Leaflet No.

The Republic of the Union of Myanmar
Ministry of Natural Resources and Environmental Conservation

Effects of Planting Method and Fertilizer Application on the Early Growth of *Dipterocarpus tuberculatus* (Roxb.)

Yu Ya Aye (Ph.D), Assistant Director
Khaing Wut Hmone, Staff Officer
Phyo Min Han, Staff Officer
Chaw Myat Thwe, Range Officer
Arr Marn Zaw, Range Officer
Forest Department

March, 2026

Contents

List of Figures

List of Tables

Effects of Planting Method and Fertilizer Application on the early growth of *Dipterocarpus tuberculatus (Roxb.)*

Yu Ya Aye[1*], Khaing Wut Hmone[2], Phyo Min Han[2], Chaw Myat Thwe[3], Arr Marn Zaw[3]

[1]Assistant Director, Forest Management and Silvicultural Section, Forest Research Institute
[2]Staff Officer, Forest Management and Silvicultural Section, Forest Research Institute
[3]Range Officer, Forest Management and Silvicultural Section, Forest Research Institute

Abstract

Successful plantation establishment depends on appropriate site selection, effective planting methods, and proper tending operations that enhance seedling survival and early growth, although intensive management interventions may affect long-term stand productivity. To examine the effects of planting methods and fertilization on the growth performance of *Dipterocarpus tuberculatus*, an experimental plantation was established in 2024 at two contrasting locations: within a Dipterocarpus forest area and outside the forest area. At each site, two planting methods (pit digging and direct planting) and three fertilizer applications (organic fertilizer, inorganic fertilizer, and biofertilizer) were implemented. By the end of the second growing season, trees planted using pit digging consistently exhibited greater growth than those established through direct planting. Among the fertilizer applications, organic fertilizer (cow manure) resulted in superior growth performance compared with inorganic fertilizer (NPK) and biofertilizer (EM). Additionally, height growth was significantly higher in plantations established within the Dipterocarpus forest area than in those located outside the forest area. Although this study evaluated growth responses during the first two years, continued long-term monitoring is necessary to clarify the sustained effects of site selection, planting methods, and fertilization practices on overall plantation performance.

Key words - *Dipterocarpus tuberculatus*, fertilizer application, growth performance, site selection

[*]Corresponding author: yuyaaye@gmail.com

စိုက်ပျိုးပြုစုနည်းလမ်းများ အသုံးပြုခြင်းဖြင့် အင်ပင်ကြီးထွားမှုအား လေ့လာခြင်း

ဒေါက်တာယုယအေး၊ လက်ထောက်ညွှန်ကြားရေးမှူး
ခိုင်ဝတ်မှုန်၊ ဦးစီးအရာရှိ၊ ဖြိုးမင်းဟန်၊ ဦးစီးအရာရှိ
ချောမြတ်သွယ်၊ တောအုပ်ကြီး၊ အားမန်ဇော်၊ တောအုပ်ကြီး
သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်း

သစ်ပင်စိုက်ပျိုးပြုစုသည့် နည်းလမ်းများသည် စိုက်ခင်းစတင်တည်ထောင်သည့် အချိန်တွင် စိုက်ပင်များ ရှင်သန်မှုနှင့် ကြီးထွားမှု ကောင်းမွန်စေရန်အတွက် အရေးပါသော လုပ်ငန်းများဖြစ်ပါသည်။ စိုက်ပျိုးပြုစုခြင်းလုပ်ငန်းများ ဆောင်ရွက်ခြင်းဖြင့် စိုက်ခင်းအပေါ် ရေရှည်အကျိုးသက်ရောက်မှုများကို လေ့လာရန် လိုအပ်ပါသည်။ စိုက်ပျိုးပြုစုခြင်း နည်းလမ်းများ ဆောင်ရွက်ခြင်းဖြင့် အင်သစ်မျိုးစိုက်ခင်း၏ ကြီးထွားမှုကို လေ့လာရန်အတွက် ၂၀၂၄ ခုနှစ်တွင် အင်တိုင်းတောမြေနှင့်အင်တိုင်းတောမြေ ပြင်ပနေရာတွင်တည်ထောင်စိုက်ပျိုးခဲ့ပါသည်။ စိုက်ခင်းများတွင် စိုက်ပျိုးနည်း(၂)မျိုးနှင့် မြေဩဇာ(၃)မျိုး အသုံးပြုခဲ့ပါသည်။ ၂၀၂၅ ခုနှစ်၊ ဒီဇင်ဘာလ တိုင်းတာချက်အရ ကျင်းတူးစိုက်ပျိုးသော အပင်များသည် ပုံမှန်စိုက်ပျိုးသော အပင်များထက် သစ်ပင်အမြင့် ပိုမိုကောင်းမွန်နေကြောင်း တွေ့ရှိရပါသည်။ မြေဩဇာ(၃)မျိုး စမ်းသပ်အသုံးပြုခြင်းတွင်လည်း နွားချေးမြေဩဇာ ကျွေးသော စိုက်ပင်များသည် NPK and EM fertilizer ကျွေးသော စိုက်ပင်များထက် ပိုမိုကောင်းမွန်ကြောင်း တွေ့ရှိရပါသည်။ အင်တိုင်းတောအတွင်း တည်ထောင်သောစိုက်ခင်း အပင်များသည် အင်တိုင်းတော မြေပြင်ပတွင် တည်ထောင်ခဲ့သောစိုက်ခင်း အပင်များထက် ကြီးထွားမှု ပိုမိုကောင်းမွန်နေသည်ကို တွေ့ရှိရပါသည်။ ယခုစာတမ်းသည် စိုက်ခင်း၏ ဒုတိယနှစ်တွင် တိုင်းတာတွေ့ရှိချက်များအားတင်ပြထားခြင်းဖြစ်ပါသည်။ အင်တိုင်းတောမြေနှင့် အင်တိုင်းတော မြေပြင်ပတွင် အင်သစ်မျိုးစိုက်ခင်း တည်ထောင်ခြင်း၊ စိုက်ပျိုးပြုစုနည်းများ ဆောင်ရွက်ခြင်းဖြင့်အင်ပင်များ၏ ကြီးထွားမှုအပေါ် ရေရှည်အကျိုးသက်ရောက်မှုများကို ဆက်လက် လေ့လာသွားမည်ဖြစ်ပါသည်။

Effects of Planting Method and Fertilizer Application on the early growth of *Dipterocarpus tuberculatus (Roxb.)*

1. Introduction

Forests play a crucial role in maintaining ecological balance and socio-economic stability, providing biodiversity conservation, climate regulation, water management, and livelihoods for millions, particularly in developing countries (FAO, 2020). In Southeast Asia, forests supply timber, non-timber forest products, and diverse ecosystem services. Myanmar, located within the Indo-Burma Biodiversity Hotspot, historically supported extensive tropical evergreen, dry deciduous and mountain forests, covering over half of the country's land area (Woods *et al*., 2011). Myanmar's forests have experienced substantial degradation over recent decades due to unsustainable logging, agricultural expansion, shifting cultivation, and the heavy dependence of rural communities on forest resources for subsistence and livelihoods (Bhagwat et al., 2017; Myanmar Forest Department, 2018). These drivers have contributed to a gradual decline in forest cover over recent decades. According to FAO and FD Myanmar, forest cover in Myanmar accounted for 42.92% of the total land area in 2015, declined to 42.19% in 2020, and further decreased to 42.15% in 2025 (FRA 2015, FRA 2020, FD 2025). Although the rate of decline appears moderate in term of percentage, the cumulative loss represents significant ecological, economic, and social impacts, including biodiversity loss, soil degradation, and reduced availability of forest products for local communities. These pressures have heightened the need for forest restoration and afforestation initiatives aimed at ecosystem recovery, land degradation mitigation, and carbon sequestration (Win et al., 2015).

