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Enrichment planting with *Fokienia hodginsii* and *Cinnamomum obtusifolium* for forest recovery in Northern Vietnam

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Abstract. *Minh NT, Thang NT, Duc DT, Bon TN, Khoi TT, Hoang NH, Tuan NV, Dung PT, Thanh HV, Trinh DC, Phuong NTT, Do TV. 2026. Enrichment planting with* Fokienia hodginsii *and* Cinnamomum obtusifolium *for forest recovery in Northern Vietnam. Asian J For 10 (1): r100104. https://doi.org/10.13057/asianjfor/r100104.* This study evaluated the survival, growth, and stem quality of *Fokienia hodginsii* and *Cinnamomum obtusifolium* in enrichment planting for forest recovery. The study was conducted in Lao Cai Province, Vietnam, where *F. hodginsii* and *C. obtusifolium* were planted using the line planting technique under forest canopy conditions. Three 1,000 m² plots were established, and survival rates, growth parameters, and stem quality were assessed over four years. Results indicated high survival rates of 90.32% for *F. hodginsii* and 92.47% for *C. obtusifolium*, with no significant difference between species (p>0.05). Both species exhibited over 82% good-quality stems. While *F. hodginsii* showed slightly higher diameter growth ($D_{1.3}$=2.03±0.28 cm vs. 1.88±0.15 cm) and greater height (H=2.88±0.22 m vs. 2.49±0.20 m), though these differences were not statistically significant (p>0.05). Linear correlations among growth parameters were significant for both species (p<0.005, R^2=0.42-0.77), demonstrated predictable growth patterns, with both species adapting well to the site's environmental conditions. These findings confirm the ecological compatibility and economic viability of using *F. hodginsii* and *C. obtusifolium* in enrichment planting programs. This study provides insights into optimizing restoration strategies and highlights the potential of these species to support sustainable forest management and ecological recovery in degraded tropical landscapes.

Keywords: *Cinnamomum obtusifolium*, degraded forest restoration, *Fokienia hodginsii*, growth performance, native tree species

INTRODUCTION

Enrichment planting has gained prominence as an effective silvicultural practice for the restoration of degraded forests worldwide, particularly in tropical regions where deforestation and forest degradation are pervasive challenges. This technique involves the deliberate introduction of valuable tree species into secondary or degraded forests to enhance biodiversity, improve forest structure, and expedite ecological recovery (Lamb et al. 2005). In tropical Asia, enrichment planting has been implemented extensively to rehabilitate forests and improve their economic value through the introduction of high-value timber species (Appanah and Weinland 1993). Studies have demonstrated that enrichment planting can significantly accelerate the recovery of forest biomass and complexity compared to natural regeneration alone (Robin and Manuel 2016). Moreover, this practice contributes to the restoration of ecosystem services, including carbon sequestration, soil conservation, and habitat provision for wildlife (Chazdon 2008). Despite its benefits, the success of enrichment planting is influenced by factors such as species selection, site conditions, and management practices, necessitating research to optimize its implementation in different ecological contexts (Finegan and Nasi 2004; Borawake et al. 2021).

Fokienia hodginsii, a valuable conifer species native to Southeast Asia, has been the subject of studies exploring its potential in enrichment planting programs. Belonging to the family Cupressaceae, *F. hodginsii* is valued for its durable timber and aromatic wood, which have led to overexploitation and a decline in natural populations. Research has investigated the growth performance and survival rates of *F. hodginsii* in enrichment planting trials, indicating that this species can successfully establish in degraded forest sites when appropriate silvicultural techniques are employed (Li et al. 2024). Studies on related genera within the Cupressaceae family, such as *Calocedrus* and *Chamaecyparis*, have also demonstrated the feasibility of using these conifers in restoration efforts due to their adaptability and ecological importance (Enright and Hill 1995; Zhang et al. 2012). Recent studies have further confirmed the climate sensitivity and growth potential of *F. hodginsii* in mountainous regions of Southeast Asia. These findings suggest that enrichment planting with *F. hodginsii* and related species holds promise for enhancing forest recovery while providing economic benefits through timber production.

