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Growth, Yield, and Stem Quality of *Tectona grandis* Grown with Different Spacings at Longuza Forest Plantation, Tanzania

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Abstract

Spacing is a silvicultural practice that affects the growth of trees in forest plantations. However, the yield depends on growth, which is determined by spacing. In addition, spacing influences the quantity of the final crop available for harvesting, specifically in forest plantations for sawlog production. Spacing is also used as a management practice to control the quality of trees, as dense stands are expected to have trees with good stem quality. However, little has been done to address the effects of spacing on the growth, yield, and stem quality of Tectona grandis until final harvesting age. Teak plantations in Tanzania are grown at a rotation age of 20 years. Thus, this study aimed to assess the effect of spacing on the growth, yield, and stem quality of 24-year-old T. grandis in a Longuza Forest plantation in Muheza, Tanzania. Data were collected from a spacing trial using a randomized complete block design with three treatments: 2 m × 2 m, 3 × 3 m, and 4 m × 4 m, with three replications. The growth and yield parameters assessed were diameter at breast height (dbh) total tree height, and stem quality. Data were analyzed to obtain the basal area, volume, and mean annual increment. Statistical analysis was performed using analysis of variance (ANOVA), and multiple comparisons among treatment means were performed using Tukey's honest significant difference test (p-value = 0.05). The results showed that spacing did not significantly affect growth and yield parameters. The stem quality was significantly different in some treatments. The highest dbh and height growth were observed at 4 m× 4 m spacing. The highest values of basal area, volume, and mean annual increment were observed at a 3 m× 3 m spacing. Stem quality differed significantly between the 2 m× 2 m and 4 m× 4 m spacings. Because teak plantations in Tanzania are aimed at sawlog production, it is recommended to continue practising a spacing of 3 m× 3 m, which will ensure a higher mean annual increment with a higher volume at the stand level. In addition, a spacing of 3 m × 3 m ensured a higher percentage of trees with good stem quality.

Keywords: *Tectona grandis, spacing, volume, mean annual increment, stem quality*

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Introduction

Tectona grandis L.f. (Teak) is the most valuable tropical cultivated hardwood worldwide because of its excellent wood properties. These properties include strength, straightness, workability, resistance to many pests, good dimensional stability, aesthetic qualities, pathogens (Bermejo et al., 2004; Zanin, 2005), and durability and stability (Palanisamy et al., 2009). It naturally occurs in India, Myanmar, Laos, and Thailand (Nocetti et al., 2011).

Globally, the source of *T. grandis* wood is >29 million ha of natural forests and 6.89 million ha of plantations (Kollert & Cherubini, 2012). However, the global demand for *T. grandis* continues to increase, whereas the source of *T. grandis* from its natural range is decreasing due to illegal logging and competition with other natural resources (Rahmawati et al., 2021). This has drawn attention to artificial cultivation in plantations (Robertson & Reilly, 2004). The area covered by Teak plantations ranges from 4.35 to 6.89 million ha worldwide of which tropical Asia (India, Indonesia, Thailand, Myanmar, Bangladesh, and Sri Lanka) accounts for more than 80%, while tropical Africa accounts for only 10%, and tropical America (Costa Rica, Trinidad, and Tobago) accounts for 6% of the total planted area (Kollert & Kleine, 2017).

In Tanzania, *T. grandis* was first introduced during the colonial era by Germans in 1898 using seeds originating from the Calcutta region of India. Good performance in established experimental trials in 1905 and 1936 using seeds from Java, Burma, India, and Thailand led to the establishment of *T. grandis* plantations in 1952 (Longuza and Rondo) and 1961 (Mtibwa) (Madoffe & Maghembe, 1988; Ngaga, 2011).