The Forest Department Myanmar initiated the Myanmar Reforestation and Rehabilitation Programme (MRRP) with the aim of reducing deforestation, conservation of natural forest and increasing forest cover. Plantation establishment, implemented by both government and private sectors, is one of the activities of MRRP program. The program includes several plantation categories: economic plantations aimed at timber production, mangrove plantations for coastal protection and ecosystem restoration, watershed conservation plantations to protect soil and water resources, and local supply plantations designed to meet community-level demand for forest products. Although the wide range of plantation activities implemented, the ecologically and socioeconomically important native species *Dipterocarpus tuberculatus* (locally known as "Inn") has remained underrepresented in plantation establishment programs. *Dipterocarpus tuberculatus* timber is highly valued for furniture, boats, carts, railway carriages, flooring, beams, Fuelwood, and posts (Anony, 1985; Pearson et al., 1932; Rodger, 1936). Beyond its timber potential, *D. tuberculatus* provides a range of non-timber forest products (NTFPs), including resin, edible mushrooms that grow under its leaf litter, and leaves used for various domestic purposes. The dry leaves of *D. tuberculatus*, locally called "Inn phet," are widely used as roofing material in rural areas. Fresh leaves are also commonly used for wrapping traditional foods, including meat, vegetables, and flowers. Resin extracted from the tree serves as a source of income and is used for household and commercial purposes. In addition, the species contributes fuelwood and supports local food systems through associated forest products. Such multipurpose uses highlight the species role in sustaining rural livelihoods and reducing vulnerability among forest-dependent communities. Traditionally, leaves and timber were harvested from natural forests and it led to forest degradation and deforestation.

This practice increases pressure on remaining natural forests and undermines long-term sustainability. The absence of systematic plantation establishment for *D. tuberculatus* represents a missed opportunity to integrate timber production, NTFP provision, and community livelihood support within reforestation strategies. Establishing plantations of this species could contribute not only to forest cover restoration but also to diversified income generation and improved resilience of rural households. The present study is motivated to initiate the *D. tuberculatus* in plantation programme. Specifically, the study aims to establish a small-scale research plantation to evaluate appropriate silvicultural techniques. By assessing growth performance and survival under different management treatments, the research seeks to develop practical recommendations for the large-scale establishment of *D. tuberculatus* plantations.

Planting methods play a crucial role in determining plantation success. The Forest Department Myanmar currently applies pit-digging methods in watershed conservation plantations and direct planting methods in other plantation types. However, the effectiveness of these two planting methods has not been systematically evaluated for *D. tuberculatus*. Differences in soil preparation, root establishment, moisture retention, and nutrient availability may significantly influence early growth and survival rates. Therefore, a comparative evaluation of pit digging and direct planting methods is necessary to identify the most suitable technique for *D. tuberculatus* plantation establishment. In addition to planting methods, nutrient management is another critical factor affecting plantation performance. In many plantations, inorganic fertilizers particularly NPK formulations are commonly used to enhance early growth. However, the use of organic fertilizers (Effective Microorganisms-EM) and biofertilizers (cow manure) remains limited. Organic and biofertilizers can improve soil structure, enhance microbial activity, increase nutrient availability over time, and promote sustainable soil fertility management. Their potential benefits for native species plantations, including *D. tuberculatus*, have not been adequately investigated.

Accordingly, this study is designed to evaluate the effects of three fertilizer treatments, inorganic fertilizer (NPK), organic fertilizer (EM), and biofertilizer (cow manure), on the growth and survival of *D. tuberculatus* species. By comparing these treatments, the research aims to determine which fertilization approach is most effective and sustainable for plantation establishment. The findings will contribute to silvicultural guidelines that balance productivity, cost-effectiveness and environmental sustainability. This research addresses a need for reforestation activities by focusing on a native, multipurpose species that has significant ecological and socioeconomic value.

2. Objectives

This study aims to assess the influence of site, planting method, and fertilizer treatment on growth performance of *Dipterocarpus tuberculatus* (Robx.) plantations. The specific objectives are

(i) To evaluate the effect of planting methods on the survival rate and growth of *Dipterocarpus tuberculatus*

(ii) To identify the impact of different fertilizer treatments on tree growth

3. Materials and Methods

3.1. Study area

The study was conducted in Taungoo District, Site-1 (inside Dipterocarp Forest) and Site-2 (outside Dipterocarp Forest). Site-1, situated at a latitude of 19.3472° N and longitude of 96.2358 ° E. It is in a monsoon climate region with maximum temperatures of 41 °C (105 °F) and a minimum temperature is 25 °C (77 °F). Annual mean precipitation is 1778 mm, and the yearly average relative humidity 74%. The Site-2 is situated at latitude of 18.4972° N and longitude of 96.2458 ° E. It is in a monsoon climate region with maximum temperatures of

40 °C (103 °F) a minimum temperature is 25 °C (77 °F). Annual mean precipitation is 2573 mm, and the yearly average relative humidity 75%.

3.2. Methods

Dipterocarpus tuberculatus research plantation was established in 2024 at a spacing of 2.7 m × 2.7 m (9 ft × 9 ft). The two planting methods were used: Pit Digging (M1) and Direct Planting (M2). The pit-digging method, pits measuring 0.6 m × 0.6 m × 0.6 m (2 ft × 2 ft × 2 ft) were prepared.

The three fertilizer applications were applied in each planting methods: Inorganic fertilizer (N15:P15:K15) (T1), Organic fertilizer (EM_effective microorganisms) (T2), and Biofertilizer (Cow manure) (T3). The experiment was arranged in a randomized complete block design (RCBD) with three replications. Each replicate contained 30 plants, resulting in a total of 90 plants per treatment. Each planting method included 270 plants, and a total of 1,080 trees were established across both sites.

3.3. Data Collection

Biannual measurements of height will conduct to evaluate the long-term effects of site preparation and fertilizer application. In this paper, the second year's growth response of two places of under two planting methods and three fertilizer applications were analyzed. Tree growth was measured start from the first-year plantation. Every six-month, tree growth will be re-measured at the level of individual trees.