Similarly, *Cinnamomum obtusifolium*, a species in the Lauraceae family, has attracted attention for its potential role in enrichment planting initiatives. *Cinnamomum obtusifolium* is known for its medicinal properties and valuable wood, making it an economically significant species in Vietnam and other parts of Southeast Asia (Le et al. 2012). Research has highlighted its adaptability to varied environmental conditions and its ability to thrive in partially shaded environments, which is advantageous for underplanting in degraded forests (Hung et al. 2010). Studies on other *Cinnamomum* species, such as *C. camphora* and *C. tamala*, have shown that members of this genus can enhance soil fertility and support biodiversity by providing habitat and food sources for wildlife (Hoang et al. 2018; Rawat et al. 2023). The incorporation of *Cinnamomum* species in enrichment planting programs can thus contribute to both ecological restoration and the livelihoods of local communities through the provision of non-timber forest products.

The importance of enrichment planting in tropical forest recovery cannot be overstated, as it offers a strategic approach to restore degraded ecosystems, enhance biodiversity, and mitigate climate change impacts (Gaisberger et al. 2022). By selecting appropriate species such as *F. hodginsii* and *C. obtusifolium*, enrichment planting can accelerate forest succession, improve structural complexity, and restore ecosystem functions more effectively than passive restoration methods (Holl and Aide 2011). Furthermore, this practice supports the sustainable use of forest resources, balancing ecological integrity with economic needs (Parrotta and Knowles 2001). Recent advances in adaptive management approaches have demonstrated the importance of species-specific silvicultural strategies in maximizing restoration success (Jamie et al. 2011; Noel et al. 2023).

Despite the documented potential of both species, limited information exists on their comparative performance under enrichment planting conditions in Vietnam's northern provinces. Understanding species-specific growth dynamics, survival rates, and stem quality under field conditions is essential for optimizing species selection and management practices in forest restoration programs. Moreover, quantitative data on growth allometry and predictable growth relationships are critical for developing evidence-based silvicultural guidelines. Considering the pressing need for effective restoration strategies in the tropical forests of Vietnam's northern provinces, this study aimed to: (i) evaluate the survival rates and stem quality of *F. hodginsii* and *C. obtusifolium* four years after enrichment planting, (ii) compare growth parameters between the two species, and (iii) assess the relationships among key growth variables to inform future silvicultural practices.

MATERIALS AND METHODS

Study area

The experiment was conducted in Lao Cai Province, Northeastern Vietnam, located at 21°29’26’’N and 104°21’56’’E at an elevation of 812 meters above sea level. The study site is characterized by an evergreen broadleaved forest dominated by species such as *Betula alnoides*, *Schima wallichii*, *Cinnadenia paniculata*, *Euodia meliaefolia*, *Lithocarpus ducampii*, *Syzygium wightianum*, and *Lithocarpus dealbatus*. Although *F. hodginsii* and *C. obtusifolium* naturally occur in the area, they are not dominant species. The forest stand has a density of 300-350 stems per hectare, a canopy height of 12-13 meters, an average stem diameter of 20-25 cm, and a canopy cover of 0.4. The soil is thick, well-drained, and rich in humus content.

The region experiences a humid subtropical climate with distinct seasonal patterns. The annual average temperature ranges from 18°C to 22°C, with cooler conditions prevailing at higher altitudes. Annual precipitation averages 1,800-2,000 mm, primarily concentrated during the rainy season (May to October), which is marked by high humidity and heavy rainfall. The dry season (November to April) is characterized by lower humidity, occasional cold spells, and winter temperatures dropping below 15°C in some areas. These climatic conditions support diverse ecosystems but pose challenges to plants during extreme weather events.

In 2020, *F. hodginsii* and *C. obtusifolium* were planted under the forest canopy as part of an enrichment silviculture practice in an area of 2 ha. A planting line technique was employed, involving 2-meter-wide lines cleared of vegetation under 1 meter in height before planting. The distance between planting lines was 5 meters. Within each line, *F. hodginsii* and *C. obtusifolium* were mixed-planted in a 1:1 ratio, with 3 meters between individual trees. Seedlings were approximately 30-40 cm in height and stump diameter of 0.2-0.3 cm at the time of planting, sourced from the local nursery. Planting holes measuring 40×40×40 cm were prepared, and 150 g of NPK (16:16:8) fertilizer was applied per hole 15 days before planting.

Planting was carried out during the rainy season, with replanting of dead seedlings conducted one month after the initial planting. Tending activities, including weeding, soil mounding, and vine cutting, were performed twice annually in 2021, 2022, and 2023.

