

# Tree nutrition and productivity changes in mahogany (*Swietenia macrophylla* King) based agrisilvicultural system in humid tropical India

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## Research Article

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# Abstract

The study was carried out in a six-year-old mahogany plantation that was established at Mala, Kerala, India during 2009 at a spacing of 2.5 x 2.5 meters. The trial was laid out in a split plot design during June 2014 with fertilizer levels as main plots and intercrops as sub plots in three replications and trial repeated for two consecutive years (2014-2016). The various N, P, K fertilizer combinations were *viz.* F<sub>1</sub>- 0:0:0; F<sub>2</sub>- 50:25:25; F<sub>3</sub>- 100:50:50 and F<sub>4</sub>- 150:75:75 kg ha<sup>-1</sup> yr<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O. Tree growth in terms of height, diameter, basal area and volume showed significant increase with increase in fertilizer levels. The volume production was the highest under the highest fertilizer regimes (F<sub>4</sub>) (105.28 m<sup>3</sup> ha<sup>-1</sup>) which was almost 135 per cent higher as compare to unfertilized control plot (F<sub>1</sub>: 44.84 m<sup>3</sup> ha<sup>-1</sup>). This clearly indicated that nutrient supplementation at younger ages can bring substantial increase in tree productivity for mahogany. Yet another observation was the greater complementarity between the mahogany trees and the herbaceous intercrops. The positive influence of fertilizer on the tree growth was reflected on the intercrop yield as well. The yield reduction in mahogany intercropped plots was found compensated by tree fertilization. In brief, the study revealed the rationale for tree fertilization at younger stages of mahogany growth which may be desirable for the enhancing the productivity of the intercrops.

## Introduction

The ever increasing demand for wood and wood products has led to serious decline in the ecologically important natural forests across the world (Bansal, 2021; Peng et al. 2023). This realization alongside the acute scarcity of wood has prompted establishing plantations as a promising strategy for meeting the diverse wood based products and services (Kainyande et al. 2022). The plantation expansion provides opportunities to reduce pressure on natural forest from 1.3 billion m<sup>3</sup> in 2000 to 6000 million m<sup>3</sup> in 2015 (Bull et al. 2006; Zhang and Stanturf, 2008).

Despite the growing interest in expanding forests plantations (McEwan et al. 2020; Clark et al. 2021), the poor productivity (Saxena 1992; Altieri, 2004; Ravindran and Thomas, 2000; Saha et al. 2012) and long gestation period often deterred farmers from tree farming especially in the tropics. The agroforestry practices have been promoted as alternate strategy where the intercrops offer interim returning to the farmer during the early slog periods of tree growth. However, the management of tree based polyculture systems demands considerable managerial skills unlike the management of simple monoculture systems. Scientific understanding on the combined response of the tree-crop components to the limited biophysical resources will provide the farmers with ample opportunities to optimize productivity of the system. Among the diverse agroforestry management practices, tree nutrition plays cardinal role in maintaining productivity especially in nutrient poor tropical soils (Kumar 2016). It assumes utmost care in ensuring the improvement in the combined productivity and compatibility among the tree-crop components in the sharing of applied nutrients and their responses to stand management practices. The lack of such information often leads to sub optimal performance of many agroforestry systems. The

effectiveness of fertilization is often influenced by the species, spatial and temporal arrangement of tree-crop components (Kraft et al. 2021), management practices (Graves et al. 2017) and biophysical conditions of the site (Cardinael et al. 2020) and belowground root distribution.

Big leaf mahogany (*Swietenia macrophylla* (Family: Meliaceae)) is a prominent plantation species of demand in the humid tropical regions of Kerala, India primarily due to its fast growth and good timber value (Kumar et al. 2015). In view of the spatial limitation for the extensive farming of such tree species, integration of potential shade loving crops with trees may benefit both economically and ecologically (Nasielski et al. 2015). However, our understanding is limited on the potential crop combinations that can be offer diversified outputs on a sustainable basis. Conventional shade tolerant crops of preference to Kerala such as ginger (*Zingiber officinale*), turmeric (*Curcuma longa*) and wild turmeric (*Curcuma aromatic*) may be suitable with mahogany considering their fitness for integration with many woody ecosystems (Kumar and Tiwari, 2017; Zeng et al. 2020). Though nutrition studies in mahogany offer positive response to growth and productivity, there is genuine lack of information on the changes in such responses in the intercropped scenario involving mahogany. There is need to standardize the fertilizer regimes for mahogany trees in agroforestry parlance so as to ensure optimal growth and productivity of mahogany trees and the associated understorey crops. In this back drop, a field study was conducted with the objective of evaluating the growth response of mahogany woodlot and associated crops to various levels of applied fertilizers.

## Methodology

### *Experimental area*

The study was carried out in a 5-year-old *Swietenia macrophylla* plantation that was established at Mala, Thrissur, Kerala, India (N 10°15'33" latitude and E76°18'7" longitude and at an elevation of 39 m above sea level) during 2009 at a spacing of 2.5 x 2.5 m (density at 1600 trees ha<sup>-1</sup>). The experimental area experiences typical warm humid tropical climate with an annual rainfall ranging from 2500-2750 mm, most of which was received during the South-West monsoon (June to September). The mean maximum temperature ranged from 29.10° to 35.40° C in July and March respectively while the mean minimum temperature varied from 22.19° to 24.83° C in December and May respectively. The topography is plain with soil predominantly lateritic in origin and with moderate soil depth.

### *Fertilizer cum intercropping trial*

The study involved a fertilizer cum intercropping trial which was superimposed on this existing mahogany plantation. The experiment followed a split plot design with fertilizer treatments as main plot and intercrops as sub plots replicated thrice (Fig 1). The main plot treatments include four fertilizer levels as given below (Table 1).

Table 1: Details of various fertilizer dosages (NPK) treatments applied to five-year-old *Swietenia macrophylla* at Mala, Thrissur, Kerala, India

| Fertilizer Levels | Nitrogen                             |              | P <sub>2</sub> O <sub>5</sub>        |              | K <sub>2</sub> O                     |              |
|-------------------|--------------------------------------|--------------|--------------------------------------|--------------|--------------------------------------|--------------|
|                   | kg ha <sup>-1</sup> yr <sup>-1</sup> | Per tree (g) | kg ha <sup>-1</sup> yr <sup>-1</sup> | Per tree (g) | kg ha <sup>-1</sup> yr <sup>-1</sup> | Per tree (g) |
| F1                | 0                                    | 0            | 0                                    | 0            | 0                                    | 0            |
| F2                | 50                                   | 68           | 25                                   | 78           | 25                                   | 26           |
| F3                | 100                                  | 136          | 50                                   | 156          | 50                                   | 52           |
| F4                | 150                                  | 205          | 75                                   | 234          | 75                                   | 78           |

The various N, P, K fertilizer treatment combinations viz. F<sub>1</sub>- 0:0:0; F<sub>2</sub>-50:25:25; F<sub>3</sub>- 100:50:50 and F<sub>4</sub>- 150:75:75 kg ha<sup>-1</sup> yr<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O which were equivalent to 0:0:0, 50:10.75:20.75, 100:21.5:41.5 and 150:32.25:62.25 kg ha<sup>-1</sup> per year of elemental N, P and K, respectively. The fertilizer trial was repeated following the treatment protocol during June in two successive years of 2014 and 2015.

