# Agroforestry-Based Intercropping under Clonal Teak Stands: Effects on Tree Growth and Crop Yield

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**Abstract.** Clonal teak is one of the leading hardwood species that remains in high demand due to increasing global needs. Increasing the productivity of cloned teak plays a crucial role, one of which is through effective spacing management. Spacing management also has the potential for intercropping under the canopy. The study aimed to determine the effect of several spacing treatments on the productivity of teak clones and intercropped plants (*Curcuma longa* L.). Four spacing were used: 3 m x 3 m, 6 m x 2 m, 8 m x 2 m, and 10 m x 2 m. *C. longa* L. was planted under the stands at different spacing and harvested at 8 months. The study design used RCBD and was analyzed using ANOVA and t-tests. The results showed that wide spacing (10 m x 2 m and 8 m x 2 m) contributes positively to increasing the productivity of teak clones and *Curcuma longa* L. However, intercropping of clonal teak didn't significantly differ from monoculture. Intensive silviculture, specifically the selection of teak clones and spacing, is crucial for enhancing teak and crop productivity, and also plays a role in the success of large-scale teak clone plantations.

## 1 Introduction

Teak (*Tectona grandis* L.f.) is one of the tree species that produces high-value wood and is widely cultivated in plantation forests in tropical regions [1]. As global demand for teak wood increases, the development of teak plantation forests has become an important strategy in the sustainable supply of wood raw materials. Teak plants have been developed through tree breeding, and superior clones have been obtained [2]. The use of clonal teak is a strategic innovation because it can produce faster growth [3] and wood quality that is not significantly different from conventional teak originating from seeds [1]. Despite their genetic advantages,

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the silvicultural management of clonal teak must also consider growing space, such as the spacing between plants. Proper spacing will stimulate fast growth [4]. In Indonesia, teak clones generally use initial spacing of 3 m x 3 m or 6 m x 2 m with periodic thinning [5].

Teak trees have been successfully cultivated in agroforestry systems alongside food crops, medicinal plants, and tubers, particularly in Java, Indonesia [6]. Optimising growing space by adjusting planting spacing also has the potential for agroforestry under tree canopies to increase productivity, produce diverse products, and contribute to food security [7]. Agroforestry contributes to improved soil fertility and food [7], as well as increasing farmers' income and community [7]. Optimising land use under tree canopies requires the development of plant species that are tolerant to shade, one of which is *Curcuma longa* L., a herbal commodity with many uses [8]. *C. longa* is a widely used spice with multiple applications, including as a culinary ingredient and as a raw material in industries such as perfumery, pharmaceuticals, and cosmetics [8]. The primary bioactive compound in *C. longa* is curcumin, which exhibits antioxidant, antiseptic, and anti-inflammatory properties [9]. The shade tolerance of *C. longa* [8] indicates a high potential compatibility with clonal teak during the middle phase when the canopy is already closed. The presence of *C. longa* as an underplant also has the potential to increase soil organic matter content through fertilization, which will enhance the growth of clonal teak [8]. This study aims to understand the effect of spacing on the productivity of clonal teak and also the productivity of intercropping plants (*C. longa*) under the canopy. The previous studies have suggested that yield of *C. longa* and the percentage of curcumin vary depending on light conditions [8][9]. This is why these factors were measured in this study. Many studies have been conducted on the effect of spacing on the growth of conventional teak or other plants and intercropping teak with crops. However, scientific studies that specifically identify the optimal spacing for the growth of clonal teak and intercropped plants under the canopy are still limited. Therefore, research on agroforestry-based clonal teak with herbal plants (*C. longa*) is very important to support the success of clonal teak cultivation and the welfare of communities around the forest.

## 2 Methods

The study was conducted in the Ngawi Forest Management Unit (FMU), Java, Indonesia. The clonal teak plantations used were 9 years old. The design used a randomized complete block design (RCBD) with 3 blocks as replicates. Each block consisted of 4 initial spacings, including: 3 m x 3 m; 6 m x 2 m; 8 m x 2 m; 10 m x 2 m, resulting in different stand densities (Table 1; Fig. 1). *Curcuma longa* plants were intercropped under the clonal teak from December 2019, being planted in half of the area of each spacing section, and were harvested eight months after planting (Fig. 1*)*. Weeding and fertilization were carried out as maintenance activities in the intercropping area, but not in the control area. *Curcuma longa* plants were harvested under clonal teak trees with sampling measuring 1 m x 1 m at each spacing and 3 replicates.