In forest plantations aimed at sawlogs, spacing is among the factors that influence the growth rate, as it is expected that trees grown at wider spacing have greater diameters than those of the same age at close spacing, resulting from reduced competition for moisture and nutrients. Additionally, understanding the optimal spacing for *T. grandis* plantations ensures growth, quality of wood products (Iddi et al., 1996), and larger diameters (Zahabu et

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al., 2015). Moreover, the value of the final crop in forest plantations is mainly determined by log size and stem quality (Glencross et al., 2012). Some spacings commonly used in *T. grandis* plantations have been reported by several studies, including 1.37 m × 1.37 m, 1.98 m × 1.98 m, and 2.9 m × 2.9 m (Ola-Adams, 1990); 1.5 m × 1.5 m, 2 m × 2 m, 2.5 m × 2.5 m and 3 m × 3 m (Sibomana et al., 1997); 1 m × 1 m (Haninec et al., 2016); and 2 m × 2 m, 3 m × 3 m, and 4 m × 4 m (Zahabu et al., 2015).

The effects of spacing on the growth, yield, and stem quality of young *T. grandis* have been widely studied. For example, Rahmawati et al. (2022) evaluated an eight-year-old clonal teak plantation in Java Monsoon Forest, Indonesia. Rahmawati et al. (2021) studied a seven-year-old clonal teak plantation in the East Java Monsoon Forest Area. In addition, Kamara et al. (2020) studied a nine-year-old forest plantation in the transition rainforest of Sierra Leone. Likewise, a study (Kainyande et al., 2023) on five-year-old spacing trial plots at Njala University, Southern Province, Sierra Leone.

Since planted tree species, especially *T. grandis,* need to remain in the field until the final harvesting age (rotation age), the effects of spacing on growth, yield, and stem quality at older ages need to be known. In contrast, little has been done to address this in Tanzania, where a study by Sibomana et al. (1997) reported that at 9 years diameter at breast height, total height and basal area were statistically affected by spacing. Also, the study by Zahabu et al. (2015) at the age of 14 showed that diameter growth, height growth, and volume increment were statistically influenced by spacing. Both studies did not report on the effect of spacing on stem quality but spacing has been used to control the quality of trees by maintaining high-quality stem shape and restricting branch growth (Glencross et al., 2012).

Although in Tanzania teak plantation are now grown at 20-year rotation, they were previously grown at a 25 years rotation age. It is thus, not known if spacing will have the same effect at full rotation compared to half rotation reported by Zahabu et al. (2015) on studied growth and yield parameters. Thus, this study was intended to assess the effects of spacing on growth, yield and stem quality 10 years after last assessment but 4 years after the current rotation age. The results of this study have a potential in widening knowledge on spacing effects at older ages of the studied parameters. The results also provide guidance to decision makers during development of various tree planting guidelines.

Methods

Study area description The study was conducted on a 24-year-old *T. grandis* spacing trial located at Longuza Forest Plantation, Muheza District, Tanga Region, at latitudes S4°48' and S5°13' and longitudes E38°32' and E38°48'. The area has an average altitude of 180 m above sea level and a mean annual rainfall of 1,548 mm, with long rains from March to May followed by a dry spell between June and September. This area experiences short periods of rainfall, from October to December. The mean maximum temperature of the area varies between 26 °C and 32 °C, and the minimum temperature ranges from 15 °C to 20 °C. The topography ranges from undulating lower slopes between 5.71° and 11.31° to a steeper upper slope from 14.04° to 19.29°. The soil texture is sandy clay loam, dark reddish-brown to dark red or red, and becomes redder down the profile, with a pH ranging from strongly acid (4.5–5.0) to neutral (6.6–7.3). The soils are characterized by shallow depth (less than 20 cm) to very deep depth (greater than 120 cm), although most are moderately deep (40–80 cm) (Zahabu et al., 2015).

Experimental design The spacing trial assessed in this study was established in April 1998 at the Longuza Forest Plantation by the Sokoine University of Agriculture, in collaboration with the Forest and Beekeeping Division under the Ministry of Natural Resources and Tourism. The trial followed a complete randomized block design consisting of three planting spacing levels of 2 m × 2 m, 3 m × 3 m, and 4 m × 4 m, each replicated three times (Figure 1). Each plot was planted with 25 seedlings in a 5 × 5 layout (variable area plots), except for the center plot with a 4 m × 4 m spacing, which had 23 trees. The trial had two guard rows to avoid edge effects.