3.4. Collection of soil samples

Soil samples were systematically collected from each sampling plot at depths of 0–10 cm, 40–50 cm, and 80–90 cm prior to plantation establishment. Comprehensive soil profile descriptions and samples were also obtained from each experimental site. All samples were stored in individually labeled polyethylene bags and transported to the laboratory for subsequent physical and chemical characterization.

3.5. Statistical analysis

One-way analysis of variance (ANOVA) was used to test the different fertilizer applications. Post-hoc test was used to know the significant of one-way ANOVA. Tukey's HSD test was performed for post-hoc comparisons between treatments mean at the 95% probability level ($P<0.05$). Differences in average tree height per planting methods (pit digging and direct planting) in each trial were assessed using independent sample t-test.

4. Results

The present study was designed to investigate the long-term effects of site selections on productivity and determine any possible interactions with two planting methods and three fertilizer applications. Every six months, tree growth were measured at the level of individual trees.

4.1. Growth performance of *Dipterocarpus tuberculatus* plantation in Site 1 and Site 2

The mean height of *Dipterocarpus tuberculatus* seedlings was measured over three time points: December 2024, June2025, and December 2025 in Site-1 (inside the Dipterocarp forest) and Site-2 (outside the Dipterocarp forest) (*Figure 1*). In December 2024, trees in Site-1 had a mean height of 0.31 ± 0.003 m, which was significantly higher than the 0.27 ± 0.007 m observed in Site-2 ($p < 0.05$). By June 2025, although mean height remained slightly higher in Site-1 (0.381m ± 0.003) compared with Site-2 (0.370 m ± 0.009), the difference was not statistically significant. December 2025: Trees in Site-1 achieved a mean height of 0.53 m, significantly higher than the 0.50 m observed in Site-2 ($p < 0.05$).

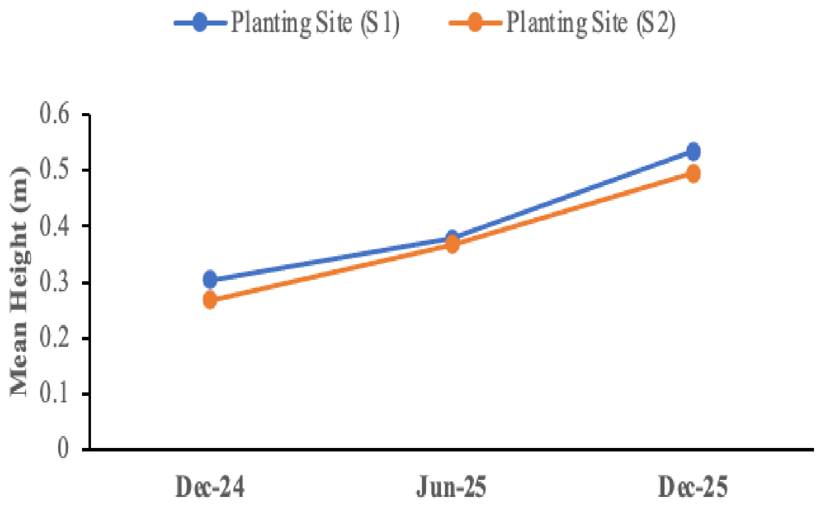

Figure 1. Growth performance of *D. tuberculatus* plantation in two Sites

The growth performance of *D. tuberculatus* tree indicates that the forest environment in Site-1 may provide slightly more favorable conditions. The higher initial mean height in December 2024 in Site-1 could be attributed to better microclimatic conditions, and potential protection from harsh external conditions typical of intact Dipterocarp Forest areas. By June 2025, seedlings in both sites showed comparable growth, suggesting that early growth rates may be influenced by factors such as planting techniques and initial care. However, by December 2025, the significant height difference in favor of Site-1 suggests that long-term growth is better supported within the forest environment, possibly due to higher moisture retention, reduced temperature extremes, and protection from wind or grazing.

Tree growth is better in Site-1 (inside the Dipterocarp Forest) compared to Site-2 (outside the forest) despite Site-1 is lower soil fertility profile (Appendix-1). Although soil properties are not much different in two sites, the better growth performance was fond in Site-1. It may be due to the autecology of Dipterocarps, which are shade-tolerant during early establishment and form obligate ectomycorrhizal associations prevalent in native forest soils. Site-1 may have favored mycorrhizal dependency, recycling nutrients via litter decomposition and fungal networks, whereas Site-2 open exposure increased nutrient leaching during monsoons.

These results align with previous studies indicating that *D. tuberculatus* exhibits optimal growth under forested conditions, while growth outside the forest may be slightly constrained by abiotic stressors. Management and conservation programs for this species should therefore prioritize forested habitats for plantations to maximize growth performance and survival rates.

4.2. Survival of *Dipterocarpus tuberculatus* plantation in different sites

The survival percentage of *Dipterocarpus tuberculatus* plantations differed markedly between Site-1 and Site-2 across all assessment periods (December 2024, June 2025, and December 2025) (**Error! Reference source not found.**). In December 2024, Site-1 recorded a high survival rate of 96.67%, whereas S-2 showed a considerably lower survival rate of

83.52%. In June 2025, survival in Site-1 slightly declined to 95%, while Site-2 remained unchanged at 83.52%. By December 2025, Site-1 maintained a stable survival rate of 95%, whereas Site-1 showed a slight decrease to 83.33%. Overall, survival rates remained consistently higher in Site-1 than in Site-2 throughout the study period. The difference between the two sites ranged from approximately 11–13%, indicating a substantial and persistent spatial variation in plantation performance. Temporal variation within each site was minimal, particularly in S1, where survival remained above 95% after the first assessment.

The consistently higher survival percentage in S-1 suggests that planting *Dipterocarpus tuberculatus* within its natural Dipterocarp Forest habitat provides more favorable ecological conditions for establishment and persistence. The lower survival rates observed in S-2 (outside the Dipterocarp Forest area) suggests that while the species can establish outside its natural forest environment, its performance is reduced compared to in-forest conditions. Temporal trends indicate that most mortality likely occurred during the early establishment phase (prior to or around December 2024), as survival percentages remained relatively stable thereafter. The slight decline observed in S-2 by December 2025 may indicate ongoing environmental stress or weaker long-term adaptability outside the natural forest ecosystem. These findings emphasize the importance of site selection in plantation programs involving native forest species. Establishing *D. tuberculatus* within or near its natural forest habitat appears to significantly improve survival success. For plantations outside natural forest areas, additional site preparation, soil improvement, shading, or irrigation measures may be necessary to enhance establishment and long-term survival.