The sub plot treatments included four intercrop levels viz. I<sub>1</sub> - Turmeric (*Curcuma longa* var. Sona), I<sub>2</sub> - Ginger (*Zingiber officinale* Roscoe var. Aswathi), I<sub>3</sub> - Wild turmeric (*Curcuma aromatica*) and I<sub>4</sub> - Without intercrop. The main plot size was 40 x10 m (400 m<sup>2</sup>) and sub plot size: 10 x10 m (100 m<sup>2</sup>). The total number of main plots were 12 (4 x 3) and total sub plots were 48 (4 x 4 x 3). Also, the number of trees in each main plot was 64 while the number of trees per sub plot was 16.

Prior to the application of the fertilizers each individual *S. macrophylla* tree was scrape weeded at a radius of one meter. Ring basin with the 50 cm radius and 10-12 cm depth were taken around each tree (with minimum disturbance to tree roots). The fertilizers were applied during June 2014 as per the calculated dosage (Table 1). Same fertilizer protocol was repeated during the next year (June 2015). Care was taken to cover the tree basin with thin layer of soil of 5 cm thickness to avoid possible leaching losses of fertilizers. Also, the fertilizer was applied few days after the monsoon rains when the soil was adequately well drained.

Measurements such as total height and DBH of all *S. macrophylla* trees were recorded at six monthly intervals during the period 2014-2017. Tree height measurements were taken using Clinometer (Suunto PM-5, Finland). From the height and diameter data, tree basal area and volume were computed and recorded as given below:

Basal area =  $\pi D^2/4$  (where, D- is the diameter at breast height, DBH)

Volume =  $\pi D^2/4 \times H \times F$  (where D- the diameter at BH, H- the total height and F- form factor of the tree). The basal area and volume were also represented on stand level (per ha) by multiplying the mean tree basal area and volume with the corresponding stand density (number of trees per ha).

### *Intercrop trial*

The understorey crops selected for the study included ginger (*Zingiber officinale* R. var. Aswathi), turmeric (*Curcuma longa* var. Sona) and wild turmeric (*Curcuma aromatica*) which were grown in beds of size 10 m × 1.0 m × 0.3 m in between the centrally located hedge-row of *S. macrophylla* sub plots (sub plot size 10 x10 m with 16 trees). The beds were established in the *S. macrophylla* stand in such a way that beds were 1.5 m away from the rows of *S. macrophylla* and oriented in East-West direction so as to ensure maximum exposure to available sunlight. The intercrops were planted at 0.25 x 0.25 m spacing following recommended package of practices (KAU 2011). In addition to these treatments, an absolute treeless control was established where the herbaceous crops were raised in open contiguous plots. The intercrops were managed following recommended practices (KAU 2011). Soon after planting of rhizomes, the beds were mulched with green leaves preferably *Macaranga peltata* and *Gliricidia sepium* @ 15 Mg ha<sup>-1</sup>. Mulching with green leaves was repeated twice first 45-60 days and second 90-120 days after planting. Weeds were removed by hand weeding before each mulching and repeated as and when required. The intercropping trial was repeated during two consecutive years corresponding to the two periods of fertilizer applications.

### *Understorey biometric observations*

The growth performance of the intercrops (ginger, turmeric and wild turmeric) and biometric observations were recorded (after destructive sampling) at regular intervals of 90, 180 and 210 days after planting (DAP) during the two consecutive years. However, the present paper discusses only the understorey crop yields corresponding to the second year of planting during the second fertilization trial limiting to intercrop growth observations to 6 months after planting and at final harvest.

Four plants in a quadrat of 50 x 50 cm were randomly selected from each bed corresponding to each species for biometric observations. All plants in the quadrat were then uprooted carefully. After cleaning, the plant samples were carried to the laboratory and detailed biometric observations such as plant height, pseudo stem length, number of tillers per plant, number of leaves per plant, leaf area and maximum root length were taken. The aboveground and belowground portions were separated and their fresh weight recorded. The samples were then oven dried at 70 °C until constant weight was achieved. The dry matter production was computed on area basis (m<sup>2</sup>). The component dry matter production and final rhizome yield (210 DAP) for ginger, turmeric and wild turmeric were determined. For this, the rhizome fresh weights were multiplied by their corresponding moisture content which was computed from 250 g of triplicate rhizome samples. The intercropping trial was repeated during the second year and the growth observations recorded as detailed above (only second year data has been presented here) (only 180 days and final harvesting data presented here).

## **Results**

Fertilizer effects on mean tree height growth showed significant response for 6-year-old *S. macrophylla* (p= 0.01) (Table 2). A consistent increase in tree height was observed with increase in fertilizer levels with maximum height corresponding to the highest fertilizer level (F4). However, the differences in height

growth among the higher fertilizer dosages F3 and F4 were minimum. The changes in height growth corresponding to 6 months and 24 months after fertilizer application was highest for F4 which were 21.57, and 26.10% more as compared to height growth in the unfertilized control. Also, the differences in height between 6 months and 24 months (1.5 years) were considerably higher for highly fertilized plots as compared to unfertilized control. Despite such trends, the tree height growth did not show any significant change consequent to the presence of various intercrops. Nevertheless, all the intercropped plots showed apparently better height growth than the unfertilized control plots.

Table 2: Fertilizer dosage and intercrop response on tree growth in five-year-old *Sweitenia macrophylla* during six and 24 months after application of fertilizer at Mala, Thrissur district, Kerala, India.