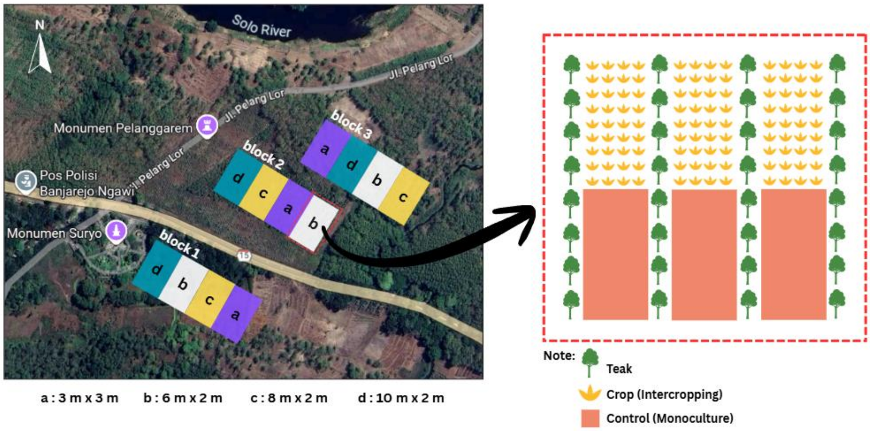


**Fig 1.** Research Design

We measured diameter at breast height (DBH), teak productivity, crop yield, and percent of curcumin. Tree productivity was calculated using the volume formula proposed by [10]:

Volume ($m^3$/trees) = (-0,0884+0,0297*DBH)$^2$ (1)
Volume ($m^3$/ha) = Volume ($m^3$/trees) * Stand Density (2)

Crop yield was expressed per unit area (ton/ha). Curcumin content was analyzed using UV–Vis spectrophotometry .

**Table 1.** Stand Density at Each Spacing

| Code | Spacing | Stand Density (trees/ha) |
|---|---|---|
| a | 3 m x 3m | 1111 |
| b | 6 m x 2 m | 833 |
| c | 8 m x 2 m | 625 |
| d | 10 m x 2 m | 500 |

All measured variables were compared among the different spacing treatments using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test for multiple comparisons. To compare the growth of monoculture teak clones and intercropped teak clones used the t-test analysis. All differences were considered statistically significant at $p < 0.05$.

## 3 Results and Discussion

### 3.1 The effect of spacing and intercropping on the productivity of Teak Clones

The results showed that the spacing between teak clones significantly affected diameter growth ($p < 0.001$) (Table 2). The largest to smallest diameter growth was observed at spacing of 10 m x 2 m, 8 x 2 m, 6 m x 2 m, and 3 m x 3 m, respectively. The 10 m x 2 m spacing produced the largest diameter growth in 9-year-old teak clones (24.89 cm). This finding is consistent with previous studies reporting that wider spacing enhances tree diameter growth by reducing inter-tree competition [4]. Furthermore, several studies have indicated that spacing does not have a significant effect on wood quality [1]. These results suggest that wider spacing can promote diameter growth without adversely affecting wood quality.

**Table 2.** Tree growth under different spacing treatments

| Spacing | DBH (cm) | | Tree Productivity ($m^3$/ha) | |
|---|---|---|---|---|
| | Mean ± SD | CV | Mean ± SD | CV |
| 3 m x 3 m | 18.13c ± 2.87 | 14% | 235.48ns ± 95.42 | 41% |
| 6 m x 2 m | 21.05b ± 3.16 | 15% | 245.51ns ± 68.33 | 28% |
| 8 m x 2 m | 22.58b ± 2.55 | 11% | 221.31ns ± 75.40 | 34% |
| 10 m x 2 m | 24.89a ± 0.50 | 2% | 216.73ns ± 60.85 | 28% |

note: Different letters indicate significant differences among treatments at tα 0.05; ns: non-significant; SD: Standard Deviation; CV: Coefficient of Variation (%)

Meanwhile, tree productivity did not differ significantly among spacing treatments, but it tended to be relatively higher at closer spacing (Table 2). This is influenced by the number of individual trees, where the denser the trees in one hectare, the greater the number of individuals. Tree productivity is influenced by stand density and various parameters such as age and average DBH [11]. This study found that lower tree density resulted in greater DBH and individual volume, while tree productivity did not differ among spacing [12].

