Pesquisa Florestal Brasileira
http://pfb.sede.embrapa.br/pfb/

e-ISSN: 1983-2605

Scientific Notes

First thinning intensity on growth and yield of *Khaya grandifoliola*

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Index terms:
African mahogany
Forest management
Wood production

Termos para indexação:
Mogno-africano
Manejo florestal
Produção de madeira

Received on 7 April 2026
Technical approval on 2 September 2026
Final approval on 10 November 2026
Published on 18 November 2026

Abstract - The study evaluated the impact of varying thinning intensities on the growth and timber yield of African mahogany (*Khaya grandifoliola*) trees. The experiment was conducted in a 10-year-old stand using a no-thinning control alongside thinning treatments removing 22%, 45%, and 63% of the initial tree density. During the first thinning cycle, diameter at breast height and total height were measured, and basal area and wood volume were estimated. Growth of the remaining trees did not improve under the no-thinning treatment control, whereas all thinning treatments stimulated growth.

Intensidades do primeiro desbaste no crescimento e no rendimento de *Khaya grandifoliola*

Resumo - O estudo avaliou o impacto de diferentes intensidades de desbaste no crescimento e no rendimento madeireiro em árvores de mogno-africano (*Khaya grandifoliola*). O experimento foi realizado em um povoamento de 10 anos de idade, comparando-se uma testemunha (sem desbaste) com tratamentos com desbaste que removeram 22%, 45% e 63% da densidade inicial de árvores. Durante o primeiro ciclo de desbaste, foram medidos o diâmetro à altura do peito e a altura total, enquanto a área basal e o volume de madeira foram estimados. O crescimento das árvores remanescentes não apresentou melhorias na testemunha, enquanto tratamentos com desbaste estimularam o crescimento.

African mahoganies are valuable tropical hardwood species of high economic importance to African countries. They belong to the genera *Khaya*, *Entandrophragma,* and others. However, there is a lack of interest in the intensive silviculture of these species in their center of origin due to long rotation periods and pest incidence (Opuni-Frimpong et al., 2016). In Brazil, alongside its economic value in international market, *Khaya* is an exotic genus that may exhibit a degree of resistance to shoot borer attacks, making it an attractive alternative to the native *Swietenia macrophylla* King (Falesi & Baena, 1999).

Currently, over 60,000 ha are planted with *Khaya* spp. in Brazil (Frank, 2023), following a significant expansion in African mahogany plantations during the first two decades of the 2000s. As these stands reach approximately 15 years of age, many have been managed based on empirical knowledge derived from other species. Therefore, there are still many research gaps that must be explored to assure the success of African mahogany plantations in Brazil, such as studies on the response to thinning practices (Ferraz Filho et al., 2021).

Thinning reduces stand density, providing space for crown and root expansion, which consequently enhances stem wood growth. By mitigating competition for light, water, and nutrients, which otherwise restricts tree development, thinning concentrates site

https://doi.org/10.4336/2026.pfb.46e202602401

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resources on the remaining trees. Additionally, early thinned timber can be commercialized for fuelwood or charcoal production, generating early financial returns for growers (Opuni-Frimpong et al., 2016).

There are few studies on thinning in *Khaya* spp. in Brazil (Ribeiro et al., 2018, 2026; Costa, 2022; Silva et al., 2023; Fonseca et al., 2025). Despite these previous efforts, the present study is unique in using an experimental design evaluated continuously from its setup (prior to the first thinning) until growth analyses indicated the need for a second thinning. Therefore, tree growth and wood production were evaluated under different thinning regimes to assess their influence on the stand development and yield.

The study was conducted in the municipality of Cachoeira Alta, Goiás State, Brazil (18º28'53''S and 51º08'19''W). According to the Köppen classification, the climate is Tropical savanna with a dry winter (Aw), with an average annual temperature of 22.7 ºC and average annual precipitation of 1,692 mm (Alvares et al., 2013). The soil at the study site is classified as a Red Latosol.