| Treatments                  | Tree growth (months after fertilizer application) |                              |                              |                              |                                                  |                               |                                              |                               |
|-----------------------------|---------------------------------------------------|------------------------------|------------------------------|------------------------------|--------------------------------------------------|-------------------------------|----------------------------------------------|-------------------------------|
|                             | Height (m)                                        |                              | Diameter (cm)                |                              | Basal area<br>(m <sup>2</sup> ha <sup>-1</sup> ) |                               | Volume<br>(m <sup>3</sup> ha <sup>-1</sup> ) |                               |
|                             | Six months                                        | 24 months                    | Six months                   | 24 months                    | Six months                                       | 24 months                     | Six months                                   | 24 months                     |
| <b>Fertilizer dosage</b>    |                                                   |                              |                              |                              |                                                  |                               |                                              |                               |
| F1- 0:0:0                   | 7.51 <sup>b</sup><br>(0.24)                       | 9.31 <sup>c</sup><br>(0.25)  | 6.99 <sup>b</sup><br>(0.12)  | 8.28 <sup>c</sup><br>(0.22)  | 6.16 <sup>c</sup><br>(0.23)                      | 8.69 <sup>c</sup><br>(0.48)   | 24.65 <sup>c</sup><br>(1.12)                 | 44.84 <sup>d</sup><br>(2.24)  |
| F2- 50:25:25                | 7.80 <sup>b</sup><br>(0.25)                       | 9.85 <sup>bc</sup><br>(0.24) | 7.73 <sup>b</sup><br>(0.18)  | 9.45 <sup>b</sup><br>(0.19)  | 7.55 <sup>b</sup><br>(0.33)                      | 11.27 <sup>b</sup><br>(0.43)  | 35.04 <sup>b</sup><br>(2.19)                 | 68.12 <sup>c</sup><br>(3.69)  |
| F3- 100:50:50               | 8.19 <sup>ab</sup><br>(0.43)                      | 10.45 <sup>b</sup><br>(0.43) | 8.61 <sup>a</sup><br>(0.17)  | 10.71 <sup>a</sup><br>(0.24) | 9.37 <sup>a</sup><br>(0.37)                      | 14.50 <sup>a</sup><br>(0.64)  | 46.59 <sup>a</sup><br>(2.88)                 | 93.31 <sup>b</sup><br>(5.06)  |
| F4- 150:75:75               | 9.13 <sup>a</sup><br>(0.28)                       | 11.74 <sup>a</sup><br>(0.28) | 8.63 <sup>a</sup><br>(0.24)  | 10.84 <sup>a</sup><br>(0.26) | 9.45 <sup>a</sup><br>(0.53)                      | 14.87 <sup>a</sup><br>(0.69)  | 52.45 <sup>a</sup><br>(4.20)                 | 105.28 <sup>a</sup><br>(6.20) |
| F value                     | 4.89                                              | 11.08                        | 20.55                        | 29.01                        | 19.97                                            | 30.18                         | 18.91                                        | 40.44                         |
| p value                     | 0.001                                             | 0.001                        | 0.0001                       | 0.0001                       | 0.001                                            | 0.001                         | 0.001                                        | 0.001                         |
| <b>Intercropping system</b> |                                                   |                              |                              |                              |                                                  |                               |                                              |                               |
| I1- Ginger                  | 7.90<br>(0.44)                                    | 10.13<br>(0.49)              | 8.17 <sup>a</sup><br>(0.28)  | 10.11<br>(0.42)              | 8.49<br>(0.58)                                   | 13.10 <sup>a</sup><br>(1.04)  | 40.67<br>(4.39)                              | 81.86<br>(8.63)               |
| I2- Wild turmeric           | 8.27<br>(0.40)                                    | 10.54<br>(0.47)              | 8.16 <sup>a</sup><br>(0.31)  | 10.05<br>(0.43)              | 8.50<br>(0.64)                                   | 12.96 <sup>b</sup><br>(1.08)  | 42.32<br>(4.99)                              | 83.82<br>(9.67)               |
| I3- Turmeric                | 8.27<br>(0.36)                                    | 10.39<br>(0.43)              | 8.05 <sup>ab</sup><br>(0.24) | 9.78<br>(0.35)               | 8.22<br>(0.47)                                   | 12.21 <sup>ab</sup><br>(0.85) | 40.39<br>(4.03)                              | 77.12<br>(8.22)               |
| I4-Without intercrop        | 8.20<br>(0.25)                                    | 10.28<br>(0.29)              | 7.59 <sup>b</sup><br>(0.25)  | 9.33<br>(0.31)               | 7.31<br>(0.49)                                   | 11.05 <sup>b</sup><br>(0.71)  | 35.34<br>(3.40)                              | 68.75<br>(6.33)               |
| Mean                        | 8.15                                              | 10.33                        | 7.99                         | 9.81                         | 8.13                                             | 12.33                         | 39.68                                        | 76.38                         |
| F value                     | 0.28                                              | 0.27                         | 2.33                         | 2.44                         | 2.40                                             | 2.99                          | 1.08                                         | 2.42                          |
| p value                     | >0.05                                             | >0.05                        | >0.05                        | >0.05                        | >0.05                                            | >0.05                         | >0.05                                        | >0.05                         |
| <b>Dosage x Intercrop</b>   |                                                   |                              |                              |                              |                                                  |                               |                                              |                               |
| F value                     | 0.50                                              | 0.59                         | 1.39                         | 1.12                         | 1.43                                             | 1.32                          | 0.89                                         | 1.36                          |
| p value                     | >0.05                                             | >0.05                        | >0.05                        | >0.05                        | >0.05                                            | >0.05                         | >0.05                                        | >0.05                         |

Values in the parenthesis are standard error of the mean

Values followed by same superscript in a column do not differ significantly

Fertilization significantly enhanced tree diameter growth (DBH) for *S. macrophylla* with corresponding increase for increase in dosage ( $p= 0.001$ ). The maximum diameter growth was observed in the highest fertilizer dosage treatment (F4-150:75:75 kg ha<sup>-1</sup> year<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O) which however was on par with diameter corresponding to second highest fertilizer dosage (F3). The increase in tree DBH after 24 months of fertilizer application in the highest fertilized treatment plots was 23.46% higher as compared to the unfertilized control plots (Table 2). Also, the diameter growth increment 6 months and 24 months after fertilizer application was higher for F4 treatment compared to unfertilized control plots. The combined effect of intercrop and fertilizer on the diameter growth of mahogany was not significant though the intercropped plots had a modest advantage. However, trees in all the intercropped plots had better diameter growth compared with the unfertilized control.

Fertilizer dosages had significant effect on the basal area per hectare for *S. macrophylla* with a steady decline with decrease in the dosage of NPK fertilizers ( $p= 0.001$ ) (Table 2). The maximum basal area per hectare was observed in the highest fertilizer dosage treatment (F4-150:75:75 kg ha<sup>-1</sup> year<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O) followed by F3 (100:50:50 kg ha<sup>-1</sup> year<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O). For instance, the basal area of *S. macrophylla* were 8.69, 11.27, 14.50, 14.87 m<sup>2</sup> per ha for fertilizer regimes F1, F2, F3 and F4 respectively after 24 months of fertilizer application. However, only marginal differences were observed between F3 and F4 treatments. The increase in basal area from 6 months to 24 months (1.5 years) was highest for F4 treatments (5.42 m<sup>2</sup>) as compared to the unfertilized control (2.53 m<sup>2</sup>). Interestingly, the effect of fertilization on tree basal area showed significant variation in intercropped mahogany plots. For instance, the higher BA was observed for trees intercropped with ginger followed by wild turmeric and turmeric. The lowest value was for non-intercropped control plots.

