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# Resource use efficiency in sandalwood (*Santalum album*) based agroforestry model with *Melia dubia* as the secondary host in Karnataka

**Soundarya SR, BL Patil, JS Sonnad, GN Kulkarni and VS Patil**

**Abstract**
Sandalwood holds global significance due to its cultural and commercial value. However, its recent depletion has prompted the need for sandalwood domestication on the farm fields. In order to achieve this successfully, the efficient use of resources via appropriate silvicultural methods is required. In this context, the study was conducted in Karnataka to understand the present utilization of resources by the farmers. Among 200 sample farmers, the majority were practising sandalwood cultivation along with red gram and *Melia dubia* in an agroforestry system. Resource use efficiency was evaluated using the MVP: MFC ratio. Sandalwood saplings were overutilized due to lack of guidance while planting material of host plants, irrigation, and machine labour were underutilized. The findings advocate for improved technical guidance for adopting appropriate planting density. The study also highlighted the potential for optimizing resource allocation in sandalwood cultivation.

**Keywords:** Sandalwood, *Melia dubia*, agroforestry, resource use efficiency

## Introduction
Sandalwood, a plant species of immense commercial and cultural importance, belongs to the family *Santalaceae* and the genus *Santalum*. Within *Santalum*, there exist 61 species, of which 17 are recognized and five are commercially exploitable. Notably, the *Santalum album* (Indian Sandalwood) stands out first with its rich oil content of four to nine percent, rendering it the "Queen of Sandalwood".

The commercial and the most economical part of sandalwood is the heartwood. The global sandalwood market size was US$ 260 million in 2021 and it has increased by 0.65 percent to US$ 261.69 million in 2022. The global market size of Sandalwood oil alone constituted US$ 154.8 million in 2022 (www.marketwatch.com) [9]. However, this global market includes all five commercial species of sandalwood. The annual global demand for sandalwood is 20,000 MT and oil is estimated to be 1,000 MT in the international markets (Anonymous, 2020) [2]. However, the current production across the world accounts for only one-fourth of the global market demand. Approximately, 150 tonnes of sandalwood oil are produced per annum worldwide (Goswami and Tah, 2018) [5]. Hence, there is a huge gap between the demand and supply of sandalwood.

The geographical occurrence of Indian sandalwood can be seen in India, Indonesia, and Australia. In India, sandalwood was naturally distributed on the Deccan Plateau. The total extent of its distribution was around 9,000 km$^2$, of which 8,285 km$^2$ was in the states of Karnataka and Tamil Nadu (Rai, 1990) [7]. India alone constituted 85 percent followed by Indonesia (10%) of the total global production of Indian sandalwood (Ananthapadmanabha, 2000) [1]. However, later many researchers worked to figure out the area and production of sandalwood and it is to be noted that the natural habitation of sandalwood in India has almost declined. At present, the Maryoor forest of Kerala is the only place where sandal trees grow naturally (Kumar *et al.*, 2012) [6].

Due to its robust depletion, sandalwood has been categorized as a 'Vulnerable' species by the International Union for Conservation of Nature in 1998 (Arunkumar *et al.*, 2019) [3]. In addition, realizing the pitfalls in the sandalwood policy which endangered the species, the Government of Karnataka came up with an amendment to the Karnataka Forest Act in 2001 to encourage private domestication of sandalwood and gave landowners the legal right to have sandalwood trees on their land.

Sandalwood is well suited to cultivation under an agroforestry system since it needs a host plant for its growth and development. It parasitizes neighbouring plant roots *via* a haustorium adaptation. This adaptation with other plants helps the tree to obtain macronutrients such as nitrogen, phosphorus, and potassium, particularly during its initial stages of growth but it can photosynthesize its own food. More than 300 species are identified as the hosts of sandalwood and it can parasitize from grass to other Sandalwood trees under gregarious conditions. The survival of sandalwood seedlings without a host was found to be 30 to 34 percent in the first two years of planting and 20 percent in the next two successive years (Das and Tah, 2016) [4]. This shows the importance of host plants for sandalwood. However, in the agroforestry systems, attention should be given during the selection of host plants by knowing the shade nature, root type, economic value, and its contribution to sandalwood. Hence, there is a need for the farming community to know about the identification of suitable sandalwood based agroforestry models and their resource use efficiency, hence this study has been conducted.