The experiment was established in a 10-year-old commercial stand of *Khaya grandifoliola* planted at a spacing of 5 m x 5 m. A randomized complete block design was used, comprising four treatments and four blocks. Over the 10-year period preceding the experiment, cumulative mortality and self-thinning reached 17%. Consequently, the treatments consisted of varying thinning intensities: removal of 22%, 45%, and 63% of the remaining trees, alongside an unthinned control (which experienced only 17% natural mortality). The plots had a single-tree border and plot sizes varied according to treatment: 800; 1,000; 1,600, and 2,800 m² for the unthinned control, 22%, 45%, and 63% thinning treatments, respectively. The reason for using different plot sizes across treatments was to maintain a similar number of trees at the end of the experiment. For the treatment application, smaller, broken, and crooked trees were removed. When selecting trees for removal, care was taken to avoid canopy gaps and to achieve as uniform a spatial distribution as possible among the remaining trees.

All trees within the experiment were measured for diameter at breast height (DBH, 1.30 m above ground level) using a diameter tape. Basal area (BA) was calculated from DBH. Total height (H) was measured on five sample trees per diameter classes (across five classes), using a TruPulse® hypsometer. The H/DBH ratio was calculated as H divided by DBH. Tree mortality was expressed as the percentage of dead trees relative to the total number originally planted per plot. Measurements were conducted in 2019 (one year prior to the first thinning), 2022, 2024, and 2025 (preceding the anticipated second thinning). To estimate missing heights, hypsometric relationships were evaluated annually using linear, quadratic, and Prodan models. The top-performing model was further tested with and without the intercept (β_0), and the model demonstrating the best statistical fit was selected for final height predictions.

Individual tree volume was obtained via destructive sampling in 2023, midway through the thinning evaluation period. Three trees in each of the five diameter classes were felled adjacent to the experiment area. Stem diameters were measured at 0.1, 0.7, 1.3 m, and at 1.5 m intervals thereafter up to a top diameter of 3 cm. Individual volume was obtained using the Smalian method, considering the volume with bark for the trunk and branches. Through this method, sawmill volume (Vs - between the cutting height of 10 cm and a diameter of 20 cm), fuelwood volume (Vf - between diameters of 20 cm and 3 cm) and commercial volume (Vc = Vs + Vf) were obtained. To fit volumetric equations for each volume component, linear, quadratic, Kopezky-Gehrhardt, and Meyer models were tested (Finger, 1992). The candidate models with the highest goodness-of-fit were subsequently evaluated with and without the intercept (β_0).

Total height and individual stem volumes were estimated using the fitted models. Stand volume per hectare was calculated by summing individual tree volumes within each plot and scaling the values to a one-hectare basis.

SAS® Studio software was used for fitting hypsometric and volumetric models and for statistical analysis. Statistical analysis was performed considering a randomized blocks design with repeated measures, with four thinning treatments (unthinned control and removal of 22%, 45%, and 63% of trees), four replications (blocks), and three repeated measures (3 years after thinning: 2022, 2024 and 2025).

The variables analyzed were DBH, H, BA, Vs, Vf, and Vc throughout the first thinning period. Normality of residuals and homogeneity of variances were tested using the Shapiro-Wilk and Bartlett tests, respectively. When these assumptions were not met, the Box-Cox transformation was applied. Statistical analyses included the three years measured after the thinning, since these years reflected the treatment effects. A repeated-measures MANOVA was

performed, in which the response variable across the three measurement periods was adjusted for thinning treatments and block effects. The Hotelling-Lawley trace test was used to assess overall significance. For variables showing significant effects, linear and quadratic models were used to adjust the thinning treatments at different years. The best fit was evaluated through the coefficient of determination (R^2). All statistical tests were conducted at the level of 5% probability.

Mean annual increment (MAI) was evaluated for Vs, Vf, and Vc under each thinning treatment. Periodic annual increment (PAI) was also calculated for the same variables. Because the intervals between measurements were only one to two years and tree growth did not vary substantially during these periods, PAI was considered equivalent, or very close, to the current annual increment (CAI). Thus, the relationship between MAI and PAI, rather than the conventional MAI-CAI comparison, was used to determine whether an additional thinning intervention would be required.

Increase of DBH, H, and BA showed significant main effects of year and thinning ($p<0.01$), but no for year x thinning interaction ($p>0.05$).

DBH increased over the years by 0.87 cm year^{-1} and by about 0.90 cm per 10% increment of thinning (Figure 1). Considering only the trees remaining from the beginning to the end of the experiment, DBH increased 4.5 cm or 18% in the unthinned control and 7.0 cm or 26% for the treatment with the greatest thinning intensity.

