P. pinnata*. The lowest volume of main stem was in higher heart wood content was with *C. equisetifolia* (25.93 %) followed by *S.grandiflora*, *M. dubia*, *M. indica*, *M zapota*. The lowest heart wood content was with *Punica granatum* (8.17 %) which was on par with *Moringa oleifera*, *Tectona grandis* and *Dalbergia latifolia*. The significantly higher oil content was with *Casuarina equisetifolia* (3.13 %) followed by *Swietenia mahogany* and *Manilkara zapota.* The least was with *Tectona grandis* (0.15 %) (Table 4, Fig. 1). Jain et al (2003) reported that the essential oil in *Santalum album* tree varies one to eight per cent depending on the age, soil, climate and genetic factors. Similarly, Mishra et al (2018) reported that sandalwood trees aged between 8 to 35 years and having the girth class between 30 to 80 cm recorded oil content in the range between 1.0 to 4.0 per cent and with increase in age. Sandeep et al (2016) observed that in Maharashtra, Orissa, Punjab, Rajasthan reported that maximum oil concentration is 1.0 to 2.29 per cent and estimated heartwood content was significantly varied with girth class and locations and heartwood content and oil per cent varied significantly with girth class, locations and host. The heartwood formation is not uniform with respect to the different host plants (Liu et al 2011) and also it depends on genetic makeup of the tree (Arunkumar et al 2012) and girth (Brand et al 2012, Sandeep et al 2016)

Influence of host trees on carbon and biomass accumulation in nine years old Sandalwood plantations at Haveri district: Different host trees in Haveri significantly influenced the biomass and carbon storage in Sandalwood trees (Table 5). Maximum total tree height was *D. latifolia* (2.76 m) on par with *M. koenigii*. Minimum sandalwood height

Table 3. Soil type, spacing and management practices followed in sandalwood trees and host plants

Location	Soil type	Spacing adopted (m)		Management practices followed
		Sandal	Sandal to host	
Kudapalli	Black soil	2x2	1x1	Pruning, drip irrigation, soil working
Hirekerur	Red clay	4x4	2x2	Pruning, soil working and weeding
Nandihalli	Loamy soil	3x3	1x5	Pruning, weeding, soil working
Byadagi	Laterile soil	5x4	2x2	Pruning, irrigation
Hiremaranahalli	Red loamy	3x3	2x2	Pruning, weeding
Savanur	Black soil	3x2	1x1	Pruning, drip irrigation, soil working

was with *S. mahogani* (1.92 m). Volume of sandalwood tree was significantly higher with *C. equisetifolia* (18.31 dm^3) which was on par with *M. indica.* Total AGB was significantly maximum with *M.koenigii* (35.55 t ha^{-1}) whereas, minimum of 7.05 t ha^{-1} with *M. dubia.* In the same fashion BGB and CS were maximum with *M. koenigii* (BGB- 9.24 $tha^{-1}$and CS- 21.05 tha^{-1}) and minimum with *M. dubia* (BGB- 1.83 tha^{-1} and CS- 4.17 t ha^{-1}) canopy volume was maximum with *S. grandiflora* (2.11 m^3) which was on par with *M. koenigii*, *E. officinalis and M. dubia and* minimum was in *T. grandis.* In a

Table 4. Influence of host trees on growth, heart wood initiation and oil content on nine year old sandalwood trees at Haveri district

Secondary host plants	Sandal clear bole height (m)	Tree girth (cm)	Volume of main stem (dm^3)	Heart wood content (%)	Oil content (%)
Melia dubia	1.37	19.17	4.00	17.17	1.80
Sesbania grandiflora	1.47	29.55	10.91	22.93	1.54
Tectona grandis	1.33	13.25	1.76	9.50	0.15
Casuarina equisetifolia	1.58	30.50	11.01	25.93	3.13
Swietenia mahogani	2.24	15.17	1.83	13.67	2.07
Emblica officinalis	1.18	21.00	4.15	11.83	1.22
Punica granatum	1.31	18.12	3.78	8.17	0.92
Murraya koenigii	1.40	16.58	3.05	13.83	1.32
Manilkara zapota	1.23	13.17	1.67	16.67	1.95
Moringa oleifera	1.20	18.25	3.27	10.50	0.77
Pongamia pinnata	1.43	28.44	9.02	13.20	1.03
Mangifera indica	1.40	32.63	12.27	17.02	1.73
Dalbergia latifolia	1.94	20.71	4.54	9.30	0.91
Calliandra haematocephala	2.05	16.87	4.76	13.50	1.28
Mean	1.51	20.96	5.43	14.52	1.42
CD (p=0.05)	0.62	4.33	3.97	2.49	0.41

Table 5. Influence of host trees on carbon and biomass accumulation in nine years old Sandalwood trees at Haveri district