## Materials and Methods

An exponential non-discriminative snowball sampling method was employed for the selection of sandalwood farmers in Karnataka because of their diverse and scattered nature. In this sampling technique, the first sandalwood farmer considered for the sample provides multiple referrals. Each new referral will then provide more sandalwood farmers as respondents. This approach allows for the inclusion of a broader and more diverse set of respondents. This geometric chain of sampling sequence continued until the number of respondents reached the required sample size of 200. But among these sampled farmers 52 were practising the sandalwood based agroforestry model with *Melia dubia* (commonly called Hebbevu or Malabar Neem) as the secondary host. This model included sandalwood as the main crop, red gram as the primary host and *Melia dubia* as the secondary host and very few farmers followed intercropping during the initial years in between the rows of sandalwood. The gestation period of sandalwood was considered 15 years based on past studies (Viswanath *et al.*, 2010) [8]. The primary data was elicited from the sample farmers.

### Production function analysis

To study the resource productivity and allocative efficiency in the sandalwood based agroforestry models with *Melia dubia* as a secondary host, a Cobb-Douglas type of production function was estimated. This was done with a view to determining the extent to which the important resources have been quantified, explaining the variability in the gross returns of the agroforestry model and determining the optimal use of resources in this agroforestry model.

The general form of the function is $Y = aX_i^{bi}$ where '$X_i$' is the variable resource measure, '$Y$' is the output, '$a$' is a constant and '$b_i$ ' are the estimates of the extent of the relationship between $X_i$ and $Y$ when $X_i$ is at different levels. The '$b$' coefficient also represents the elasticity of production in Cobb-Douglas production function analysis. The function of the following form was fitted for this sandalwood based agroforestry model.

$$Y_i = aX_1^{b1} .X_2^{b2} .X_3^{b3}. X_4^{b4} . X_5^{b5} . X_6^{b6} X_7^{b7}.e^u$$

On linearization through logarithmic transformation, it becomes

$$\log Y = \log a + b_1\log X_1 + b_2\log X_2 + b_3\log X_3 + b_4\log X_4 + b_5\log X_5 + b_6\log X_6 + b_7\log X_7 + u$$

Where,

$Y$ = Gross returns (₹/ha)
$X_1$ = Expenditure on Sandalwood saplings (₹/ha)
$X_2$ = Expenditure on Planting material of host plants [Red gram and Hebbevu] (₹/ha)
$X_3$ = Expenditure on Farm Yard Manure (₹/ha)
$X_4$ = Expenditure on Fertilizers (₹/ha)
$X_5$ = Expenditure on Irrigation (₹/ha)
$X_6$ = Expenditure on Human labour (₹/ha)
$X_7$ = Expenditure on Machine labour (₹/ha)
$a$ = Intercept
$b_i$ = Elasticity of production ($i$ = 1 to 7)
$u$ = Error term

### Returns to scale

The returns to scale was estimated directly by getting the sum of $b_i$ *'s* coefficients.
If $\Sigma\, b_i < 1$, Decreasing returns to scale
If $\Sigma\, b_i = 1$, Constant returns to scale
If $\Sigma\, b_i > 1$, Increasing returns to scale

### Marginal value product (MVP)

The ratio of Marginal Value Product (MVP) and Marginal Factor Cost (MFC) of the resources was used to judge the resource use efficiency. A resource is said to be optimally allocated when its MVP = MFC. If MVP is less than one, then the resources are being used excessively, leading to diminishing returns and inefficiency. If MVP is greater than one, then the resources are not fully utilized. The MVP was calculated at the geometric mean levels of the variables using the following formula,

$$\text{MVP} = \text{b}i\,\frac{\bar{\text{Y}}}{\bar{\text{X}}\text{i}}$$

Where,
$\bar{Y}$ = Geometric mean of gross returns from major sandalwood based agroforestry models
$\bar{X}$ = Geometric mean of $i^{th}$ variable input
$b_i$ = Regression coefficient of $i^{th}$ input ($X_i$)

The MFC was taken as unity since the Y and X variables were considered in monetary terms.