Data collection In this study, data on dbh, tree height, and stem quality data were collected at each spacing. The total tree height and dbh were measured using a Vertex IV and caliper, respectively. The stem quality of all trees was assessed by scoring, with four scores of 1–4 based on the merchantable height and tree form (Table 1).

Data analysis The basal area (m^2) of the individual tree was calculated as the cross-sectional area of the tree at dbh using Equation *[1]*.

$$Ba = 0.0000785 dbh^2 \qquad [1]$$

note: *Ba* = basal area (m^2), *dbh* = diameter at breast height (cm).

The total volume (m^3) of individual trees was calculated using a single-volume model (Malimbwi et al., 1998), as shown in Equation *[2]*.

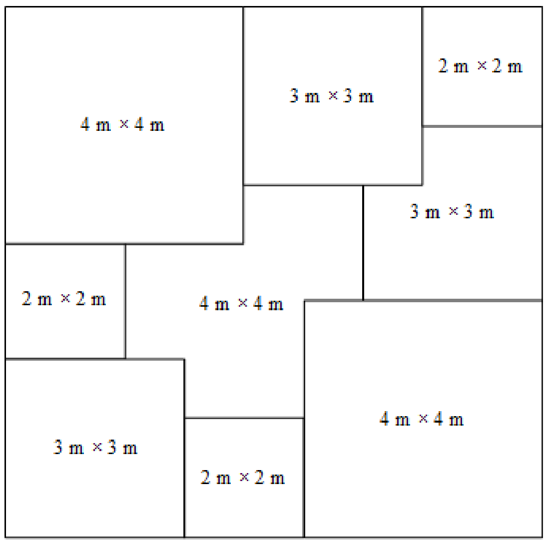

Figure 1 Spacing trial layout.

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Table 1 A detailed description of stem quality scores

S/No	Description	Score
a	Straight to the top and good stem form	
b	Straight and good stem form but with straight top forks	1
a	Straight and good stem form but with one slight bend less than 1 m in length	
b	Straight and good stem form but with slightly bent or crooked mid/top forks	
c	Straight and good stem form but with buttresses within 1 m height	2
a	Slight bends less than 1 m at bottom and top with a straight middle part	
b	One slight bend more than 1 m in length	
c	Slight crook, slight taper, buttressed within 2 m height	3
a	Serious crook, excess taper, and buttressed beyond 2 m height	4

Source: Gumadi et al. (2023)

$$V = 0.00024 dbh^{2.35} \quad [2]$$

note: V = volume (m^3), dbh = diameter at breast height (cm)

The mean annual increment (MAI) was calculated as the total tree volume divided by tree age using Equation *[3]*.

$$MAI = V_t / A \quad [3]$$

note: MAI = mean annual increment ($m^3\ ha^{-1}\ year^{-1}$), V_t = total volume per hectare ($m^3 ha^{-1}$), A = tree age (years).

Statistical analysis One-way ANOVA was used to determine the effect of spacing on all studied variables, including dbh, height, basal area, volume, MAI, and stem quality. The score data for stem quality were square root transformed before being subjected to statistical analysis (Chamshama et al., 1999). Tukey's honest significant difference test at p-value = 0.05 was used for multiple comparisons among variable means. All analyses were performed using R Software version 4.2.3.