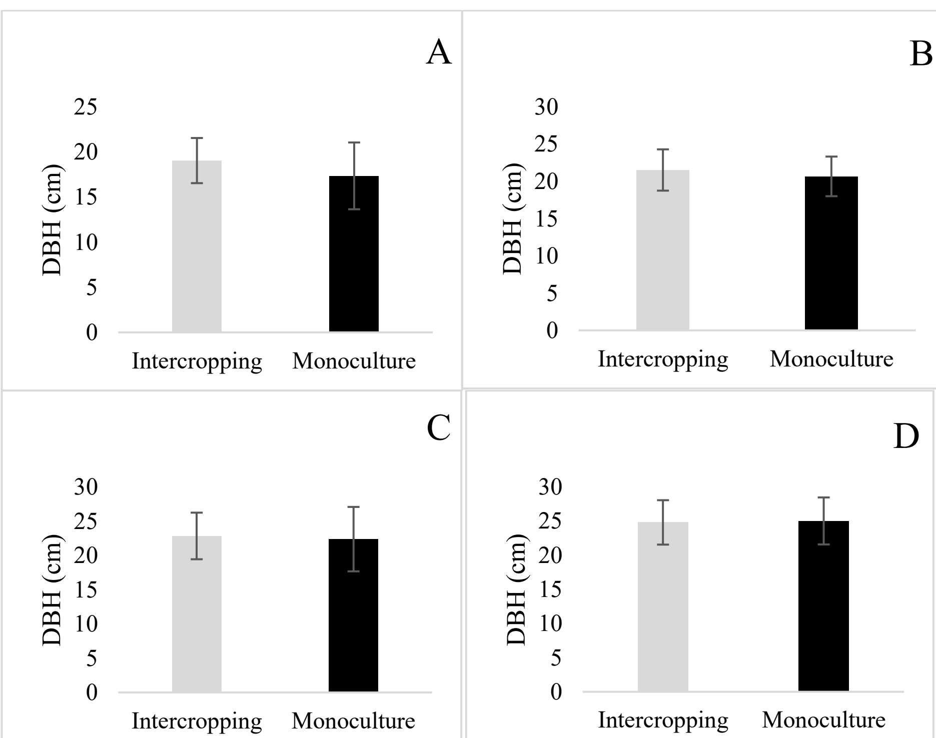


**Fig 2.** Comparison of the growth of intercropped and monoculture teak clones at spacing a. 3 m x 3 m ; b. 6 m x 2 m ; c. 8 m x 2 m ; d. 10 m x 2 m

On the other hand, intercropping of teak clone did not significantly differ from monoculture at all spacing (*t-test* > 0,05) (Fig. 2). In this results, Teak trees intercropped with *C. longa* produced larger diameters compared to monoculture teak at various spacing except for 10 m x 2 m spacing (Fig. 2). Previous studies demonstrating that intercropping systems promote superior growth and quality compared to monoculture systems [13]. This is due to intensive practices in intercropping, such as fertilization and weed control, which have a positive impact on teak growth [8]. On the other hand, belowground competition for water and nutrients could also potentially reduce teak growth [4]. Therefore, growing *C. longa* as an intercrop for eight months has not had a significant effect on teak growth.

### 3.2 The effect of spacing on Crop Productivity

The results showed that the spacing of teak clones had a significant effect on crop yield (Table 3). The highest crop yield of *C. longa* was obtained at a spacing of 8 m x 2 m at 8 months of age (3.52 tons/ha). The results show that the spacing of 8 m x 2 m increases the yield of *C. longa*, but decreases at the spacing of 10 m x 2 m (Table 3). This is due to the effect of shade level, where more openness increases crop yield [6]. The intercropping system of teak clones with *C. longa*, as well as the canopy openness at a spacing of 8 m × 2 m, is shown in Fig. 3. However, if it is too open, it can significantly reduce the rate of photosynthesis due to photorespiration [14], resulting in suboptimal growth of *C. longa* [8]. However, crop productivity is not only influenced by light intensity but also by soil conditions, climate, and cultivation methods [15].

**Table 3.** Productivity of crops under teak clones at different spacing treatments.

| Spacing | Crop Yield (ton/ha) | | Percent of curcumin(%) | |
|---|---|---|---|---|
| | Mean ± SD | CV | Mean ± SD | CV |
| 3 m x 3 m | 1.27b ± 0.83 | 65% | 5.10ns ± 0.90 | 18% |
| 6 m x 2 m | 2.17ab ± 0.75 | 35% | 4.92ns ± 0.58 | 12% |
| 8 m x 2 m | 3.52a ± 0.71 | 20% | 5.44ns ± 0.91 | 17% |
| 10 m x 2 m | 2.39ab ± 1.07 | 45% | 6.20ns ± 1.18 | 19% |

note: Different letters indicate significant differences among treatments at tα 0.05;ns: non-significant; SD: Standard Deviation; CV: Coefficient of Variation (%)

On the other hand, the spacing of teak clones did not significantly affect curcumin content (Table 3). The widest spacing (10 m x 2 m) produced the highest percentage of curcumin in *C.longa* harvested at 8 months. This is in line with research findings that show that the wider the spacing, the higher the percentage of curcumin [9]. Increasing shade cover can reduce the curcumin content in *C. longa* [8]. The curcumin content in *C. longa* is not only influenced by light intensity, but also by other factors such as rainfall, humidity, and wind [8].