### Marginal Value Product (MVP) Adjustment

Estimation of the percentage variation in MVP for each variable input is necessary to optimally utilize the inputs, which means MVP = MFC which was computed by the equation,

$$D = \left(1 - \frac{MFC}{\text{MVP}}\right) * 100$$

Where,
$D$ = Percentage variation in MVP for each variable input
$MVP$ = Marginal Value Product
$MFC$ = Marginal Factor Cost
$D$ indicates the elasticity of production with respect to that

specific variable resource. A higher absolute *D* value suggests that MVP is highly responsive to changes in the quantity of variable input, whereas, a lower absolute value of *D* indicates MVP is not very responsive to changes in the quantity of variable input. However, if the absolute value of *D* is one, then it signifies the unitary elastic nature.

## Results and Discussion

In the study area, red gram was used as the primary host because past research has validated that red gram is an ideal primary host due to its nitrogen-fixing capabilities, ability to provide gentle shading, rapid growth, and propensity to increase field survival rates of sandalwood. Red gram was provided along with sandalwood saplings in polythene bags from the nurseries in the study area. The farmers also planted red gram seeds close to the sandalwood plants after transplanting them in the fields. These red gram plants were intentionally not harvested; they were allowed to naturally wither away. The primary purpose of introducing red gram as the primary host was to offer enhanced support to the sandalwood plants, rather than for generating income.

The farmers in the study area selected their secondary hosts based on multiple factors. Some farmers chose timber species due to their cost-effective maintenance, especially *Melia dubia*. It was observed that the planting of *Melia dubia* was influenced by some plywood companies and also forest officials during their initial establishment.

In order to maximize the profits of an enterprise, the optimum use of resources is imperative. This was examined based on the productivity of resources used in the production activities. The technique of Cobb Douglas production function was used to measure the resource use efficiency of the sandalwood based agroforestry model with *Melia dubia* as the secondary host.

**Table 1:** Estimates of Cobb-Douglas production function in sandalwood based agroforestry model with *Melia dubia* as the secondary host

| Particulars | Parameters | Estimates | Standard Error |
|---|---|---|---|
| Intercept | *a* | 6.48 | 0.81 |
| Sandalwood saplings | $X_1$ | -0.14** | 0.04 |
| Planting material of host plants | $X_2$ | 0.43*** | 0.04 |
| Farm Yard Manure | $X_3$ | 0.04 | 0.05 |
| Fertilizers | $X_4$ | 0.01 | 0.08 |
| Irrigation | $X_5$ | 0.13** | 0.10 |
| Human labour | $X_6$ | 0.04 | 0.08 |
| Machine labour | $X_7$ | 0.36*** | 0.02 |
| R-square | $R^2$ | 0.92 | |
| Adjusted R-square | Adjusted $R^2$ | 0.90 | |
| Returns to scale | $\Sigma b_i$ | 0.87 | |
| F value | - | 149.61*** | |

**Note:** *** and ** indicate the level of significance at one and five percent respectively

The estimated coefficients of the Cobb-Douglas production function of sandalwood based agroforestry model with *Melia dubia* as the secondary host during the gestation period of sandalwood were given in Table 1. The observed value of Adjusted $R^2$ (0.90) indicated that 90 percent of the variations in gross returns from the sandalwood cultivation with *Melia dubia* as the secondary host were explained by the explanatory variables included in the model, suggesting a good fit of the model. The F-value (149.61) was highly significant at one percent level, indicating that the overall model was reliable.