Results and Discussion

Growth Spacing had no significant effect on dbh (F = 2.34; p-value > 0.05), and height (F = 0.87; p-value > 0.05) (Table 2) at the age of 24-year-old. The results showed a difference in the mean values of dbh, and height, but the difference was not significant. The spacing of 4 m × 4 m had the highest mean dbh of 32.17 cm, followed by 2 m × 2 m with a mean of 28.37 cm, and then 3 m × 3 m with a mean of 28.00 cm. Furthermore, the highest mean height (29.40 m) was observed at 4 × 4 m, followed by 2 × 2 m, with a mean of 27.18 m and 3 × 3 m had the lowest mean height of 27.07 m. The results revealed that dbh increased with increasing spacing, although the increase was not statistically significant at an older age of 24 years. This is in contrast to other findings that reported a significant increase in dbh with an increase in spacing. For instance, at the age of 14 years, Zahabu et al. (2015) reported a significant increase in dbh with increasing spacing, where a spacing of 4 m × 4 m had the highest mean dbh. Similarly, Rahmawati et al. (2021) revealed that a wider spacing of 10 m × 2 m produced a significantly higher dbh at eight years old. Moreover, after seven years, Rahmawati et al. (2022) showed that a wider spacing of 10 m × 2 m still produced a significantly higher dbh. In the present study, the differences in mean dbh were not significant, which may be due to competition being higher at closer spacings (Vigulu et al., 2019). Thus, mortality was higher with closer spacing and the remaining trees had more space for growth. Regarding height growth, the results showed an insignificant difference in the mean height among the spacings, with the highest mean height being at 4 m × 4 m. This is in agreement with several findings that revealed that height growth is not affected by spacing, but is sensitive to differences in site quality (Cardoso et al., 2013; Medeiros et al., 2018). In addition, Rahmawati et al. (2021) found similar findings, where the difference in mean height was not statistically significant among spacings of 3 m × 3 m, 6 m × 2 m, 8 m × 2 m, and 10 m × 2 m.

Yield The results showed that spacing had no significant effect on basal area per hectare (F = 0.97; p-value > 0.05), volume per hectare (F = 1.04; p-value > 0.05), and MAI (F = 1.04; p-value > 0.05) at the age of 24-year-old (Table 3). A spacing of 3 m × 3 m produced the highest mean basal of 33.33 $m^2 ha^{-1}$, followed by 4 m × 4 m, with a mean of 29.44 $m^2\ ha^{-1}$, and the spacing of 2 m × 2 m had the lowest mean of 22.05 $m^2\ ha^{-1}$. Moreover, the highest mean volume at a spacing of 3 m × 3 m (336.76 $m^3\ ha^{-1}$) did not differ much from a spacing of 4 m × 4 m with a mean volume of 312.53 $m^3\ ha^{-1}$, while the lowest mean volume was observed at a spacing of 2 m × 2 m with a mean volume of 220.68 $m^3\ ha^{-1}$. Similarly, the highest MAI was observed at a spacing of 3 m × 3 m (14.03 $m^3\ ha^{-1}\ year^{-1}$), followed by a spacing of 4 m × 4 m with MAI of 13.02 $m^3\ ha^{-1}\ year^{-1}$, and then the lowest MAI of 9.02 $m^3\ ha^{-1}\ year^{-1}$ was observed at a spacing of 2 m × 2 m. Although spacing had no significant effect on either volume or MAI, both volume and MAI at a spacing of 3 m × 3 m had a higher mean value, which was, however, relatively higher compared to 2 m × 2 m than at a 4 m × 4 m spacing. The lower volume and MAI at 2 m × 2 m may be attributed to low stocking because of higher mortality due to competition from individual trees. Similar results were reported by Zahabu et al. (2015), where 3 m× 3 m spacing produced a relatively higher volume and MAI than 2 m × 2 m and 4 m × 4 m spacing. In contrast, other findings reported a significantly higher volume with closer spacing during the early age of planting. For example, at 8 years of age, Rahmawati et al. (2022) reported a higher volume in a 3 m × 3 m spacing compared to other spacings of 6 m × 2 m, 8 m × 2 m, and 10 m × 2 m. This indicates a decrease in volume with an increase in the spacing. Rahmawati et al. (2021) reported the same trend of a decrease in volume with an increase in spacing at 7 years of age. Furthermore, the spacing of 3 m × 3 m recorded a higher non-significant mean basal area than the other two spacings. Similar results were

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Table 2 Effects of spacing on dbh and height

Variable	Spacing(m)			*F*-value
	2 × 2	3 × 3	4 × 4	
Dbh (cm)	28.37 ± 4.26[a]	28.00 ± 0.85[a]	32.17 ±1.27[a]	2.34[ns]
Height (m)	27.18 ± 3.83[a]	27.07 ± 1.66[a]	29.40 ± 0.73[a]	0.87[ns]