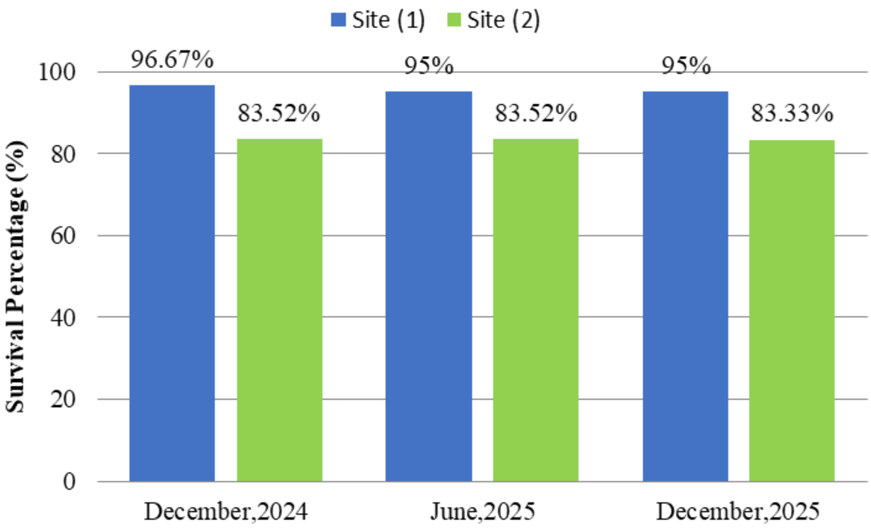

Figure 2. Survival Percentage of *D. tuberculatus* plantation in Site-1 and Site-2

The survival percentage of *Dipterocarpus tuberculatus* varied according to site (inside vs. outside Dipterocarp Forest area), planting method (pit digging vs. direct planting), and assessment period (December 2024, June 2025, and December 2025). (**Error! Reference source not found.**3) Across all planting methods and time periods, survival was consistently higher in S-1 (inside Dipterocarp Forest area) than in S-2 (outside forest area). In S-1, pit digging consistently resulted in slightly higher survival than direct planting across all periods. In S-2, direct planting showed marginally better survival than pit digging in June and December 2025, although the differences were small (generally <1%). Survival rates remained relatively stable over time in both sites and planting methods.

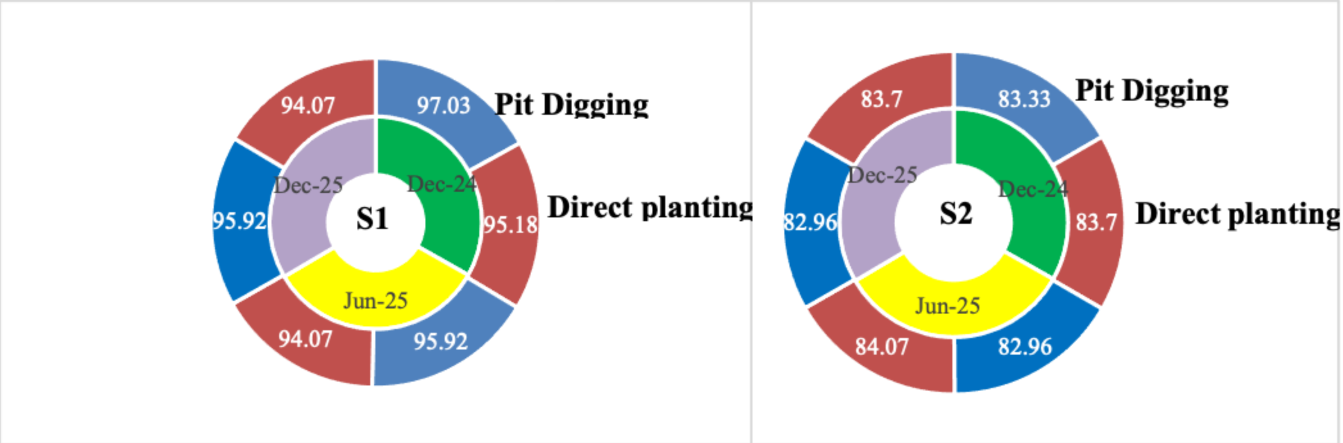

Figure 3. Survival Percentage of *D. tuberculatus* plantation by two plantation methods in Site-1 and Site-2

In S-1, survival slightly declined after December 2024 but remained above 94%. In S-2 survival fluctuated minimally, remaining around 83–84% throughout the study period. This suggests that ecological compatibility plays a crucial role in plantation success. As a native Dipterocarp species, *D. tuberculatus* is likely well adapted to the soil characteristics, microclimate, shade conditions, and biological interactions present within its natural forest habitat. These conditions may reduce transplant shock and environmental stress, thereby enhancing survival.

Regarding planting methods, pit digging showed a slight but consistent advantage in S1. Pit digging may improve root establishment by loosening soil, enhancing aeration, and increasing moisture retention. These benefits appear to be more pronounced in favorable forest environments where soil biological activity is high. Interestingly, in S-2, direct planting performed slightly better than pit digging during later assessments. This may indicate that under more open or stressful site conditions, reduced soil disturbance could help conserve soil structure and moisture. However, the differences between methods were minimal, suggesting that planting method had a secondary influence compared to site condition.

Temporal stability in survival percentages indicates that most mortality likely occurred during the early establishment phase. After initial adaptation, survival rates remained relatively constant, reflecting successful acclimatization of surviving seedlings. Overall, the study highlights the importance of ecological site suitability in plantation programs involving *Dipterocarpus tuberculatus*. While planting method has some influence, especially in forest environments, site conditions (inside vs. outside natural forest area) are the primary determinant of survival success. For plantations outside natural Dipterocarp forests, additional management interventions such as soil improvement, mulching, shading, or moisture conservation techniques may be necessary to improve survival outcomes.

4.3. Effect of planting methods on the growth of *Dipterocarpus tuberculatus* plantation

At the first measurement in S1, trees established with pit digging (M1) exhibited a significantly greater mean height (0.313m ± 0.005) than those under direct planting (M2) (0.300 ± 0.067 m). Statistical analysis indicated a significant difference between the two planting ($p < 0.05$), demonstrating an early growth advantage associated with pit preparation. By June 2025, pit digging continued to outperform direct planting (0.392 ± 0.004 m vs. 0.370 ± 0.003 m), with the difference being highly significant ($p < 0.001$). The difference between treatments remained statistically significant, indicating that the positive effect of pit digging persisted into the second growing season. However, by December 2025, although mean height remained slightly higher under pit digging (0.543m ± 0.009) compared with direct planting (0.527 m ± 0.009), the difference was no longer statistically significant. (**Error! Reference source not found.**)

The results demonstrate that *Dipterocarpus tuberculatus* exhibits continuous and stable growth within its natural forest habitat in S1. The consistent increase in mean height across all assessment periods indicates favorable environmental conditions inside the Dipterocarp Forest area, supporting successful establishment and development. The early significant advantage of pit digging over direct planting suggests that soil preparation plays an important role during the establishment phase. Pit digging likely improves root penetration, soil aeration, water infiltration, and nutrient availability. These factors can reduce transplant shock and promote early root system development, leading to enhanced initial height growth. However, by December 2025, the difference between planting methods became statistically non-significant. This suggests that once seedlings are well established, the influence of planting method diminishes, and environmental conditions become the dominant driver of growth. The convergence in height indicates that direct planting can eventually achieve comparable growth performance under suitable forest conditions. In summary, while pit digging provides an early growth advantage for *Dipterocarpus tuberculatus*, both planting methods ultimately support similar height development under favorable in-forest conditions. For operational plantation programs inside natural Dipterocarp Forest areas, pit digging may enhance early establishment, but long-term growth differences between methods appear minimal.