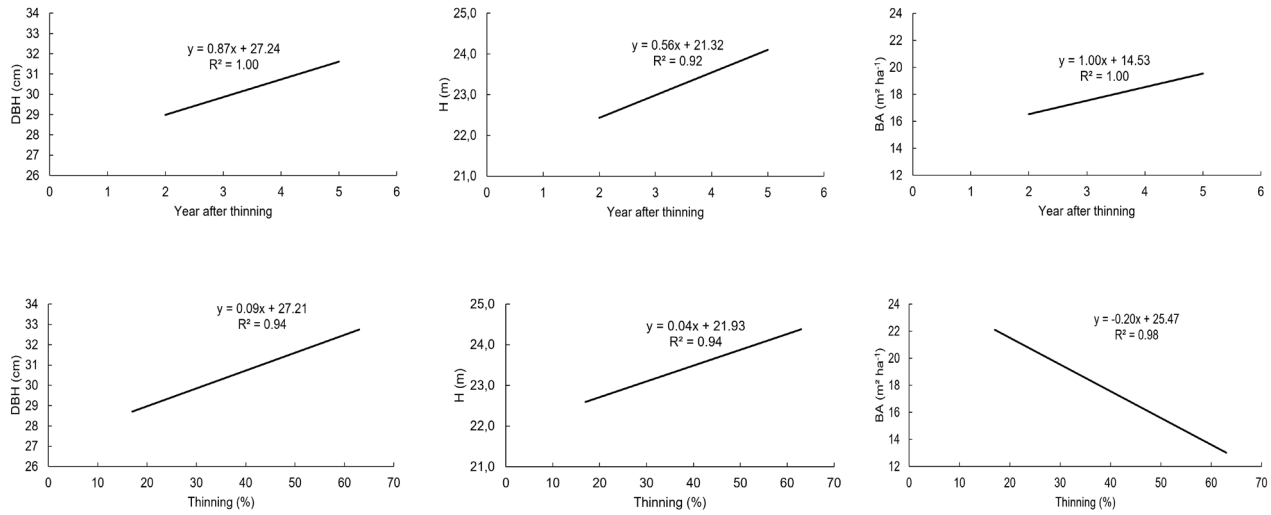


Figure 1. Increases in diameter at breast height (DBH), height (H), and basal area (BA) across years after thinning and thinning treatments.

The increase in DBH with age was expected because annual growth layers are continuously added over previously formed wood, as reported by Silva & Barreira (2023). Increasing thinning intensity leads to greater gains in DBH. This occurs because reducing stand density minimizes competition among trees for growing space, sunlight, and soil resources. As a result, individual trees have improved conditions for growth, allowing them to allocate more resources toward increasing their diameter rather than competing for light (Deng et al., 2019).

The decision on the thinning intensity to be implemented will depend on the established objective, such as target minimum diameter, volume, and economic yield (Resquin et al., 2024). For example, following the same curve patterns observed in the present study, trees with an estimated DBH of 40 cm at 20 years of age are only achievable under the most intensive thinning treatment, which removes 63% of the remaining trees. In contrast, lighter thinning treatments do not allow trees to reach the target minimum DBH of 40 cm within this timeframe.

There was an increase in H over the years and with increasing in thinning intensity (Figure 1). When considering only the trees remaining from the beginning to the end of the experiment, tree height in the unthinned control increased by 2.2 m (10%), compared to an increase of up to 3.4 m (14%) in the highest thinning intensity.

Height increase was expected as a function of time after thinning, since the stand was at an intermediate age, as observed by Silva & Barreira (2023). Height increase with increased thinning is consistent with the growth curves modeled by Ribeiro et al. (2018); however, Silva & Barreira (2023) found greater H value for intermediate spacing.

As expected, there was an increase in BA over the years and a decrease in BA with increasing thinning intensity (Figure 1). These findings indicate that implementing a 50% thinning from below results in a residual BA of 68%, reflecting the presence of numerous individuals with smaller DBH, whose contribution to the overall BA is minimal.