Methods

Four years after planting (2024), at the experimental site, three plots, each measuring 1,000 m² (25×40 m), were randomly established for data collection across the study site to capture spatial variability in stand conditions. Plots were located at least 150 m apart to ensure spatial independence. Within each plot, all surviving stems of *F. hodginsii* (Figure 1.A) and *C. obtusifolium* (Figure 1.B) were measured for diameter at breast height ($D_{1.3}$ in cm), total height (H in m), height under crown (H_{uc} in m), and crown diameter (D_t in m). Diameter was measured using a digital caliper to the nearest 0.01 cm, while heights were measured using a measuring pole to the nearest 0.1 m. Crown diameter was calculated as the average of two perpendicular measurements of the crown. Dead stems were recorded to estimate survival rates.

Figure 1. Four-year-old of *F. hodginsii* (A) and *C. obtusifolium* (B)

Each surviving stem was classified into one of three quality categories: good, medium, or poor. Good stems (Ruano et al. 2023; Nocetti and Brunetti 2024) were defined as those with straight bole (deviation <10° from vertical measured at 1.3 m height using a clinometer), symmetrical crown (assessed visually as balanced distribution in at least 3 cardinal directions), no visible disease symptoms (absence of cankers, necrotic lesions, or fruiting bodies), and no major physical damage (no broken leaders or stems with wounds). Poor stems exhibited severe bole curvature (>20° deviation), asymmetrical or poorly developed crown, visible disease symptoms, or major physical damage. Medium stems showed intermediate characteristics between good and poor categories.

Data analysis

Survival rates were calculated as the percentage of living stems relative to the initial number of planted seedlings in each plot. Means and standard errors were calculated for all growth parameters for both species using data from all measured individuals. Independent samples *t*-tests were used to evaluate statistically significant differences in growth parameters between species when data met assumptions of normality (Shapiro-Wilk test, $p>0.05$) and homogeneity of variance (Levene's test, $p>0.05$). Welch's *t*-test was applied when variances were unequal ($p<0.05$ in Levene's test). Mann-Whitney U test was used for data that violated normality assumptions ($p<0.05$ in Shapiro-Wilk test), specifically for survival rate, stem quality rate, and crown diameter.

Linear regression analysis was performed to assess the relationships between stem diameter and stem height, stem diameter and crown diameter, and total height and height under the crown, separately for each species. Regression models were evaluated based on coefficient of determination (R^2), F-statistics, and *p*-values. All statistical analyses were conducted using SAS 9.2 (SAS Institute Inc., Cary, NC, USA), with a significance level set at $p=0.05$.

RESULTS AND DISCUSSION

Four years after planting, both species exhibited high survival rates, with *F. hodginsii* achieving 90.32% and *C. obtusifolium* achieving 92.47% (Figure 2). The difference in survival rates between species was not statistically significant (Mann-Whitney U test; U=6, $p=0.513$; n=3). Additionally, both species demonstrated a high proportion of good-quality stems, with *F. hodginsii* at 82.80% and *C. obtusifolium* at 86.02%. The good stem quality did not differ significantly between species (Mann-Whitney U test; U=4, $p=0.827$; n=3).

The growth parameters of both species after four years of planting are presented in Table 1. The height under the crown (H_{uc}) and crown diameter (D_t) of *F. hodginsii* were slightly lower than those of *C. obtusifolium*, whereas the diameter at breast height ($D_{1.3}$) and total height (H) of *F. hodginsii* were slightly higher. However, statistical comparisons revealed that the differences in these four parameters between the two species were not statistically significant (Table 1; $p>0.05$ for all parameters).

After four years, *F. hodginsii* attained a height of 2.88 m and a diameter at breast height of 2.03 cm, compared to 2.49 m and 1.88 cm, respectively, for *C. obtusifolium*. The height under the crown remained relatively short, measuring 0.72 m for *F. hodginsii* and 0.77 m for *C. obtusifolium*. Both species exhibited crown diameters of less than 0.9 m.

Significant linear regression relationships were observed between growth parameters for both species, with *p* values less than 0.005 (Figures 3 and 4). Linear models provided the best fit for all relationships, indicating that an increase in one parameter corresponds to increases in the others. However, the slopes of the linear models differed substantially between the two species.