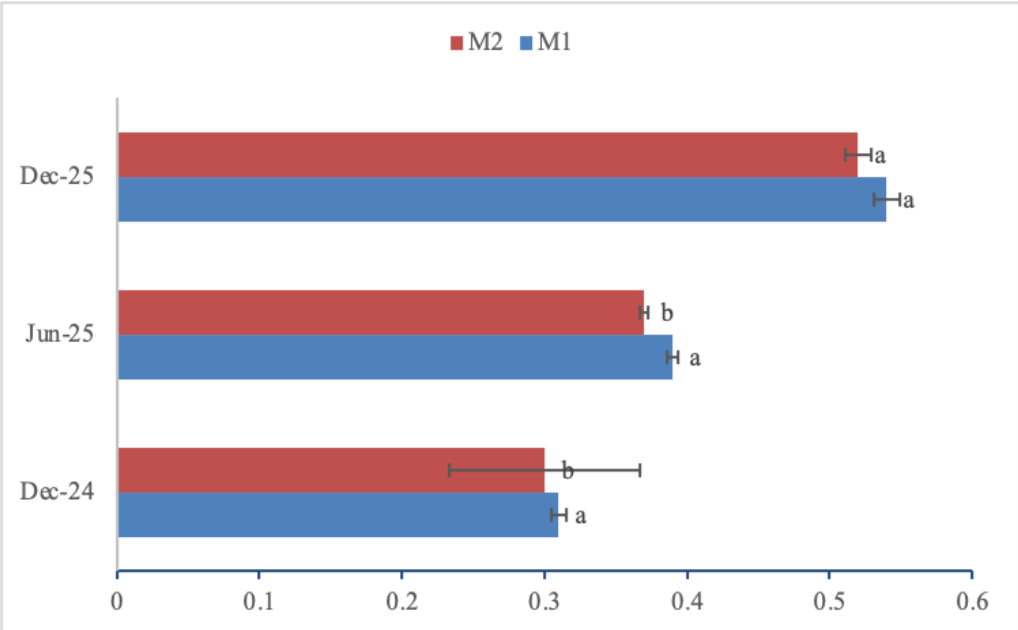

Figure 4. Growth of *D. tuberculatus* plantation by different planting methods in Site-1

According to the three-time measurement in Site-2, Independent samples *t*-tests indicated no statistically significant differences in mean tree height between pit digging and direct planting. (Figure 5) In December 2024, mean tree height was marginally higher at pit digging (0.279 m ± 0.011) than at direct planting (0.263 m ± 0.010); however, this difference was not significant. Similarly, in June 2025, pit digging again showed a slightly greater mean height (0.376 m ± 0.014) compared with direct planting (0.363 m ± 0.013), but the difference remained non-significant.

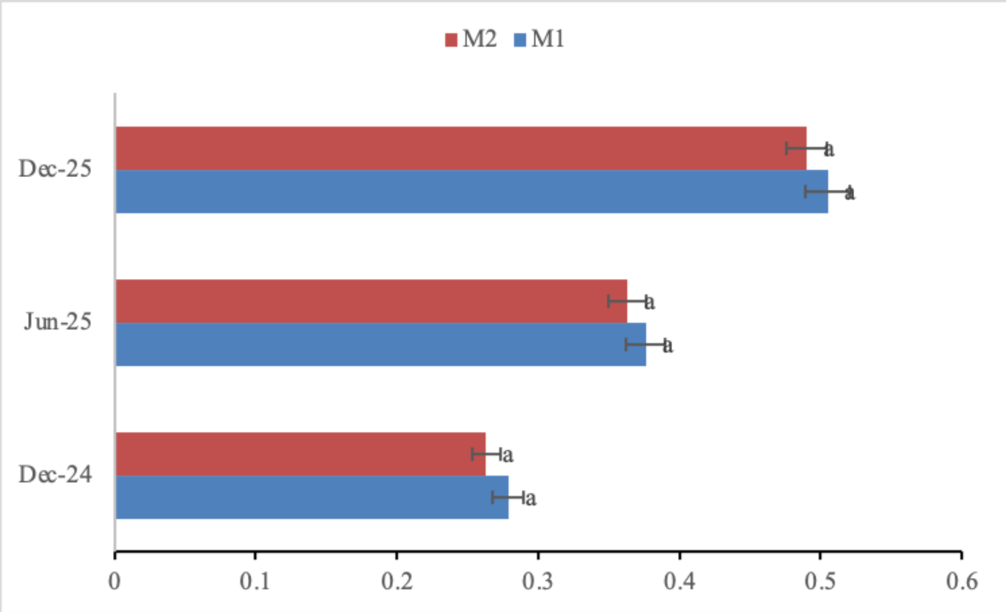

Figure 5. Growth of *D. tuberculatus* plantation by different planting methods in Site-2

By December 2025, although mean height continued to be marginally higher at pit digging (0.505 m ± 0.016) than direct planting (0.490 m ± 0.014), the difference was not statistically significant. Both pit digging and direct planting showed consistent and progressive tree height growth throughout the study period.

The results indicate that *D. tuberculatus* can achieve steady growth outside its natural Dipterocarp Forest habitat in Site-2. Mean height increased consistently across all assessment periods, demonstrating successful establishment and adaptation under non-forest conditions. Planting method did not significantly influence height growth at any time during the study. Although pit digging showed slightly higher mean values numerically, the differences were small and statistically non-significant. This suggests that under outside-forest conditions, environmental constraints may play a more dominant role than soil preparation techniques.

The gradual and uniform increase in height over time suggests that once seedlings are established, growth proceeds steadily regardless of planting method. The relatively small error bars indicate consistent performance among individuals within treatments. While both planting methods support satisfactory growth of *Dipterocarpus tuberculatus* in S-2, neither method provides a significant advantage in height increment under outside-forest conditions. Therefore, from a practical and cost-efficiency perspective, direct planting may be considered equally suitable for plantations outside the natural Dipterocarp Forest area, provided that site conditions are adequately managed.

4.4. Effect of fertilizer application on growth of *Dipterocarpus tuberculatus* plantation by pit digging in two different sites

The effect of fertilizer applications (T_1, T_2, and T_3) on the growth of *Dipterocarpus tuberculatus* established by pit digging in Site-1 was evaluated over three assessment periods: December 2024, June2025, and December 2025 (N = 90 per treatment). In December 2024, mean height ranged from 0.3071 ± 0.0098 m (T_1) to 0.3198 ± 0.0074 m (T_3). Although T_3 recorded the highest mean value, there are no significant difference among fertilizer applications. By June2025, mean height increased in all treatments, ranging from 0.3866 ± 0.0089 m (T_1) to 0.4005 ± 0.0063 m (T_3). Similar to the first assessment, no statistically significant differences were detected among treatments. Clear treatment effects became evident in December 2025. Mean height was T_1: 0.5165 ± 0.0141 m, T_2: 0.5317 ± 0.0144 m,

T_3: 0.5808 ± 0.0208 m. All treatments differed significantly from one another at this stage. T_3 produced the highest mean height, followed by T_2 and T_1. growth increased progressively over time in all treatments, but significant fertilizer effects were only observed at the third assessment (December 2025).

