BORNEO SCIENCE
THE JOURNAL OF SCIENCE & TECHNOLOGY

RESEARCH ARTICLE

Journal homepage: https://jurcon.ums.edu.my/ojums/index.php/borneo-science

COMPARATIVE GROWTH PERFORMANCE OF *NEOLAMARCKIA CADAMBA* ROXB. BOSSER (WHITE LARAN) UNDER DIFFERENT SITE CONDITIONS IN FOREST PLANTATION AT JAWALA PLANTATION INDUSTRY, SAPULUT FOREST RESERVE, NABAWAN

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Received: 21 Jan 2025
Revised: 25 March 2025
Accepted: 29 March 2025
Published online: 29 March 2025

DOI :
10.51200/bsj.v46i1.6017

Keywords:
Indigenous, Fast-growth species, Site conditions

ABSTRACT. *This study investigated the growth of Neolarmakia cadamba Roxb Bosser (White Laran) across various site conditions characterised by differing elevations, slopes, distances from roads, and forest fringes. Plots meeting specific criteria were established in two distinct sites, one year and five years old, of planted N. cadamba trees. The findings indicate that the one-year-old trees at higher elevations on flat terrain show a greater mean diameter at breast height (DBH = 8.75 cm), mean total height (5.84 m), and volume (0.16 m³) compared to those at lower elevations on hilly land. Conversely, for the five-year-old trees, higher average DBH and total height were observed in flat areas near roads and forest edges. Analysis using the Kruskal-Wallis test demonstrated significant differences in DBH, height, and volume among the plots, with p < 0.05. This study suggests that variations in the growth of N. cadamba arise from different site conditions related to slope, altitude, and proximity to roads and forest edges, likely due to differences in nutrient availability and light access. These findings may prompt further research in this area, particularly regarding treatment recommendations and predictions for the early growth of the species in diverse site conditions.*

INTRODUCTION

Forest plantations are becoming increasingly important in the global forest estate. The plants chosen for the restoration area include fast-growing exotics, such as *Acacia mangium*, *Shorea leprosula*, *Neolarmakia cadamba* (*N. Cadamba*), Binuang (*Octomeles sumatrana* Miq.), and others. Despite indigenous species being a priority for restoration programs, several factors must be considered to optimise growth performance, including site conditions such as soil type (Kanowski *et al*., 2005). Different tree species exhibit varying growth rates due to their unique surroundings, which in turn affects their growth. Some factors that may influence tree growth include nutrient availability (Binkley, 2003), light intensity and absorption (Poorter *et al*., 2012; Dieler & Pretzsch, 2013), soil quality (Kozlowski, 1999), and water availability (Lebourgeois *et al*., 2013). To accurately record the growth, measurements of the tree must be taken, such as its height and diameter at breast height (DBH). The growth is quantified by assessing the tree's diameter at breast height (DBH), approximately 1.3 meters above the ground, and its height (Walker *et al*., 2011). In a tree plantation, keeping track of its growth is crucial for carrying out pruning and care according to the prescribed schedule. The growth rate is widely used in the plantation to monitor the growth of the trees planted (Hodge *et al*., 2001). It ensures that the tree growth meets the requirements and characteristics needed for high-quality timber. Tree height is also an indicator typically used in sites to assess tree growth rate performance (Skovsgaard *et al*., 2008). The DBH and height of tree data can generally be used to demonstrate that the growth rate of the same tree species at different locations varies due to differences in nutrient intake, tree competition, soil conditions, light intensity, and water availability.

Numerous research studies and publications have focused on the growth of *N. cadamba* across various countries; however, there is still limited evidence regarding its growth performance in Sabah. Until recently, little was known about how specific site characteristics, such as soil type and quality, elevation, light conditions, and other environmental factors, affect the growth metrics (including above-ground dimensions and biomass) of *N. cadamba* in a rainforest plantation environment. The lack of silvicultural data on native species and insufficient growth and yield information hinders their use in large-scale plantations (Hashim *et al*., 2015). Understanding these factors is crucial for enhancing forest management practices and promoting the efficient growth of this valuable species under diverse conditions. Due to market demand and its unique traits, such as adaptability to intermittent waterlogged conditions (M. Khatta *et al*., 2023), *N. cadamba* has been more frequently utilized in Sabah compared to other fast-growing species (Yulianti & Sudrajat, 2016). According to Lee *et al*. (2005), the internal rate of return (IRR) for *N. cadamba* ranges from 12% to 29%, which is considered high based on financial analysis. Thus, comprehending the growth of this species in Sabah is essential.

This study examined the growth of the indigenous species *N. cadamba*, commonly known as Laran, at Jawala Plantation Industries Sdn. Bhd. in the Sapulut Forest Reserve, Nabawan, Sabah. The research aims to explore how the growth of *N. cadamba* varies under different site conditions. Specifically, it seeks to assess the effects of various surrounding factors on the growth of *N. cadamba* in forest plantations, such as elevation, slope, and soil compaction. The study has two primary objectives: 1) To compare the growth of one-year-old *N. cadamba* across different slope and elevation conditions, and 2) To evaluate the relationship between the growth of *N. cadamba* and varying site conditions, including slope, distance from the road, and proximity to forest edges. All chosen variables related to site conditions were considered to assess their influence on the growth of *N. cadamba*. This research aims to enhance the limited knowledge regarding *N. cadamba* early growth in diverse site conditions.