The regression values for *C. obtusifolium* (Figure 4) were generally higher than those for *F. hodginsii* (Figure 3). The strongest regression was observed between stem diameter and crown diameter in *C. obtusifolium* ($R^2=0.77$, F=59.32, p<0.001; n=20), while the weakest regression was found between total height and height under the crown in *F. hodginsii* (R^2=0.42, F=11.03, p<0.005, n=17). All regression models met the assumptions of linearity, independence, homoscedasticity, and normality of residuals based on diagnostic plot inspection.

Discussion

Species performance in enrichment planting

The high survival rates observed for both *F. hodginsii* (90.32%; Figure 2) and *C. obtusifolium* (92.47%) demonstrate the ecological suitability of these species for enrichment planting under the environmental conditions of the study site. These results are consistent with previous studies in tropical Asia reporting survival rates exceeding 85% for enrichment planting programs utilizing native species (Robin and Manuel 2016; Horacio and Sebastian 2023; Li et al. 2023a), suggesting that both species possess physiological adaptations enabling establishment under partially shaded forest understory conditions. *Fokienia hodginsii*, a conifer endemic to Southeast Asia, is valued for its durable timber and aromatic wood, making it economically significant but also prone to overexploitation (Thanh et al. 2017). The species' tolerance to shade during juvenile stages likely contributed to its successful establishment in this study. Similarly, *C. obtusifolium* exhibits a remarkable ability to thrive in shaded environments, thus supporting its application in underplanting strategies (Hung et al. 2010). The slightly higher survival rate of *C. obtusifolium* compared to *F. hodginsii*, although not statistically significant, may reflect its greater phenotypic plasticity in response to variable light conditions typical of forest gaps and understory environments.

The uniformity in stem quality between species, with over 82% (Figure 2) of stems classified as good quality, indicates that the silvicultural practices employed, including proper site preparation, appropriate planting techniques, and consistent tending activities, effectively supported healthy stem development. Previous studies have emphasized that tailored silvicultural practices, particularly regarding seedling quality, planting timing, and post-planting care, are crucial for optimizing survival and growth in degraded forests (Appanah and Weinland 1993; Phan et al. 2020; Noel et al. 2023; Ruano et al. 2023; Nocetti and Brunetti 2024).

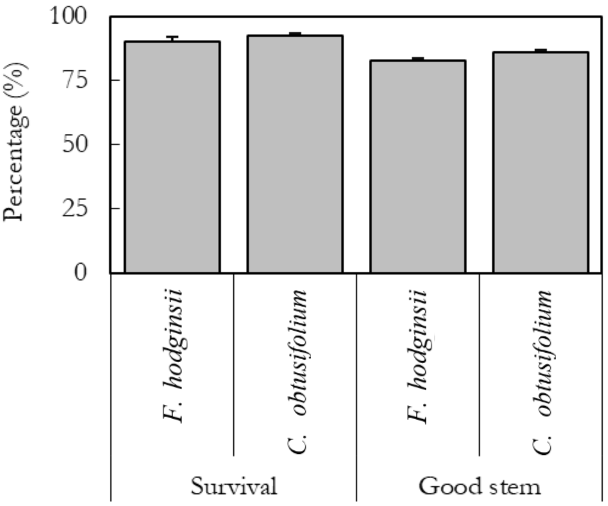

Figure 2. Survival and stem quality of two studied species at 4 years old. Bars indicate +SE (Standard Error)

Table 1. Growth parameters (mean ± SE) of *F. hodginsii* and *C. obtusifolium* four years after enrichment planting

Species	**Growth parameter (±SE)**			
	$D_{1.3}$ (cm)	**H (m)**	**H_{uc} (m)**	**D_t (m)**
F. hodginsii	2.03±0.28	2.88±0.22	0.72±0.07	0.79±0.07
C. obtusifolium	1.88±0.15	2.49±0.20	0.77±0.06	0.82±0.08

Note: $D_{1.3}$: Diameter at breast height (Welch's *t*-test, *t-value*=0.932, *p-value*=0.359, *df*=26.6), H: Total height (independent samples *t*-test, *t-value*=1.327*, p-value*=0.193, *df*=35), H_{uc}: Height under crown (independent samples *t*-test, *t-value*=-0.384*, p-value*=0.703, *df*=35), D_t: Crown diameter (Mann-Whitney U test, *U-value*=143*, p-value*=0.418), SE: Standard error