Table 1. Effect of fertilizer application on growth of *D. tuberculatus* plantation by pit digging in Site-1

Treatment	**Tree height (m)**			**Sample Size (N)**
	December, 2024	June, 2025	December, 2025	
T 1	0.3071 ± 0.0098^a	0.3866 ± 0.0089^a	0.5165 ± 0.0141^a	90
T 2	0.3099 ± 0.0099^a	0.3895 ± 0.0097^a	0.5317 ± 0.0144^b	90
T 3	0.3198 ± 0.0074^a	0.4005 ± 0.0063^a	0.5808 ± 0.0208^c	90

Mean value ± Standard Error are showed. Different letters indicate a significant difference between fertilizer applications ($P \leq 0.05$).Treatment 1 (T 1) (N_{15}:P_{15}:K_{15}, control), Treatment 2 (T 2) (0rganic fertilizer fermented with effective micro-organisms (EM), EM-Fertilizer) and Treatment 3 (T 3) (cow manure).

The results indicate that fertilizer applications influenced the long-term growth of *Dipterocarpus tuberculatus* planted by pit digging in Site-1. Although no significant differences were observed during the first two assessments, clear treatment effects emerged by December 2025. The absence of significant differences in December 2024 and June 2025 suggests that fertilizer effects were not immediately expressed during the early establishment phase. During this period, seedling growth may have been primarily influenced by transplant adaptation, root establishment, and existing soil nutrient reserves. The pit digging method likely provided adequate initial soil conditions, reducing short-term differences among treatments.

However, by December 2025, significant variation among treatments became evident. T_3 demonstrated the greatest height growth (0.5808 m), significantly outperforming both T_2 and T_1. The progressive ranking ($T_3 > T_2 > T_1$) suggests a dose-response or nutrient-efficiency effect, where improved or enhanced fertilizer input promoted greater cumulative growth over time. The delayed expression of treatment effects indicates that fertilizer benefits may become more pronounced as nutrient demand increases with plant age and biomass accumulation. As seedlings transition from establishment to active growth phases, external nutrient supply likely plays a greater role in supporting stem elongation and overall vegetative development. The relatively small standard errors across treatments indicate consistent responses within each group (N = 90), enhancing the reliability of the findings. Fertilizer application had minimal short-term impact but significantly enhanced long-term growth of *Dipterocarpus tuberculatus* under pit-digging conditions in S-1 (inside the Dipterocarp Forest Area). Among treatments, T_3 was the most effective in promoting height growth by the end of the study period. These findings highlight the importance of appropriate fertilizer management for maximizing plantation productivity, particularly during later growth stages.

Table 2. Effect of fertilizer application on growth of *D. tuberculatu*s plantation by pit digging in Site-2

Treatment	Tree height (m)			Sample Size (N)
	December, 2024	June, 2025	December, 2025	
T 1	0.2675 ± 0.0223^a	0.3620 ± 0.0265^a	0.4586 ± 0.0295^a	90
T 2	0.2757 ± 0.0186^a	0.3719 ± 0.0239^a	0.5082 ± 0.0271^{ab}	90
T 3	0.2932 ± 0.0193^a	0.3937 ± 0.0234^a	0.5483 ± 0.0268^b	90

Mean value ± Standard Error are showed. Different letters indicate a significant difference between fertilizer applications ($P \leq 0.05$).Treatment 1 (T 1) (N_{15}:P_{15}:K_{15}, control), Treatment 2 (T 2) (0rganic fertilizer fermented with effective micro-organisms (EM), EM-Fertilizer) and Treatment 3 (T 3) (cow manure).

The effect of fertilizer applications (T_1, T_2, and T_3) on the growth of *Dipterocarpus tuberculatus* established by pit digging in S-2 was evaluated over three assessment periods (N = 90 per treatment). In December 2024**,** mean tree height ranged from 0.2675 ± 0.0223 m (T_1) to 0.2932 ± 0.0193 m (T_3). Although T_3 recorded the highest mean value numerically, no significant difference was found among fertilizer applications. By June 2025, mean height increased across all treatments. But tree height did not significantly different among fertilizer applications. By December 2025**,** tree height differed more noticeably among treatments, with T3 exhibiting the highest mean value (0.548 m), followed by T2 (0.508 m) and T1 (0.459 m). In the third time measurement, tree height in T3 significantly higher than T1.

One-way ANOVA indicated that fertilizer applications did not produce significant differences in tree height during the first and second assessment periods, but treatment effects became more pronounced by the third measurement. Height growth increased steadily over time for all treatments, with significant fertilizer effects observed only at the third measurement.

The findings indicate that fertilizer applications influenced the long-term growth of *Dipterocarpus tuberculatus* planted by pit digging in S-2, although the effect was not evident during early growth stages. The absence of significant differences in December 2024 and June2025 suggests that fertilizer inputs did not immediately translate into measurable height differences. During the establishment and early vegetative phases, growth may have been primarily controlled by root system development, environmental adaptation, and inherent soil nutrient availability. Under outside-forest conditions, environmental constraints or higher exposure may limit the immediate responsiveness to fertilizer application. By December 2025, treatment effects became apparent. T_2 significantly outperformed T_1, indicating that fertilizer application enhanced cumulative growth over time.

The delayed response to fertilizer application suggests that nutrient demand increases as seedlings mature and biomass accumulates. Over time, fertilizer availability may contribute more substantially to stem elongation and overall vegetative growth. However, the less distinct separation among treatments compared to more favorable sites implies that site conditions outside the natural forest area may partially constrain the effectiveness of fertilizer inputs. fertilizer application enhanced the long-term growth of *Dipterocarpus tuberculatus* in Site-2, particularly for T_2 and T_3 treatments. However, treatment effects were moderate and appeared later in the growth cycle, likely influenced by environmental limitations outside the Dipterocarp forest ecosystem. These findings suggest that while fertilizer application can improve plantation performance, its effectiveness may depend strongly on site quality and environmental conditions.

4.5. Effect of fertilizer application on growth of *Dipterocarpus tuberculatus* plantation by direct planting in two different sites

During the first measurement (December 2024) and the second measurement (June 2025), no significant differences among treatments were detected (*Table 3*). This suggests that in the initial establishment phase, growth was likely governed by root development, adaptation to site conditions, and existing soil nutrient availability. The favorable forest environment may have provided sufficient baseline fertility to support early growth regardless of fertilizer application. However, by December 2025, clear and significant differences emerged among treatments. The progressive ranking ($T_3 > T_2 > T_1$) indicates a strong fertilizer response over time. T_3 resulted in the highest mean height (0.5621 m), demonstrating the greatest cumulative growth advantage. This pattern suggests that as tree growing and nutrient demand increased, the influence of fertilizer application became more pronounced. The superior performance of T_3 indicates that higher or more effective fertilizer input can substantially improve height growth in forest-based plantations. These findings underscore the importance of appropriate nutrient management strategies to optimize plantation productivity, particularly during later growth stages when nutrient demand increases.