Higher stand volume was associated with tree plots subjected to higher levels of fertilizer application followed by a consistent reduction in volume with reduction in applied fertilizer dosage. The tree volume of *S. macrophylla* varied from 44.84 (unfertilized) to 105.28 m<sup>3</sup> ha<sup>-1</sup> (highest dosage) after 24 months of fertilizer application. The increase in tree volume in the heavily fertilize plot compared to unfertilized control plot were 120%, 126.31%, 130.43% and 135.71% during 6, 12, 18 and 24 months after the fertilizer application (Table 2). Unlike the basal area trends, there were significant differences in volume production among the higher fertilizer dosage treatments (F3 and F4). Also, there was considerable variation in the volume production for unfertilized control and highly fertilized (F4) plots between 6<sup>th</sup> and 24<sup>th</sup> month after fertilizer application which was the highest for fertilizer regime F4 (52.83 m<sup>3</sup> ha<sup>-1</sup>) as against 20.19 m<sup>3</sup> ha<sup>-1</sup> for unfertilized control (F1).

## Intercrop growth

### Ginger

The changes in biometric observations for ginger as function of applied fertilizer to the intercropped *S. macrophylla* six months after planting during the second fertilizer application (2<sup>nd</sup> year) are presented in Table 3. Evidently, the ginger growth variables significantly varied in response to the applied fertilizer to the *S. macrophylla* trees. For example, the plant height ( $p= 0.001$ ), pseudo stem length ( $p= 0.001$ ), root length ( $p= 0.001$ ), number of leaves ( $p= 0.001$ ), number of tillers ( $p= 0.001$ ), aboveground dry weight ( $p= 0.001$ ) and belowground dry weight ( $p= 0.05$ ) significantly varied (Table 3). Except the plant height, all the growth variables showed highest value in the open treeless condition followed by the highest fertilizer dosages treatment (F4-150:75:75 kg ha<sup>-1</sup> year<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O) and a decreased there after with decrease in fertilizer dosage. Yet another observation is the narrow growth difference in ginger in the highest fertilizer regime and the treeless open plots.

Table 3: Understorey ginger productivity after six months of planting in response to the fertilizer applied to 5-year-old *S. macrophylla* during second consecutive year at Mala, Thrissur, Kerala

| Treatments            | Plant ht.<br>(cm)             | Root Length<br>(cm)          | No. of leaves                | No. of tillers               | Above Dry wt.<br>(g plant <sup>-1</sup> ) | Below Dry wt.<br>(g plant <sup>-1</sup> ) |
|-----------------------|-------------------------------|------------------------------|------------------------------|------------------------------|-------------------------------------------|-------------------------------------------|
| F1- 0:0:0             | 57.08 <sup>c</sup><br>(1.92)  | 13.15 <sup>a</sup><br>(0.38) | 9.16 <sup>c</sup><br>(1.36)  | 1.41 <sup>c</sup><br>(0.16)  | 7.61 <sup>d</sup><br>(1.00)               | 13.12 <sup>b</sup><br>(0.36)              |
| F2- 50:25:25          | 69.58 <sup>b</sup><br>(3.80)  | 11.74 <sup>b</sup><br>(0.12) | 9.91 <sup>c</sup><br>(0.98)  | 2.00 <sup>bc</sup><br>(0.14) | 8.66 <sup>cd</sup><br>(0.39)              | 19.83 <sup>ab</sup><br>(4.11)             |
| F3- 100:50:50         | 74.75 <sup>ab</sup><br>(4.36) | 10.98 <sup>b</sup><br>(0.30) | 12.83 <sup>b</sup><br>(0.22) | 2.08 <sup>bc</sup><br>(0.36) | 9.77 <sup>bc</sup><br>(0.47)              | 22.07 <sup>a</sup><br>(2.48)              |
| F4- 150:75:75         | 80.66 <sup>a</sup><br>(1.80)  | 9.84 <sup>c</sup><br>(0.09)  | 14.33 <sup>b</sup><br>(0.44) | 2.83 <sup>b</sup><br>(0.33)  | 10.97 <sup>b</sup><br>(0.14)              | 23.59 <sup>a</sup><br>(1.66)              |
| F5- Tree less Control | 74.50 <sup>ab</sup><br>(3.04) | 13.87 <sup>a</sup><br>(0.41) | 17.00 <sup>a</sup><br>(0.50) | 4.08 <sup>a</sup><br>(0.22)  | 13.78 <sup>a</sup><br>(0.54)              | 27.13 <sup>a</sup><br>(1.30)              |
| Mean                  | 71.31                         | 11.91                        | 12.64                        | 2.48                         | 10.10                                     | 21.14                                     |
| F value               | 7.90                          | 30.11                        | 15.58                        | 15.48                        | 16.69                                     | 4.90                                      |
| p value               | 0.004                         | 0.001                        | 0.001                        | 0.001                        | 0.001                                     | <0.05                                     |

Values in the parenthesis are Standard Error of the mean

Values followed by same superscript in a column do not differ significantly

## Wild turmeric

All the biometric growth attributes of wild turmeric had positive influence on tree fertilizer treatment ( $p=0.001$ ) after six months of planting during the second season (2015) (Table 4). As observed for ginger, there was consistent reduction in intercrop growth parameters with reduction in fertilizer dosage applied to the adjacent trees. Also the performances of the intercrop in the treeless control plots were considerably higher as compared to the intercropped scenario. Further, the growth differences were considerably higher between unfertilized plots and treeless open plots. For example, reduction in height growth for wild turmeric in the treeless open compared to unfertilized control plots was about 78.30% while the corresponding reduction was only 11.71% in the highest fertilized treatment (F4). The corresponding percentage reduction in wild turmeric in higher fertilizer applied plots (F4) as compared to growth in the treeless open area (F5) for other growth parameters were: root length (30.95%), number of leaves (26.66%), number of tillers (7.69%), aboveground biomass (21.68%) and belowground biomass (38.49%) (Table 4).

Table 4: Understorey wild turmeric productivity after six months of planting in response to the fertilizer applied to 5-year-old *S. macrophylla* during second consecutive year at Mala, Thrissur, Kerala