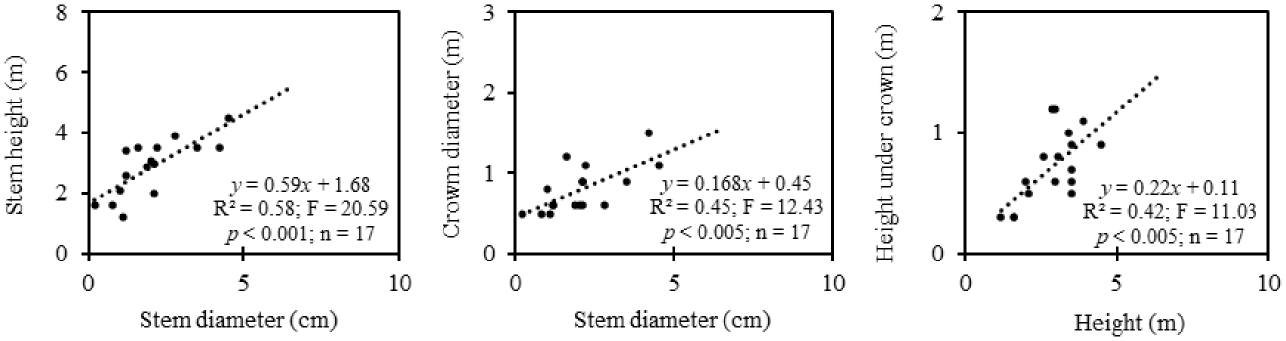

Figure 3. Relationships among growth parameters for *F. hodginsii*

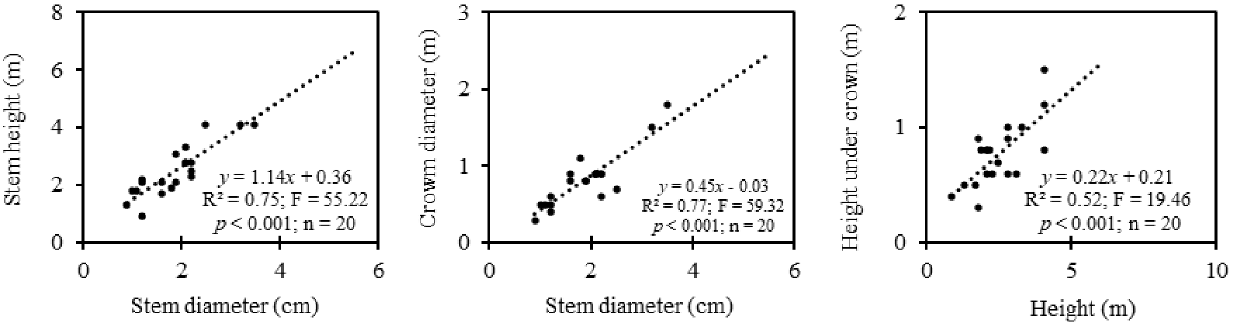

Figure 4. Relationships among growth parameters for *C. obtusifolium*

Growth dynamics and species-specific patterns

The comparative growth analysis revealed that while *F. hodginsii* demonstrated a higher diameter at breast height, *C. obtusifolium* attained slightly greater total heights (Table 1). However, the absence of statistically significant differences in growth parameters between species suggests that both exhibit comparable performance under the study site conditions. The marginally greater diameter growth in *F. hodginsii* may be attributed to its coniferous growth form, which typically allocates proportionally more resources to radial stem expansion compared to broad-leaved species (Zhang et al. 2012). Conversely, the slightly greater height attainment in *C. obtusifolium* likely reflects typical broad-leaved tree strategies of rapid vertical growth to access canopy gaps and optimize light capture (Lorien et al. 2023; Li et al. 2023b).