This table showed that fertilizer applications did not significantly affect tree height at any of the three assessment periods. In December 2024**,** mean tree height varied only slightly among treatments (0.251–0.271 m) (*Table 4*), with no significant differences detected. A similar pattern was observed in June2025**,** when mean heights increased across all treatments (0.352–0.377 m) , but remained statistically indistinguishable. By December 2025**,** tree height continued to increase (0.466–0.524 m), with Treatment 3 consistently exhibiting the highest mean; however, the overall treatment effect was not significant. Collectively, these results indicate that tree height increased progressively over time, while fertilizer-related differences remained small and statistically non-significant throughout the study period.

Table 3. Effect of fertilizer application on growth of *D. tuberculatus* plantation by direct planting in Site-1

Treatment	Tree Height (m)			Sample Size (N)
	December, 2024	June, 2025	December, 2025	
T 1	0.2895 ± 0.0079[a]	0.3623 ± 0.0061[a]	0.5063 ± 0.0146[a]	90
T 2	0.3000 ± 0.0066[a]	0.3722 ± 0.0058[a]	0.5147 ± 0.0149[b]	90
T 3	0.3098 ± 0.0064[a]	0.3764 ± 0.0067[a]	0.5621 ± 0.0202[c]	90

Mean value ± Standard Error are showed. Different letters indicate a significant difference between fertilizer applications ($P \leq 0.05$). Treatment 1 (T 1) (N_{15}:P_{15}:K_{15}, control), Treatment 2 (T 2) (0rganic fertilizer fermented with effective micro-organisms (EM), EM-Fertilizer) and Treatment 3 (T 3) (cow manure).

Table 4. Effect of fertilizer application on growth of *D. tuberculatus* plantation by direct planting in Site-2

Treatment	Tree height (m)			Sample Size (N)
	December, 2024	June, 2025	December, 2025	
T 1	0.2506 ± 0.1756[a]	0.3516 ± 0.2411[a]	0.4656 ± 0.2635[a]	90
T 2	0.2678 ± 0.1744[a]	0.3615 ± 0.2330[a]	0.4800 ± 0.2415[a]	90
T 3	0.2706 ± 0.1703[a]	0.3767 ± 0.2084[a]	0.5243 ± 0.2248[a]	90

Mean value ± Standard Error are showed. Different letters indicate a significant difference between fertilizer applications ($P \leq 0.05$).Treatment 1 (T 1) (N_{15}:P_{15}:K_{15}, control), Treatment 2 (T 2) (0rganic fertilizer fermented with effective micro-organisms (EM), EM-Fertilizer) and Treatment 3 (T 3) (cow manure).

5. Discussion

The present study evaluated the growth performance of *Dipterocarpus tuberculatus* established at two sites (inside and outside a dipterocarp forest), under two planting methods (pit planting and direct planting) and three fertilizer applications (T1: NPK, T2: EM, and T3: cow manure). The results clearly demonstrate that site condition, planting method, and fertilizer application significantly influenced early growth and survival performance.

Growth performance was generally higher inside the dipterocarp forest compared to outside the forest. This difference may be attributed to improved microclimatic conditions, including moderated temperature, reduced evapotranspiration and enhanced soil moisture retention inside the forest environment. Seedlings planted outside the native forest may have been exposed to harsher environmental conditions and soil moisture fluctuations, which can reduce growth performance and survival. The survival percentage data also support this trend, indicating better establishment under more favorable site conditions. Higher survival rates in Dipterocarp Forest indicate more favorable establishment conditions, likely associated with improved soil structure, moderated microclimate, and greater moisture stability (Ashton et al., 2019; Laclau et al., 2021). Lower survival in outside the native forest may reflect greater environmental stress or variability, emphasizing the critical role of site suitability in dipterocarp plantation success (Forrester et al., 2017). This finding highlights the importance of site selection in restoration and enrichment planting programs for *Dipterocarpus tuberculatus*.

The comparison between pit planting and direct planting showed that pit planting generally resulted in superior growth performance. Pit digging improves soil loosening, enhances root penetration, and allows better incorporation of fertilizer and organic amendments. It also improves water infiltration and reduces soil compaction around the root zone. Pit digging likely reduced soil compaction, enhanced aeration and water infiltration, and facilitated deeper root penetration. These processes are especially important for Dipterocarpus species, which characteristically develop extensive root systems during early ontogeny (Ashton et al., 2019). Direct planting, although more cost-effective and less labor-intensive, may restrict early root expansion in compact or degraded soils. The results suggest that pit planting is more suitable for sites with poor soil structure or lower fertility, while direct planting may be adequate under favorable soil conditions. early-stage growth stimulation following intensive site preparation has been documented in dipterocarp plantations and other tropical forestry systems (Appanah et al., 1998; Kettle, 2012).

Although both sites exhibited slightly acidic soils (pH 5.7–6.1) suitable for *Dipterocarpus tuberculatus*, notable differences in soil fertility and texture were evident. Site-1 (inside the Dipterocarp Forest) soils were predominantly sandy and characterized by low total nitrogen, organic matter, and exchangeable bases, reflecting nutrient-poor conditions typical of natural dipterocarp forests. Site-2 (outside the Dipterocarp Forest) soils displayed higher nitrogen content, greater exchangeable potassium and calcium, and finer textures, suggesting improved nutrient and water retention capacity. Despite these contrasts, available phosphorus was extremely low at both sites, indicating that phosphorus limitation may represent a common growth constraint across locations.

Among the fertilizer applications, cow manure (T3) consistently produced the highest mean growth values across most treatments and measurement periods. Organic manure not only supplies essential nutrients but also improves soil structure, water-holding capacity, and microbial activity. These improvements likely contributed to sustained growth increments observed over time. NPK fertilizer (T1) showed moderate growth performance, indicating that inorganic nutrients support early growth; however, its effect may be short-term compared to organic amendments. EM (T2) performed better than or similar to NPK in several treatments, suggesting that microbial enhancement can positively influence nutrient availability and root development. The significant differences observed in later measurement periods indicate that fertilizer effects became more pronounced over time, particularly under pit planting conditions. This suggests that nutrient availability and soil improvement play critical roles in sustained early growth of *Dipterocarpus tuberculatus*.

Fertilizer responses exhibited pronounced temporal differentiation. During the first (December 2024) and the second (June 2025) assessments, no statistically significant differences among fertilizer applications were detected in either site, despite consistently higher mean values under cow manure application. These findings suggest that early aboveground growth was primarily influenced by root establishment and site conditions rather than immediate nutrient inputs (Binkley et al., 2020; Forrester et al., 2021). Similar delayed fertilization responses have been observed in tropical tree species, where initial resource allocation favors root system development before substantial aboveground biomass accumulation occurs (Forrester et al., 2017; Laclau et al., 2021).