| Treatments    | Plant ht.<br>(cm)             | Root Length<br>(cm)          | No. of leaves                 | No. of tillers               | Above Dry wt.<br>(g plant <sup>-1</sup> ) | Below Dry wt.<br>(g plant <sup>-1</sup> ) |
|---------------|-------------------------------|------------------------------|-------------------------------|------------------------------|-------------------------------------------|-------------------------------------------|
| F1- 0:0:0     | 51.08 <sup>e</sup><br>(0.33)  | 14.07 <sup>a</sup><br>(0.77) | 7.50 <sup>d</sup><br>(0.62)   | 1.58 <sup>d</sup><br>(0.08)  | 8.82 <sup>b</sup><br>(1.85)               | 14.47 <sup>d</sup><br>(0.69)              |
| F2- 50:25:25  | 68.75 <sup>d</sup><br>(2.50)  | 12.95 <sup>a</sup><br>(0.44) | 8.41 <sup>cd</sup><br>(0.96)  | 2.33 <sup>c</sup><br>(0.36)  | 10.58 <sup>b</sup><br>(0.97)              | 17.71 <sup>cd</sup><br>(1.25)             |
| F3- 100:50:50 | 79.08 <sup>c</sup><br>(2.91)  | 11.60 <sup>b</sup><br>(0.11) | 10.50 <sup>bc</sup><br>(0.50) | 2.66 <sup>bc</sup><br>(0.22) | 10.22 <sup>b</sup><br>(0.28)              | 21.07 <sup>bc</sup><br>(0.60)             |
| F4- 150:75:75 | 91.08 <sup>b</sup><br>(4.74)  | 10.79 <sup>b</sup><br>(0.09) | 11.50 <sup>b</sup><br>(0.50)  | 3.25 <sup>ab</sup><br>(0.20) | 11.90 <sup>ab</sup><br>(0.33)             | 26.94 <sup>b</sup><br>(1.77)              |
| F5- Control   | 101.75 <sup>a</sup><br>(1.37) | 14.13 <sup>a</sup><br>(0.06) | 14.25 <sup>a</sup><br>(0.66)  | 3.50 <sup>a</sup><br>(0.16)  | 14.48 <sup>a</sup><br>(0.91)              | 37.31 <sup>a</sup><br>(3.73)              |
| Mean          | 78.34                         | 12.70                        | 10.43                         | 2.66                         | 11.20                                     | 23.55                                     |
| F value       | 49.17                         | 13.52                        | 15.71                         | 15.46                        | 4.21                                      | 20.69                                     |
| p value       | 0.001                         | 0.001                        | 0.001                         | 0.001                        | <0.05                                     | 0.001                                     |

Values in the parenthesis are of Standard Error of the Mean

Values followed by same superscript in a column do not differ significantly

## Turmeric

Performance of turmeric also followed similar patterns as that of ginger and wild turmeric with tree fertilization significantly influencing the turmeric growth (Table 5). All the growth parameters of turmeric barring root length, showed consistent increase with increasing the applied fertilizer dosage to the mahogany trees. Interestingly, higher turmeric root length was reported both for unfertilized control plots and treeless open plots which were significantly higher than other fertilizer regimes. Also plant height and number of tillers for turmeric were higher for plots treated with high fertilizer levels (F4) and the treeless open plots (F5) which were statistically at par. The belowground dry weight for turmeric recorded 91 per cent increase in the heavily fertilised plots (F4) plots as compared to the unfertilised control plots while the corresponding increase for treeless open plots was almost 200 per cent.

Table 5: Understorey turmeric productivity after six months of planting in response to the fertilizer applied to 5-year-old *S. macrophylla* during second consecutive year at Mala, Thrissur, Kerala.

| Treatments    | Plant ht.<br>(cm)             | Root Length<br>(cm)          | No. of leaves                 | No. of tillers              | Above Dry wt.<br>(g plant <sup>-1</sup> ) | Below Dry wt.<br>(g plant <sup>-1</sup> ) |
|---------------|-------------------------------|------------------------------|-------------------------------|-----------------------------|-------------------------------------------|-------------------------------------------|
| F1- 0:0:0     | 63.08 <sup>c</sup><br>(5.16)  | 14.06 <sup>a</sup><br>(0.57) | 8.25 <sup>c</sup><br>(1.01)   | 1.41 <sup>c</sup><br>(0.08) | 6.82 <sup>d</sup><br>(1.73)               | 13.23 <sup>e</sup><br>(0.40)              |
| F2- 50:25:25  | 69.91 <sup>c</sup><br>(2.83)  | 12.99 <sup>b</sup><br>(0.33) | 8.83 <sup>bc</sup><br>(1.30)  | 2.33 <sup>b</sup><br>(0.22) | 8.41 <sup>c</sup><br>(1.43)               | 19.14 <sup>d</sup><br>(1.44)              |
| F3- 100:50:50 | 82.25 <sup>b</sup><br>(2.89)  | 11.26 <sup>c</sup><br>(0.14) | 10.50 <sup>ab</sup><br>(0.50) | 2.75 <sup>b</sup><br>(0.14) | 11.08 <sup>bc</sup><br>(0.45)             | 21.74 <sup>bc</sup><br>(1.48)             |
| F4- 150:75:75 | 95.33 <sup>a</sup><br>(2.70)  | 10.73 <sup>c</sup><br>(0.04) | 11.41 <sup>ab</sup><br>(0.58) | 3.25 <sup>a</sup><br>(0.14) | 12.50 <sup>ab</sup><br>(1.33)             | 25.29 <sup>b</sup><br>(1.42)              |
| F5- Control   | 104.25 <sup>a</sup><br>(0.75) | 14.42 <sup>a</sup><br>(0.12) | 12.33 <sup>a</sup><br>(0.44)  | 3.58 <sup>a</sup><br>(0.08) | 15.76 <sup>a</sup><br>(0.67)              | 39.86 <sup>a</sup><br>(1.21)              |
| Mean          | 82.96                         | 12.69                        | 10.26                         | 2.66                        | 10.91                                     | 23.85                                     |
| F value       | 28.73                         | 28.55                        | 4.17                          | 34.33                       | 8.14                                      | 62.46                                     |
| p value       | 0.001                         | 0.001                        | <0.05                         | 0.001                       | 0.003                                     | 0.001                                     |

Values in the parenthesis are Standard Error of the mean

Values followed by same superscript in a column do not differ significantly

### Rhizome yield among intercrops

Ginger yield corresponding to the final harvest (210 DAP) during the two consecutive years of fertilizer treatment to the mahogany trees showed considerable differences in rhizome yield (Table 6). The overall yield was higher during the second year of intercropping as compared to the first year. The belowground biomass showed consistent increase with increase in applied fertilizers to the mahogany trees with F4 giving the highest dry weight among intercropped plots. Invariably, the maximum dry weight was associated with treeless open plot which was significantly higher than F4 treatment during the first year (2014). However, these differences showed levelling trend and were at par during the second year.

Table 6: Fertilizer response on herbaceous crop yield intercropped with 5-yr-old *Swietenia macrophylla* after 210 days after planting during two consecutive years (2014, 2015) at Mala, Thrissur, Kerala