The strong linear relationships among growth parameters observed in this study suggest (Figures 3 and 4) that both species exhibit predictable growth patterns under managed conditions, which has important implications for forest management planning and biomass estimation. The higher R^2 values observed for *C. obtusifolium* (Figure 4; 0.52-0.77) compared to *F. hodginsii* (Figure 3; 0.42-0.58) indicate more consistent allometric relationships in the broad-leaved species. This greater allometric consistency may reflect lower phenotypic plasticity in response to microsite heterogeneity within plots, whereas the higher variability in *F. hodginsii* suggests greater sensitivity to local environmental gradients such as light availability and soil conditions. These patterns should be interpreted cautiously given the nested structure of individuals within plots and potential plot-level effects on growth trajectories. These allometric relationships can be utilized to develop species-specific growth models for predicting future stand development and timber yield in enrichment planting programs.

Canopy structure and light dynamics

The structural attributes of the canopy observed in this study provide insights into the ecological roles of the species in enrichment planting systems. The limited crown diameters of both species (Table 1; <0.9 m) after four years suggest minimal competition with the existing canopy layer, which is advantageous for maintaining overstory integrity while establishing an economically valuable understory component, a key consideration in enrichment planting (Holl and Aide 2011; Collet et al. 2020). Additionally, the short height under crown observed for both species (Table 1; <0.8 m) indicates efficient light capture in the lower canopy strata (Chazdon 2008). This low branching pattern is characteristic of shade-adapted species and facilitates photosynthetic efficiency under limited light availability (Collet et al. 2020). These attributes enhance the ecological compatibility of the species with the existing forest structure and support their potential for long-term coexistence with overstory vegetation.

Implications for ecosystem services and sustainable management

Enrichment planting not only supports forest recovery but also enhances ecosystem services. Both species contribute to carbon sequestration through biomass accumulation, thereby addressing climate change mitigation objectives (Lamb et al. 2005). Although carbon stocks were not quantified in this study, existing literature on similar tropical enrichment plantings suggests that both species have substantial potential for carbon storage as stands mature, based on their observed survival and growth rates (Lindh et al. 2024). Moreover, their roles in improving soil stability and nutrient cycling are essential for long-term forest health. Notably, *Cinnamomum* species are recognized for their positive impacts on soil fertility through leaf litter decomposition and nutrient cycling, which further enhances their ecological value in restoration efforts (Hoang et al. 2018).

Economic considerations also underscore the value of enrichment planting with these species. *Fokienia hodginsii* is a source of high-value timber, while *C. obtusifolium* provides opportunities for harvesting non-timber forest products, including medicinal extracts. These dual benefits align with sustainable forest management principles that balance ecological restoration with community livelihoods (Parrotta and Knowles 2001; Patria et al. 2023). The high survival rates (>90%) and good stem quality (>82%) observed after four years suggest promising establishment success for both species. Based on growth trajectories reported for similar native species in tropical enrichment plantings, economic returns may be achievable over rotation periods of 20-30 years, though long-term monitoring is required to validate harvest ages for these specific site conditions (Lindh et al. 2024). This study's findings advocate for the integration of such species into agroforestry systems to maximize economic returns while preserving ecological integrity (Le et al. 2012).

Study limitations and future research directions

Despite the positive outcomes, limitations of this study should be acknowledged. First, the relatively short monitoring period of four years provides information only on early establishment success and juvenile growth. Long-term monitoring extending through multiple decades is necessary to assess rotation-length productivity, timber quality at harvest, and sustained ecosystem service provision. Second, this study did not measure soil properties, light availability, or microclimate variables, which limits interpretation of the mechanisms underlying the observed growth patterns. Third, the sample size, while adequate for detecting major differences, may limit the statistical power to detect subtle variations in growth patterns between species. The results emphasize the need for adaptive management strategies tailored to local conditions, corroborating findings from previous research (Finegan and Nasi 2004; Jamie et al. 2011; dos Santos et al. 2025).

Future research should focus on addressing the limitations identified in this study. Specifically, investigations should: (i) extend monitoring duration to capture long-term growth trends, mortality patterns, and timber quality development; (ii) quantify interactions between planted species and existing forest biodiversity to assess impacts on understory plant communities, soil fauna, and wildlife habitat; (iii) measure environmental variables including light availability, soil nutrients, and microclimate to elucidate drivers of growth variation; (iv) evaluate economic performance through cost-benefit analysis incorporating establishment costs, management inputs, and projected timber values; and (v) assess the potential for integrating these species into community-based agroforestry systems. Additionally, incorporating socio-economic analyses into restoration programs will ensure that these initiatives align with community priorities and contribute to sustainable development (Chazdon 2008; Hariram et al. 2023).

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