The coefficient for the cost of sandalwood saplings (-0.14) was negative and significant at a five percent level of significance. This implied that a one percent increase in the sandalwood saplings would decrease gross returns from this model by 0.14 percent. The coefficient for the use of planting material of host plants was estimated at 0.43 which was significant at one percent level. This implied that one percent increase in the planting material of host plants would lead to a 0.43 percent increase in the gross returns. Furthermore, Irrigation (0.13) and machine labour (0.43) were found to be significant at five and one levels of significance, respectively. However, other inputs like the cost of Farm Yard Manure, fertilizers, and human labour were found to be insignificant, with coefficients of 0.04, 0.01, and 0.04, respectively.

The returns to scale value of 0.87 suggested that increasing all inputs proportionally led to 0.87 times increase in gross returns. The decreasing returns to scale observed in this agroforestry model indicate the production process during the gestation period of sandalwood and the initial expansion of production might result in cost savings due to economies of scale and further increases in production might lead to diminishing returns.

The obtained production function estimates are further employed to analyze the resource use efficiency using MVP: MFC ratio which is depicted in Table 2. The MVP: MFC ratio of -82.76, indicating the significant overutilization of sandalwood saplings, it was mainly due to farmers used a higher number of sandalwood saplings, resulting in their excessive utilization within the study area. The initial planting densities observed were recorded as 1073 trees per hectare. This contrasts with the recommended plant density of 400 trees per hectare. This was because farmers had the perception that the high number of trees would yield high returns in the future. But in fact, the closer spacing between sandalwood trees would affect the heartwood formation and provide less space to accommodate host plants. The farmers overutilized the saplings merely due to the lack of technical guidance.

**Table 2:** Resource-use efficiency in sandalwood based agroforestry model with *Melia dubia* as the secondary host

| Variables | MVP: MFC ratio | D | Level of resource use |
|---|---|---|---|
| Sandalwood saplings | -82.76 | 101.21 | Over utilization |
| Planting material of host plants | 2713.41 | 99.96 | Under utilization |
| Farm Yard Manure | 4.50 | 77.80 | Under utilization |
| Fertilizers | 88.00 | 98.86 | Under utilization |
| Irrigation | 28.66 | 96.51 | Under utilization |
| Human labour | 0.91 | -9.71 | Over utilization |
| Machine labour | 170.99 | 99.42 | Under utilization |

D = Percentage variation in MVP for each variable input

The MVP: MFC ratio was 2713.41, indicating significant underutilization of host plant material. There was a positive relationship between the planting materials of host plants which includes both red gram and hebbevu, which were found to be underutilized. However, there was a scope of use of the planting materials of the host plants especially red gram which supports the sandalwood growth well in the initial stages of the establishment, which in turn increases the gross returns from this agroforestry model. Similarly, irrigation was found to be underutilized significantly since both sandalwood and hebbevu were timber species and farmers provided

sufficient irrigation only up to three years after establishment and only few farmers continued the irrigation for up to five years. Hence there was a scope for increasing the irrigation facility to increase the gross return from this model. Furthermore, the MVP: MFC ratio of 170.99 for machine labour was also found to be underutilized.
All the independent variables presented in Table 2 had higher absolute D values suggesting that MVP is highly responsive to changes in the variable inputs, which means that a small change in the input can lead to a relatively larger change in the gross returns of sandalwood based agroforestry model with *Melia dubia* as the secondary host.

## Conclusion

Indian sandalwood has been a part of Indian culture and heritage for thousands of years and was one of the first items traded with other countries. It has great historical, mythological, cultural, ecological, and economic importance in India. Since its robust depletion created a huge demand-supply gap for sandalwood, the domestication of sandalwood on the farm fields with appropriate silvicultural practices can bridge this gap. The inputs used in the sandalwood cultivation along with red gram and *Melia dubia* in the farm fields were not used efficiently and they required more attention by the farmers to allocate the resources more efficiently to achieve higher productivity and optimal production.

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