| Treatments                  | Ginger                                 |                                | Wild turmeric               |                  | Turmeric                       |                   |
|-----------------------------|----------------------------------------|--------------------------------|-----------------------------|------------------|--------------------------------|-------------------|
|                             | Dry rhizome yield (g m <sup>-2</sup> ) |                                |                             |                  |                                |                   |
|                             | 2014                                   | 2015                           | 2014                        | 2015             | 2014                           | 2015              |
| Fertilizer dosage           |                                        |                                |                             |                  |                                |                   |
| F1- 0:0:0                   | 154.72 <sup>c</sup><br>(0.60)          | 320.00 <sup>c</sup> (2.49)     | 259.20 <sup>a</sup> (1.80)  | 388.8<br>(0.51)  | 201.28 <sup>c</sup><br>(1.94)  | 233.28<br>(0.29)  |
| F2- 50:25:25                | 246.08 <sup>c</sup><br>(3.05)          | 441.76 <sup>c</sup> (3.81)     | 420.32 <sup>bc</sup> (3.91) | 629.44<br>(10.7) | 233.76 <sup>c</sup><br>(1.60)  | 425.44<br>(11.65) |
| F3- 100:50:50               | 401.28 <sup>b</sup><br>(3.26)          | 498.56 <sup>bc</sup><br>(8.77) | 458.88 <sup>bc</sup> (5.79) | 703.04<br>(8.61) | 301.44 <sup>bc</sup><br>(1.19) | 446.24<br>(10.48) |
| F4- 150:75:75               | 468.00 <sup>b</sup><br>(29.25)         | 762.88 <sup>a</sup> (4.08)     | 595.2 <sup>ab</sup> (5.95)  | 738.08<br>(7.51) | 425.44 <sup>b</sup><br>(4.79)  | 515.04<br>(14.63) |
| F5- Treeless open (control) | 672.32 <sup>a</sup><br>(3.22)          | 762.88 <sup>a</sup> (4.08)     | 780.32 <sup>a</sup> (3.88)  | 721.28<br>(4.38) | 761.28 <sup>a</sup><br>(2.00)  | 856.48<br>(12.29) |
| Mean                        | 388.48                                 | 557.12                         | 502.72                      | 635.84           | 384.64                         | 495.29            |
| F value                     | 20.37                                  | 6.08                           | 7.30                        | 1.54             | 29.21                          | 1.65              |
| p value                     | 0.001                                  | 0.01                           | 0.005                       | >0.05            | 0.001                          | >0.05             |

Values in the parenthesis are Standard Error of the Mean

Values followed by same superscript in a column do not differ significantly

The dry biomass production for wild turmeric during two consecutive years suggested similar results as that of ginger with increased production with increase in fertilizer dosage to the adjacent mahogany

trees. Interestingly, this trend was significant only during the first year while the differences were only modest during the second year. Often the differences in belowground biomass production were very narrow between treeless plots and intercropped plots during the second year. Nevertheless, the wild turmeric yield in the unfertilized plots was the lowest among all treatment combinations during both the years.

Turmeric yield at final harvesting time during first year (2014) showed highest values for treeless open plots. However, among the turmeric intercropped mahogany plots, the yields were highest for high fertilizer regime (F4) followed by F3, F2 and F1 which all were significantly different. This trend though followed during the consecutive year (2015), the corresponding values were not significant. It is noteworthy that tree fertilization with higher doses impacted considerable increase in turmeric yield often beyond 100% as compared to unfertilized control plots.

## Discussion

### *Fertilization effects on growth and productivity of mahogany*

The five-year-old mahogany trees showed considerable improvement in growth in response to fertilization indicating that in the absence of external supplementation, the available nutrient stock in the soil may be inadequate for the manifestation of potential growth of mahogany trees. Especially, in polyculture systems involving mahogany trees, intensive competition for nutrients may persist with a consequent better response to nutrient inputs (Opuni-Frimpong et al. 2016). Woody ecosystems in general, have the inherent potential to utilize the available nutrients through their efficient cycling which however, depend on the biophysical resource base of the site, the growth phase of trees, management conditions, substantial ecological and environmental effects (Zaragozi et al. 2012; Li and Li, 2017; Zalloni et al. 2019; Collalti et al. 2021; Celma et al. 2022). For instance, the mahogany trees have approached early phase of canopy closure possibly triggering the competitive interaction for available nutrients.

Usually, the plantation nutrition assume greater relevance prior to the onset of competitive interactions *i.e.*, before the canopy closure and active cycling of nutrients. However, this threshold period of nutrition is of great relevance in plantation management. The early periods of plantation growth often correspond to sub optimal utilization of the site resources which however, increase with the increase in tree growth leading to nutrient scarcity especially when the canopy closure time and the consequent nutrient cycling process is delayed (Luo et al. 2004; Norby et al. 2010; Vicca et al. 2012; Pretzsch 2014; Williams et al. 2017; Kunz et al. 2019; Guillemot et al. 2020). The fertilizer response on the tree height growth was prominent in the present study with about 26% increase registered at highest fertilizer regime ascertaining that the early periods of faster height growth necessitate greater demand for nutrients leading to their depletion in the soil especially nutrient poor tropical soils (Jacobs and Timmer, 2005; Neina 2019). Height growth in trees normally increases at faster rate during the early growth phase and subsequently levels off at the later stages (Lanner 1985).

The positive effect of fertilizer on tree height, diameter, basal area and volume was evident throughout the study. The mean tree height values recorded are fairly comparable with reports from other tropical regions (Adamek et al. 2009; Santiago et al. 2012). For example, height ranges from 2.9 to 8.7 m with a maximum value of 11.8 m was reported for 5-year-old *S. macrophylla* from South Kalimantan, Indonesia (Krisnawati et al. 2011). In the present study, increase in the height growth from 7.51 m (control) to 9.13 m (F4) during the first six month of fertilizer application clearly demonstrates the influence of fertilizer on *S. macrophylla* growth. It is also observed that the rate of change in height growth with fertilizer application increases with advancement of age. For instance, the difference in height growth between unfertilized control and heavily fertilized plot was approximately 2.5 m after 24 months of fertilizer application as against height difference of 1.62 m after 6 months of fertilizer application.

Improvement in productivity pursuant to N, P and K fertilization has already been reported in tropical plantation sector (Wright et al. 2011; Alvarez-Clare et al. 2013). The general strategy for faster height increment in even aged plantation is to maintain initial high density and make use of the spatial competitive advantage for better light availability and tree growth. This high density and faster growth regime in early growth phase impact the tree response to all biophysical resources including response to light, water, temperature, humidity etc. (Bassett, 1964; Cole and Newton, 1986; Kozlowski et al. 1991; Bejarano et al, 2014). Obviously, this period corresponds to peak nutrient uptake that may result in faster nutrient depletion in the soil. Hence, application of NPK fertilizer has been observed to be a viable strategy for faster height growth especially during the early growth phase (Misra et al. 1996; Yang 1998; Liu et al. 2009). Consistent with this, many reports suggest the faster height growth associated with trees fertilized at younger stages of plantations development (Pukkala 2017, Ornelas et al. 2022).

Further, the increase in tree height growth with increase in fertilizer quantity suggest better manifestation of the resource use efficiency for mahogany coinciding with early height growth phase.

Nevertheless, insignificance of fertilization application on tree growth has been reported for Eucalyptus species (Cromer and William, 1982; de Farias et al. 2016; Shannon et al. 2023). Such conclusions however require further validation on the growth condition, bio-physical resources potential and nutrient requirement of the plants.