Secondary host plants	Total tree height (m)	Volume of sandal tree (d m^3)	Total *AGB of sandal (t ha^{-1})	Total *BGB of sandal (t ha^{-1})	Total carbon sequestered in sandal (t ha^{-1})	Canopy volume (m^3)
Melia dubia	2.27	14.53	7.05	1.83	4.17	1.45
Sesbania grandiflora	2.03	16.47	13.31	3.46	7.88	2.11
Tectona grandis	2.05	13.82	14.90	3.87	8.82	0.66
Mangifera indica	2.30	17.50	10.61	2.75	6.28	1.07
Swietenia mahogani	1.92	13.85	14.93	3.88	8.84	0.99
Emblica officinalis	2.15	14.72	8.93	2.32	5.28	1.58
Punica granatum	2.22	14.16	8.59	2.23	5.08	1.15
Murraya koenigii	2.51	14.66	35.55	9.24	21.05	1.76
Manilkara zapota	2.23	13.68	14.75	3.83	8.73	0.84
Moringa oliefera	2.15	14.06	34.11	8.86	20.19	1.26
Pongamia pinnata	2.15	16.35	13.22	3.43	7.82	0.99
Casuarina equisetifolia	2.30	18.31	19.74	5.13	11.69	1.32
Dalbergia latifolia	2.76	15.73	9.54	2.44	5.57	1.17
Calliandra haematocephala	2.22	15.50	25.07	6.51	14.84	1.38
Mean	2.23	15.24	16.45	4.27	9.73	1.27
CD (p=0.05)	0.38	0.87	1.11	0.29	0.66	0.70

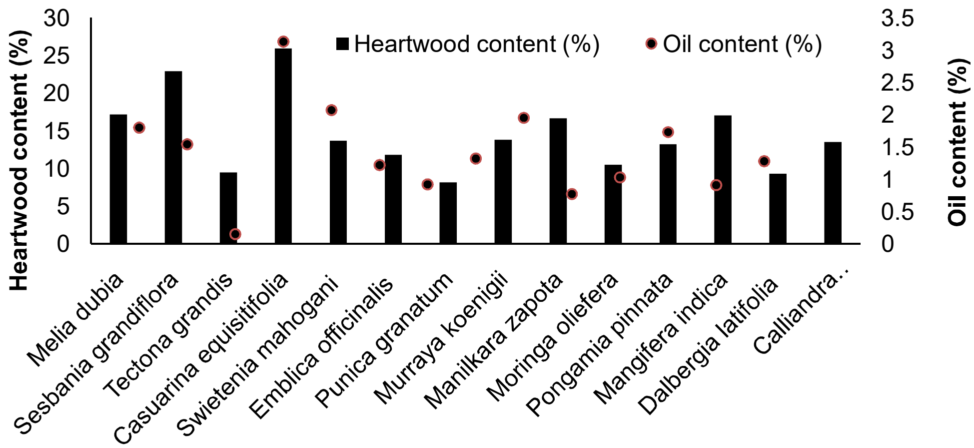

Fig. 1. Influence of host trees on heartwood and oil content on nine year old sandalwood trees at Haveri district

specific area within the northern transition zone of Haveri District, the total aboveground biomass (AGB) exhibited significant variation, with *M. koenigii* showing the highest value at 35.55 t ha-1, while the lowest value of 7.05 t ha^{-1} was for *M. dubia*. Similarly, the belowground biomass (BGB) and carbon sequestration (CS) also followed this trend, with *M. koenigii* having the maximum values (BGB- 9.24 t ha^{-1} and CS- 21.054 t ha^{-1}), and *M. dubia* having the minimum values (BGB- 1.83 t ha^{-1} and CS- 4.18 t ha^{-1}, respectively). This variation could be attributed to the favorable soil and climatic conditions in the region. Chavan (2009) focused on biomass accumulation and carbon sequestration in tree species planted under shelterbelts in the northern transitional zone of Karnataka and observed that *Acacia auriculiformis* had the highest biomass accumulation, followed by *A. indica* . Swamy et al (2017) also emphasized the potential of sandalwood tree-based systems for carbon sequestration in the northern transitional zone of Karnataka, highlighting it as one of the promising options for storing carbon both in plants and in the soil.

CONCLUSIONS

With effective pruning, drip irrigation, soil working management of Sandalwood plantation followed with significant host related heartwood formation and oil content in Haveri district of Karnataka. Haveri district of belongs to hilly zone tends to *Casuarina equisetifolia, Sesbania grandiflora* and Mangifera indica hosts performs to allow sandalwood with higher heartwood and oil content. Carrbon sequestration potential of different host based sandalwood planation was highest capacity with the host of *Murraya koenigii* and *Moringa oliefera*. A comprehensive exploration of host tree species across various agroclimatic zones in Karnataka is imperative. The refinement of core wood sample collection methods, incorporating advanced techniques such as Electrical Resistivity Tomography (ERT), can significantly enhance our ability to estimate heartwood, sapwood, and detect stress and decay in trees. A systematic evaluation of suitable host trees for sandalwood cultivation is of utmost importance. It is essential to gain a deep understanding of the intricate relationship between heartwood formation, age gradation, and the consistency of host trees across different locations. A thorough investigation into the physiological responses of secondary host plants under field conditions is a crucial aspect of this research. Moreover, conducting economic analyses of sandalwood-centered agroforestry systems across diverse agroclimatic zones in Karnataka is vital for informed decision-making and sustainable.

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