When considering only the trees remaining from the beginning to the end of the trial, BA increased 6.7 $m^2 ha^{-1}$ or 41% in the unthinned control and reached 5.2 m^2 ha^{-1} or 59% in the highest thinning intensity. Thus, BA growth in absolute values was greater in the unthinned treatments, but it was distributed in about 330 trees ha^{-1} instead of about 150 trees ha^{-1} in the most intensive thinning treatment. The trees in the highest thinning intensity made better use of the resulting environmental conditions to increase the BA, by approximately 50%. These factors caused the DBH at the end of the experiment to be 29.4 cm for the treatment without thinning and 34.8 cm for the treatment with the greatest thinning intensity, a gain of 5.4 cm or 18%. This behavior of concentrating growth in a smaller number of trees results in high-value logs, which is characteristic of intensive thinning systems, where growth of individual trees is increased, to the detriment of their number (Ferraz Filho et al., 2015).

The H/DBH ratio, as a function of thinning intensity, showed that the increased thinning resulted in lower relative allocation to height growth compared to the unthinned stand ($p<0.01$). At the time of thinning, the remaining trees had an H/DBH ratio close to 0.80, whereas the thinned trees, which belonged to lower DBH classes and were competing for space and light, exhibited an H/DBH ratio close to 1.00. This response is typical of heliophilous species, such as *Pinus massoniana*, which allocate growth preferentially to height at the expense of diameter increment when competing for light (Deng et al., 2019).

The wood volumes over bark (Vf, Vs, and Vc) did not show year x thinning interaction ($p>0.05$), but showed a statistically significant difference for year ($p<0.01$) and for thinning, where there was a statistically significant difference for Vs ($p<0.01$) and Vc ($p<0.05$), but not for Vf ($p>0.05$). There was an increase in Vf, Vs and Vc over the years, and there was a decrease in Vs and Vc with a thinning increase (Figure 2).

The decrease in Vc was 10% and in Vs was 18% for a thinning range of 46%, reflected in a low slope of the line. Although not of the same magnitude, such decreases in volumetric production were also estimated by Ribeiro et al. (2018) and Silva et al. (2023). By adopting as acceptable a decrease in volumetric production of 5%, a value assumed as a deviation or change statistically detectable when considering the expected average error for volume estimates (Skovsgaard & Vanclay, 2008), it is obtained that for Vs the appropriate thinning intensity would be 30% and for Vc it would be 40%.

When only the trees present from the beginning to the end of the experiment are considered, there is a large increase in the individual volume of sawmill wood, while there is little volume growth firewood (Table 1). A similar pattern is observed in wood production per hectare (data not shown).

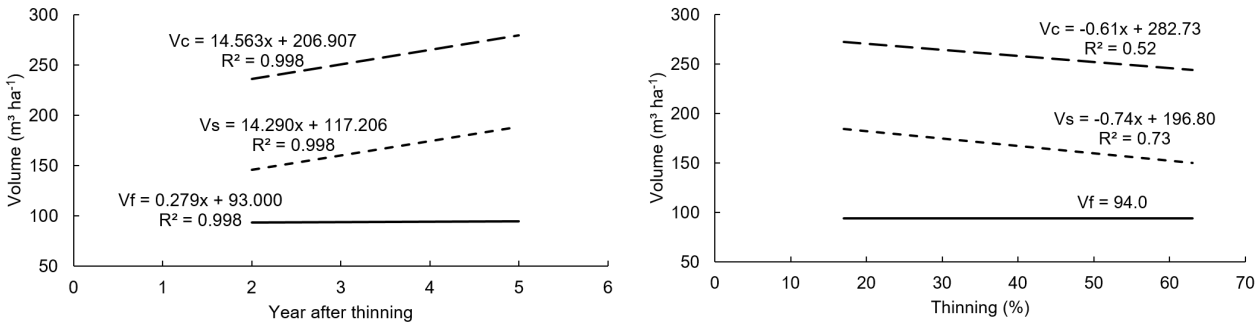
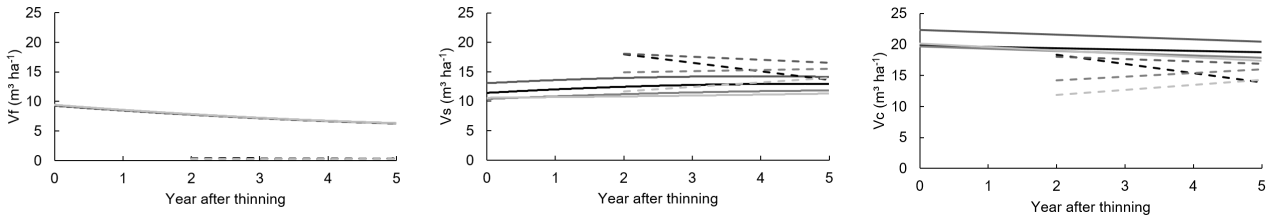


Figure 2. Models for wood volumes over bark as a function of years after thinning and thinning intensity.