During the third measurement, fertilizer effects became significant, with cow manure outperforming NPK and EM fertilizer. This delayed response likely reflects increasing nutrient demand as biomass accumulation accelerated during stand development (Thomas et al., 2020; Sardans & Peñuelas, 2022). Early nutrient uptake efficiency may have been constrained by limited root surface area and incomplete microbial symbiosis establishment (Laclau et al., 2021; Sardans et al., 2022). While EM fertilizers may enhance soil microbial activity, their growth-promoting effects often require longer periods to manifest in woody species (Kim et al., 2023; Wang et al., 2025). Cow manure provides slow-release nutrients, improves soil aggregation and water-holding capacity, and stimulates microbial processes, thereby sustaining nutrient availability over time (Agegnehu et al., 2021; Lehmann et al., 2023). Comparable long-term benefits of organic amendments have been widely documented in tropical forestry systems (Singh et al., 2022; Martinez et al., 2024).

The combined influence of site, planting method, and fertilizer application demonstrates that growth performance is not controlled by a single factor but rather by their interaction. The best overall performance was observed where favorable site conditions were combined with pit planting and organic fertilizer application. This integrated approach appears to create optimal physical, chemical, and biological soil conditions for seedling establishment. These findings are consistent with silvicultural principles that emphasize proper site preparation and soil management in tropical forest restoration programs. The study confirms that early-stage management interventions strongly influence plantation success. The results contribute valuable information for designing effective reforestation strategies using *Dipterocarpus tuberculatus*, particularly in degraded forest landscapes.

6. Conclusion

This study demonstrated that site condition, planting method, and fertilizer application significantly influence the early growth performance of *Dipterocarpus tuberculatus*. Seedlings planted inside the dipterocarp forest exhibited better growth and survival compared to those planted outside the forest, emphasizing the importance of favorable microenvironmental conditions for successful establishment. Pit planting was generally more effective than direct planting, particularly in enhancing root development and nutrient utilization. Although direct planting may reduce labor and cost, pit preparation improves soil structure and provides better conditions for seedling growth, especially on less favorable sites.

Among the fertilizer applications, cow manure showed the most consistent positive effect on growth performance. The application of organic fertilizer enhanced soil quality and supported sustained seedling development. NPK fertilizer and EM also contributed to growth improvement, but their effects were generally less pronounced compared to cow manure. The interaction among site condition, planting method, and fertilizer application indicates that an integrated management approach is essential for maximizing plantation success. For restoration and enrichment planting programs involving *Dipterocarpus tuberculatus*, the combination of favorable site selection, pit planting, and organic fertilizer application is recommended to achieve optimal early growth performance. These findings provide practical guidance for forestry practitioners and policymakers engaged in dipterocarp forest rehabilitation and sustainable plantation management.

7. References

Agegnehu, G., Srivastava, A. K., & Bird, M. I. (2021). The role of biochar and organic amendments in improving soil fertility and crop productivity. *Soil Use and Management*, 37, 235–248.

Anonymous. 1985. RAPA Monograph, Dipterocarps of South Asia. Regional office for Asia and the Pacific.

Appanah, S., & Turnbull, J. M. (1998). A review of dipterocarps: Taxonomy, ecology and silviculture. CIFOR.

Ashton, P. S., & Gunatilleke, C. V. S. (2019). Ecology of tropical rain forests. Biotropica, 51, 789–800.

Bhagwat, T., Hess, A., Horning, N., Khaing, T., Thein, Z. M., Aung, K. M., & Leimgruber, P. (2017). Losing a jewel: Rapid declines in Myanmar's intact forests from 2002–2014. *PLoS ONE*, 12(5), e0176364.

Binkley, D., Fisher, R., & Ryan, M. G. (2020). *Ecology and Management of Forest Soils* (5th ed.). Wiley.

FAO. (2020). *Global Forest Resources Assessment 2020: Main Report*. Food and Agriculture Organization of the United Nations.

Forrester, D. I. (2019). Linking forest growth with stand structure. Forest Ecology and Management, 432, 606–616.

Forrester, D. I., & Bauhus, J. (2021). A review of processes behind tree growth responses to nutrient supply. *Forest Ecology and Management*, 494, 119325.

Kettle, C. J. (2012). Ecological considerations for dipterocarp restoration. Forest Ecology and Management, 274, 1–9.

Kim, S., & Park, J. (2023). Contextual efficacy of effective microorganism fertilizers in forestry applications. *Journal of Forest Science*, 69(1), 12-25.

Laclau, J.-P., Oliveira, I. R. de, Robin, A., Jourdan, C., Paula, R. R., Pinheiro, R. C., Guillemot, J., Gonçalves, J. L. M., & Bouillet, J.-P. (2021). *Nutrient supply modulates species interactions belowground: dynamics and traits of fine roots in mixed plantations of Eucalyptus and Acacia mangium. Plant and Soil*, 460(1-2), 559–577

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2023). The concept and future prospects of soil health. *Nature Reviews Earth & Environment*, 4, 45–58.

Martinez, A. *et al*. (2024). Long-term effects of organic amendments on tree growth and soil properties in tropical plantations. *Forestry Ecology and Management*, 525, 120465.

Pearson, R.S and Brown, H.P.1932. Commercial Timbers of India. Vol. I & II Government of India. Central Publication Branch, Calcutta.

Rodger, A. 1936. A Handbook of the Forest Products of Burma. Supern intendent, Government Printing and Stationary, Rangoon.

Sardans, J. & Peñuelas, J. (2022). *The global nitrogen-phosphorus imbalance and its ecological implications.*

Singh, V., Kumar, R., & Joshi, D. (2022). Organic fertilization and its role in sustainable forestry practices. *Journal of Sustainable Forestry*, 41(4), 353-372.

Wang, L., Huang, Q., & Liu, J. (2025). Microbial activity and nutrient availability in EM-treated forest soils: Implications for tree growth. *Environmental Microbiology Reports*, 17(2), 220-233.

Win, Z., & Shrestha, R. P. (2015). Monitoring deforestation and forest degradation in Myanmar using remote sensing and GIS. *Journal of Forest and Livelihood*, 13(1), 33–45.

Woods, K., & Canby, K. (2011). *Baselines of Forest Landscape Governance in Myanmar*. Forest Trends.

Center for International Forestry Research (CIFOR). (2017). Restoring degraded landscapes in Southeast Asia. CIFOR.

Food and Agriculture Organization of the United Nations (FAO). (2015). Global Forest Resources Assessment 2015. FAO.

Food and Agriculture Organization of the United Nations (FAO). (2020). Global Forest Resources Assessment 2020: Main report. FAO.

Food and Agriculture Organization of the United Nations (FAO). (2025). Global Forest Resources Assessment 2025 update. FAO.

World Bank. (2019). Myanmar forest sector assessment. World Bank.