The trial also revealed that optimal fertilizer regime height growth for 5-year-old mahogany is NPK @ 150:75:75 which were significantly higher than the height growth attained corresponding with NPK @ 100:50:50. The composition, quantity and the time of application are the major factors that influence the effectiveness of fertilizers in plant production systems (Rietra et al. 2017). The quantity of fertilizer is often decided by the plant requirement for the particular element and its soil availability. Fertilization in tropical forest plantations has been found to be effective especially in nutrient poor soils. As against agriculture crops, forest plantations accrue considerable biomass and might deplete the soil nutrient base considerably. Dixit (2017) found that high fertilizer application in *Shorea robusta* recorded better in plant height during the seedling stage in tropical dry deciduous forest of Chhattisgarh central India and similar result found in teak seedlings in Malaysia (Abod and Siddiqui 2002).

Marked increase in diameter growth and basal area growth in the heavily fertilized plot is obvious in the present study. The diameter (DBH) increment 24 months after the fertilizer application in the heavily fertilized plots was almost 30% higher as compared to unfertilized control. Similarly, the increase in basal area per hectare in highest fertilizer dose (F4) as compare to unfertilized (F1) after 24 months of fertilizer application was approximately 71 per cent. This significant hike in basal area justifies the need for fertilizer application in young stand of *S. macrophylla*. However, the marginal difference in per hectare basal area between F3 and F4 suggested application of NPK fertilizer at the 100:50:50 kg ha<sup>-1</sup> per year elemental N, P and K, respectively (F3) would be desirable for young *S. macrophylla*.

Assessment of the response of individual nutrients on tree growth has not been attempted in the present study. However, evidences suggest that cumulative effect of multiple nutrients especially major nutrients such as NPK often decide overall growth of the trees which is evident in the present study (Vadeboncoeur 2010; Wright et al. 2011; Alvarez-Clare et al. 2013; Rietra et al. 2017; Jiang et al. 2017; Manu et al. 2022).

In production forestry, basal area per hectare is very important consideration while optimising productivity. The mean annual increment in basal are per hectare also was found to respond very well to fertilizer application (1.44 to 2.47 m<sup>2</sup> ha<sup>-1</sup> yr<sup>-1</sup>). Apart from the soil nutrient status, many soil attributes decide the nutrient use efficiency. Often fertilization effects on basal area increment are found closely related to the soil moisture regimes (Rocha et al 2019; Nilsson et al. 2021). The conducive soil moisture regimes available in humid climate may have contributed to the present high fertilizer response to tree basal area increment. Nutrient interaction has been found to increase radial growth of tropical tree species which in turn effect the availability, uptake function and distribution among the nutrients (Baez and Homeier, 2017). Often N is the most limiting nutrient for optimum plant growth (Hassan et al. 2010). The nutritional imbalances (Boccuzzi et al. 2021), nutrient antagonism (Rietra et al. 2017) and or, an adjustment in biomass allocation may influence the nutrient use efficiency in tropical forestry (Wright 2019).

Volume production is primarily a function of tree height and basal area growth, both had significant influence on fertilizer application. Obviously, volume production may have a cumulative effect on fertilizer application which is pertinent in our study. For instance, the increase in stand volume production in the highest fertilizer plots (F4) was almost 135 per cent higher as compare to unfertilized control plot. This enormous increase in stand volume further confirms the complimentary effect of fertilization on tree volume production. Fertilizer effects were also prominent on the MAI which ranged from 7.47 (F1) to 17.54 m<sup>3</sup> ha<sup>-1</sup> yr<sup>-1</sup> (F4). Though the fertilizer effect on basal area changes was modest between the F3 and F4 plots, the conspicuous improvement in volume in the highest fertilizer regime (F4) could be attributed to the better height growth in response to fertilizer application. Many researchers reported proportionate relationship in fertilizer application and biomass accumulation (Gehring et al. 1999; Dinkelmeyer et al. 2000; Davidson et al. 2004; Russo 2005; Isaac et al. 2007; Schroth et al. 2015).

Throughout the study, the presence of intercrops had only insignificant influence on tree growth suggesting that the presence of intercrops could not bring perceptible competitive interaction with the mahogany trees for resources which could lead to suboptimal growth. Closer analysis suggests that the tree growth in the fertilized-intercropped plots were much better than the unfertilized plots. Also the growth of mahogany in the fertilized plots with and without intercrops were also non-significant, further suggesting that the competition for applied nutrients could not inflict any perceptible reduction in tree growth, rather it promoted tree growth marginally. Perhaps, despite the possible sharing of part of the nutrients applied to the mahogany trees by the herbaceous crops, such sharing may not bring appreciable reduction in tree nutrient requirements and thereby on tree growth.

Hence, tree fertilization in agroforestry scenarios at younger stages of tree growth and intensive crops growth, would help to alleviate possible competition for applied nutrients there by promoting uninhibited tree and crop growth. Tree crop interaction for applied nutrients has been reported to be influenced by multitude of factors in addition to their differential nutrient demands. Often, root distribution patterns remain the most universal indicators of nutrient acquisition in agroforestry systems (Isaac, and Borden 2019). Distinctive structural and functional characteristics of tree root systems, relative to crop roots, remain a cornerstone of agroforestry. Exploration of such root level differences in nutrient acquisition at the tree-crop interface would unearth the complexities associated with the mahogany-herbaceous crop interactions in the present study.

### **Intercrop growth performance**

Tree fertilization trial aimed at improving the growth and productivity of mahogany trees had positive influence on the growth of the associated intercrops as well. The intercrops absorbed a reasonable share of the fertilizers applied to the mahogany trees which is well reflected on the growth of intercrops. Such complementary nutrient sharing has been reported for many agroforestry systems (Salehi et al. 2018; Swieter et al. 2021). In general, N is a vital role of plant protoplasm and cell division ultimately for plant growth (Sopher and Baird 1982), P helps to produce healthy reproductive parts and roots formation and K involved in enzyme activities including stomata opening, nitrogen metabolism and translocation of carbohydrates (Kramer and Kozlowski 1979). The intercropped ginger, turmeric and wild turmeric showed increase in most of growth variables in response to the applied fertilizers to the mahogany trees. These points towards a possible complementarity in resource sharing among the intercrop and mahogany trees. Even the trends observed in response to variable dosage of fertilizer on the tree growth was mirrored with respect to the growth of intercrops as well. For instance, ginger, turmeric and wild turmeric showed lowest growth for the unfertilized plots which further increased with increase in the fertilizer dosage applied to the mahogany trees. The best growth response for the highest fertilizer regime (F4). Clearly, the study revealed that there is optimal sharing of nutrients applied to the mahogany between the tree and the crops, leading to their overall growth improvement.