Note: within the same row, mean ± standard deviation followed by the same letter are not significantly different, *p*-value > 0.05; ns = non-significant, *p*-value > 0.05

Table 3 Effects of spacing on basal area, volume, and mean annual increment

Variable	Spacing (m)			*F*-value
	2 × 2	3 × 3	4 × 4	
Basal area (m^2 ha^{-1})	22.05 ± 12.28[a]	33.33 ± 7.27[a]	29.44 ± 10.06[a]	0.97[ns]
Volume (m^3 ha^{-1})	220.68 ± 121.57[a]	336.76 ± 75.98[a]	312.53 ± 108.81[a]	1.04[ns]
MAI (m^3 ha^{-1} $year^{-1}$)	9.20 ± 5.07[a]	14.03 ± 2.17[a]	13.02 ± 4.53[a]	1.04[ns]

Note: within the same row, means ± standard deviation followed by same letter are not significantly different, *p*-value > 0.05; ns = non-significant, *p*-value > 0.05

Table 4 Effects of spacing on stem quality

Variable	Spacing (m)			*F*-value
	2 × 2	3 × 3	4 × 4	
Stem quality	1.41 ± 0.01[b]	1.51 ± 0.05[ab]	1.59 ± 0.08[a]	7.93*

Note: within the same row, mean ± standard deviation followed by the same letter are not significantly different, *p*-value > 0.05; different letters indicate significant differences, *p*-value < 0.05); * = significant, *p*-value < 0.05

reported in a study conducted at 14 years of age (Zahabu et al., 2015)**.**

Stem quality Spacing had a significant effect on the stem quality ($F = 7.93$; p-value < 0.05) of *T. grandis* at 24 years of age (Table 4). The spacing of 2 m × 2 m differed significantly from that of 4 m × 4 m. There were no significant differences in other spacings. Based on the scoring point scale used (i.e., 1–4), the lower the score, the higher is the stem quality. The spacing of 2 m × 2 m had the lowest mean score of 1.41, followed by 3 m × 3 m spacing with a mean of 1.51, and the highest mean score was observed at a spacing of 4 m× 4 m. This implies that most of the trees with higher stem quality were at a spacing of 2 m × 2 m, which did not differ signifi-cantly from the spacing of 3 m × 3 m. In contrast, most trees with lower stem quality were observed at a spacing of 4 m × 4 m, which also did not differ from the spacing of 3 m × 3 m. The results revealed a significant decrease in the mean stem quality score with an increase in spacing. Similar results were reported by Adegbehin (1982), as cited in Pérez and Kanninen (2005), who reported a decrease in stem quality with an increase in spacing in a spacing trial for teak in Nigeria.

Conclusion

The results of a *T. grandis* spacing trial at the age of 24 years, four years after end of rotation showed that dbh and height growth increased nonsignificantly with increasing spacing, even though the spacing of 2 m × 2 m had a slightly higher value than 3 m × 3 m for both dbh and height. Moreover, the basal area, volume, and MAI also increased nonsignificantly with increasing spacing. In addition, the results revealed a higher value of basal area, volume, and MAI at a spacing of 3 m × 3 m compared to the other two spacings studied. This means that based on growth and yield, the spacing of 3 m × 3 m, although had relatively lower growth in dbh and height, produced a higher volume per hectare than the closer spacing (2 m × 2 m) and wider spacing (4 m × 4 m). In addition, a spacing of 3 m × 3 m had the highest MAI. In contrast, spacing significantly affected stem quality at 2 m × 2 m and 4 m × 4 m, and stem quality tended to decrease with increasing spacing. This implies that a higher percentage of trees with good stem quality is more likely to be found in stands with closer spacing.

Recommendation

Generally, since teak plantations in Tanzania are aimed at sawlog production, it is recommended to continue practising a spacing of 3 m × 3 m, which will ensure a higher MAI with a higher volume at the stand level. Also, the spacing of 3 × 3 m will ensure a higher percentage of trees with good stem quality.

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