Table 1. Firewood, sawmill, and commercial volumes for individual trees at the beginning and end of the *Khaya grandifoliola* first thinning experiment.

Purpose	Thinning (%)	Wood volume (m^3 $tree^{-1}$)		Increase (%)
		Beginning	End	
Firewood	17	0.256	0.263	2%
	63	0.252	0.270	7%
Sawmill	17	0.296	0.598	102%
	63	0.471	0.986	110%
Commercial	17	0.552	0.860	56%
	63	0.731	1.256	72%

The MAI showed an average coefficient of variation of less than 1% for Vf, 10% for Vs, and 7% for Vc. The PAI had the greatest variation, reaching 17% for Vf, 16% for Vs, and 16% for Vc. Regardless of the magnitude of the coefficient of variation, the MAI and PAI curves for Vf and Vc show a similar pattern across treatments, indicating that a clearcutting is already overdue (Figure 3). However, when the objective is sawmill production (Vs), treatment responses vary. For the unthinned treatment, year 5 indicates the need for a new intervention – thinning or clearcut; for the 22% thinning treatment, a few additional years are required before another intervention; for the 45% treatment, the period is undefined because the curves remain parallel; and for the 63% treatment, the curves diverge, indicating that the next cut will take place over a range of years. Such responses were also noted in the final harvest by Resquin et al. (2024), where for less intensive thinning denoted a fully stocked stand, more intensive thinning enabled free growth, and intermediates regimes represented increasing competition.



MAI17 (—); MAI22 (—); MAI45 (—); MAI63 (—); PAI17(– –); PAI 22 (– –); PAI45 (– –); PAI63 (– –)

Figure 3. Mean annual increment (MAI) and periodic annual increment (PAI) curves for firewood (Vf), sawmill (Vs), and commercial (Vc) volumes in thinning regimes across different years after thinning.

The intermediate thinning treatments for the MAI and PAI curves of Vs showed responses similar to the conclusions of Silva et al. (2023) and Fonseca et al. (2025), especially under periods of high market rates of return such as the current situation in Brazil. Silva et al. (2023) concluded that a 20% thinning at 9 years of age and a clearcut at 15 years old was more feasible to a 14% rate of return. For Fonseca et al. (2025), thinning by 50% at 12 years and a clearcutting at 20 years was the most cost-effective option.

Conclusions

Thinning intensity significantly affected growth and wood production of *Khaya grandifoliola* after the first thinning cycle. Higher thinning intensities promoted greater individual increments in diameter and height, resulting in trees with greater potential for producing high-value logs, although with a reduction in total wood volume per hectare. Intermediate thinning intensities (22-45%) proved to be technically balanced, promoting individual tree growth while maintaining volumetric productivity. Over the 5-year analysis period, the 22% thinning treatment was the only one to reach the MAI-PAI intersection for sawmill wood, indicating its readiness for the next silvicultural intervention.

Acknowledgments and funding sources

The authors received financial support from “Mais Verde Madeiras” to conduct this research, which was essential for setting up the experiment, collecting data, and maintaining the trial.

Conflict of interest

The authors have no conflict of interest to declare.

Author contributions

Robson Schaff Corrêa: Conceptualization, Investigation, Methodology, Supervision, Writing - original draft, Writing - review & editing. **Daniela Cursino Romão**: Investigation, Supervision. **Wendy Carniello Ferreira**: Writing - original draft, Writing - review & editing.

Declaration of use of AI technologies

During the preparation of this work, the author(s) used Copilot, a tool included in Microsoft Word, to help improve the translation into English. This tool was used in certain sections of the manuscript. After using this tool/service, the authors reviewed and edited the content as necessary and assume full responsibility for the content of the submitted manuscript.

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