Interestingly, during the second year of intercropping, there was considerable reduction in yield among the crops under unfertilized- intercropped condition compared to their yield in the treeless open

condition. However, with the growth advantage contributed by fertilization, the above yield differences were found to be reduced compared to open treeless control. For instance, no yield reduction has been observed in ginger yield for the high fertilized plots (F4) as compared to the ginger yield in the contiguous treeless plots while wild turmeric registered marginal increase in yield for plots at higher fertilizer regime (F4). However, the turmeric represented almost 40% reduction in yield compared to the treeless open. Clearly, the possible reduction in the crop yields due to the shading in the sub canopy of trees, has been compensated by the nutrients shared from the mahogany trees. The reduction in photosynthesis activity of integrated crop mainly due to shading from tree rows cause decline the crop productivity. In such circumstance silvicultural strategies such as thinning, pruning or fertilization may be effective in maintaining productivity of crop under younger stage of forest and/or plantation (Ferez et al. 2015; Lefebvre et al. 2019). Hence, the tree fertilization strategy adopted in the present trial can be a prudent example of rational agroforestry practices which tend to use the positive synergistic effects for an increase in overall productivity (Swieter et al. 2021; Li et al. 2022). Hence the study reiterates that the application of fertilizers in agroforestry systems should promote the possible complementarity between the tree-crop components in resource acquisition so as to optimize the combined productivity of the system.

### Managerial implications of the study

The two years long study aimed at characterizing the growth and understorey productivity as a function of applied inorganic fertilizers emphasis the need for fertilization in 5-year-old *Sweitenia macrophylla* at younger stages of growth in humid tropical conditions of Kerala, India. Application of N, P, K fertilizers at the rate 150:75:75 kg ha<sup>-1</sup> yr<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O would be desirable for optimal volume production for mahogany during the early growth phase. Application of fertilizer at the above dose can increase the volume production by 135 per cent during early two years. Fertilization was also found to increase the understorey productivity of intercropped ginger, wild turmeric and turmeric ensuring complementarity in resource sharing among the tree-crop interphase. Fertilization at optimal doses (F4) applied to the trees recorded almost 138% increase in ginger yield as compared to unfertilized plots. The corresponding increase for wild turmeric and turmeric were 90.38 and 120 per cent respectively.

## Conclusion

The two yearlong field trial involved integration of three medicinally important herbaceous plants viz. ginger, wild turmeric and turmeric along with 5-year-old *Sweitenia macrophylla* planted at 2.5 x 2.5 m spacing. The primary objective of the field trial was to examine the efficacy of tree fertilization on the productivity of the tree-crop components. There was significant increase in tree growth following fertilization and the best tree yield was for 150:75:75 kg ha<sup>-1</sup> yr<sup>-1</sup> N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O. The increase in stand volume was as high as 135% as compared to the unfertilized plots. All the three intercrops showed constant increase in rhizome yield with increase in fertilizer dosage applied to the mahogany trees. The trends indicate interesting interactions among the mahogany trees and the herbaceous crops. While mahogany trees positively responded to the applied fertilizer, they also shared fair amount of nutrients

among the intercrops without compromising tree growth. This sharing of nutrients has considerably improved the intercrops yields. This can be cited as an excellent example of complimentary resource sharing in mahogany based agroforestry. However, there is need for deeper introspection into the complexities associated with nutrient sharing at the tree-crop interphase in mahogany based agroforestry.

## Declarations

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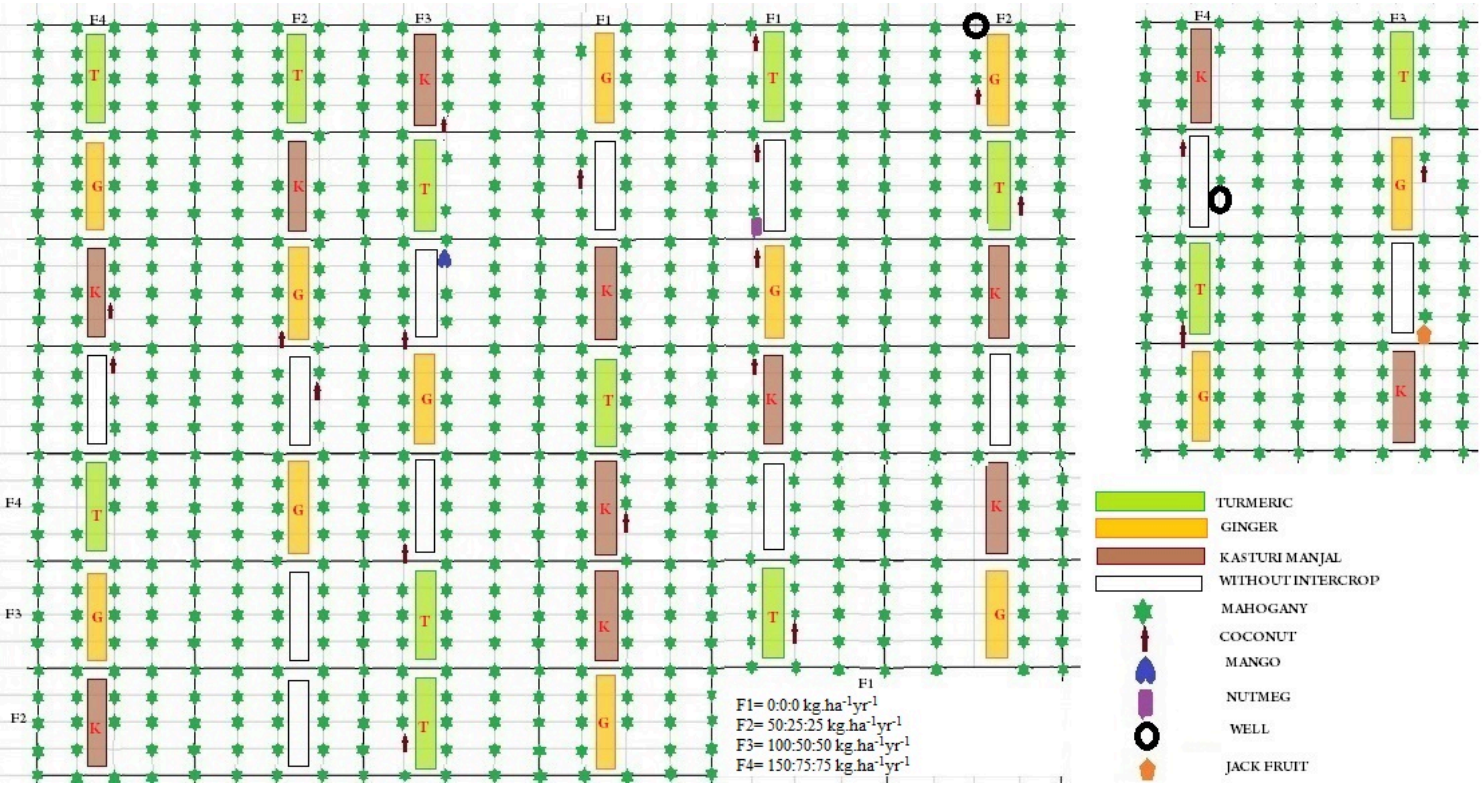
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# Figures



**Figure 1**

Layout of experimental plots in the *Swietenia macrophylla* plantation at Mala, Thrissur