(a) (b)

**Fig 3.** Intercropping teak with *Curcuma longa* L. (a) and canopy openness (b) at a spacing of 8 m x 2 m.

Intensive silvicultural practices involving the selection of superior teak clones have been shown to increase forest productivity [3], thereby contributing to accelerated forest rehabilitation in lowland forests, particularly in Java [2]. However, the use of superior clones must be accompanied by appropriate silvicultural interventions, including spacing, thinning [5], pruning [5], and fertilization [2], to further enhance stand productivity. Among these practices, appropriate spacing selection plays a crucial role in accelerating diameter growth to achieve higher timber assortment classes, improve wood quality, and provide more favorable growing conditions for intercropped plants [6].

## 4 Conclusion

The selection of appropriate spacing for superior teak clones is a critical factor in enhancing stand productivity and the performance of intercropped species. Wider spacing arrangements (10 m × 2 m and 8 m × 2 m) promote greater diameter growth and result in significantly higher crop yields compared to narrower spacing. We recommend intercropping 9-year-old teak clones with *C. longa* at a spacing of 8m x 2m to achieve high growth and high yield of *C. longa* with comparable stand productivity. Intensive silvicultural practices, particularly the use of superior clones, have been demonstrated to improve growth performance. However, these practices must be integrated with appropriate spacing selection to optimize productivity and promote intercropping. This also supports the successful implementation of large-scale teak clonal plantations in the future.

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## References

1. R.B. Rahmawati, Widiyatno, S. Hardiwinoto, Budiadi, W.D. Nugroho, A. Wibowo, D. Rodiana, Biodiversitas **23**, 4180-4188 (2022)
2. S. Hardiwinoto, A. Fiqri, Widiyatno, Biodiversitas **22**, 1750-1756 (2021)
3. Widiyatno, A. Wibowo, D. Novitasari, G.W. Seta, D. Prehaten, F. Hidayati, For. Sci. Techol. **20**, 8-15 (2024)

4. R.B. Rahmawati, S. Hardiwinoto, Widiyatno, Budiadi, Y. Amin, A. Hasanusi, J. Manaj. Hut. Trop **27**, 123-131 (2021)
5. Budiadi, Widiyatno, H. Ishii, J. Trop. For. Sci. 29, 44-53 (2017)
6. D. Prehaten, S. Hardiwinoto, M. Na'iem, H. Supriyo, Widiyatno, D. Rodiana, Biosaintifika **13**, 51-57 (2021)
7. Budiadi, Sawitri, E. Primananda, A.N. Jihad, M. Campera, R.B. Rahmawati, Plants People Planet **7**, 1-13 (2025)
8. A.B. Sharangi, M.P. Gowda, S. Das, Trees, Forests and People **7**, 100208 (2022)
9. K.M. Nelson, J.L. Dahlin, J. Bisson, J. Graham, G.F. Pauli, M.A. Walters, J. Med. Chem. **60**, 1620 (2017)
10. D. Perez, M. Kanninen, Forests, Trees and Livelihoods **13**, 345 (2003)
11. S. Sasidharan, The Teak Genome (Compendium of Plant Genomes, India, 2021)
12. R.S. da Silva, G.S. Vendrúscolo, J.R.M. da Rocha, A.G.S. Chaves, H.S. Souza, A.S. da Motta, Floresta e Ambiente **23**, 397-405 (2016)
13. S. Kruchelski, J.W. Trautenmüller, L. Deiss, R. Trevisan, F. Cubbage, V. Porfírio-da-Silva, et al., Agrofor. Syst. **95**, 1577 (2021)
14. D. Purnomo, M.S. Budiastuti, A.T. Sakya, M.I. Cholid, IOP Conf. Ser.: Earth Environ. Sci. **142**, 012034 (2018)
15. D. Maharani, A. Sudomo, D. Swestiani, Murniati, G.E. Sabastian, J.M. Roshetko, R.A. Fambayun, Agronomi **12**, 449 (2022)