MATERIALS AND METHODS

This study was carried out at Jawala Plantation Industries Sdn. Bhd. situated in the Sapulut Forest Reserve (FR), Nabawan, Sabah. The company is a wholly owned subsidiary of Jawala Corporation Sdn. Bhd., and oversees roughly 11,043 hectares, which includes areas designated for production, non-production, and conservation. The total production area spans approximately 8,930 hectares, consisting of 8,442 hectares of conventional industrial tree plantation (ITP) and 488 hectares designated for reduced-impact logging (RIL) harvesting practices. The non-production area covers about 1,364 hectares, which includes 84 hectares for roads and clearings, 1,192 hectares for streams, ponds, and riparian reserves, 868 hectares of steep terrain, and 20 hectares for infrastructure. Additionally, the conservation areas encompass 749 hectares. To achieve the research objectives of exploring the relationship between the early growth of *N. cadamba* and its surrounding environment, several methods were employed.

Study the Growth Performance of One-Year-Old Planted *N. cadamba* Under Different Slopes and Elevations.

Four plots were set up in the industrial tree plantation (ITP) for data collection, each containing 40 one-year-old laran trees (*N. cadamba*). The trees were planted with a spacing of 5 × 5 meters, and the plots were aligned with the planted trees, measuring 20 meters by 35 meters each. Two plots (A and B) were positioned at a higher elevation of 475 meters, while the other two (C and D) were situated at a lower elevation of 375 meters, as shown in Figure 1.

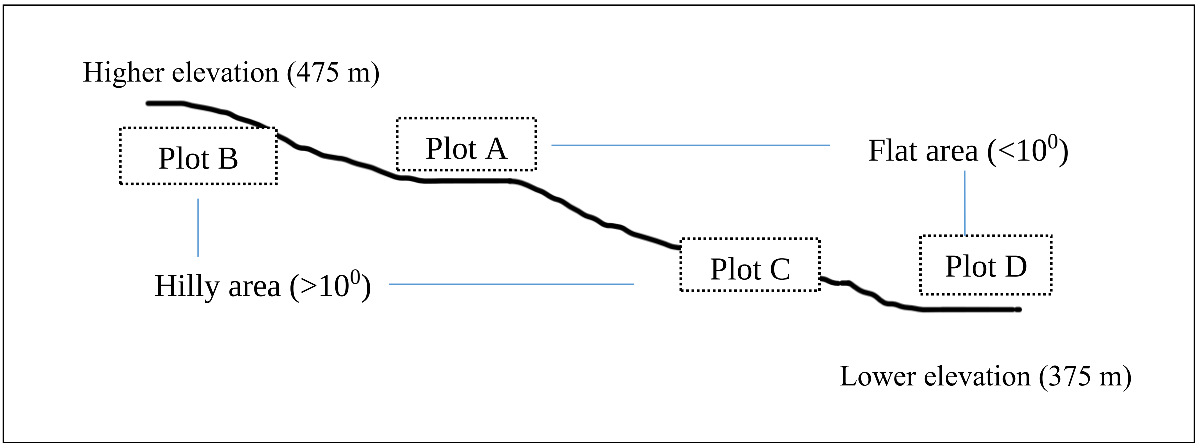

Figure 1. Illustration of the site location of study Plots (A, B, C, and D).

Each elevation features two distinct slope types: flat (plots A and D) with a slope angle of less than 10 degrees, and hilly (plots B and C) with a slope angle greater than 10 degrees. The distance between plots A and B at the higher elevation and plots C and D at the lower elevation is approximately 500 meters. Additionally, the distance between plots A and B, as well as C and D, is around 20 meters each. A total of 160 one-year-old *N. cadamba* trees were planted on-site, having previously been nurtured in a nursery before their transplant to the ITP area. Data regarding diameter at breast height (DBH), height, slope, and elevation were recorded and collected.

Study of the Growth of Five Years *N. cadamba* Planted Under Different Site Conditions.

This study was carried out by choosing study locations that fulfilled the criteria for the specific site conditions necessary for the investigation (refer to Table 1). Three plots were established, each designed with a sampling area of 100 m × 20 m. The plots differ based on slope, distance from the road, and proximity to the forest fringe, as depicted in Figure 2. Plot E is situated in a flat area (≤ 10°), close to the road (≤ 20 m), and near the forest fringe (< 20 m). In contrast, Plot F is in a hilly region (> 10°), near the road (≤ 20 m), and somewhat distant from the forest fringe (20-40 m). Finally, Plot G is also in a hilly area (> 10°) but is positioned farther from both the road (> 20 m) and the forest fringe (> 40 m). Field data collection was conducted using a diameter tape and a Trimble device; the DBH of the trees was measured with the diameter tape, while the Trimble was used to assess tree height. Soil compaction readings were obtained using a soil compaction meter.

Table 1. The different characteristics of the selected study plots.

Plot	Slope	Distance from the road (open area)	Distance from forest fringe (closed area)
Plot E	≤ 10°	≤ 20 m	≤ 20 m
Plot F	> 10°	≤ 20 m	20 – 40 m
Plot G	> 10°	> 20 m	> 40 m

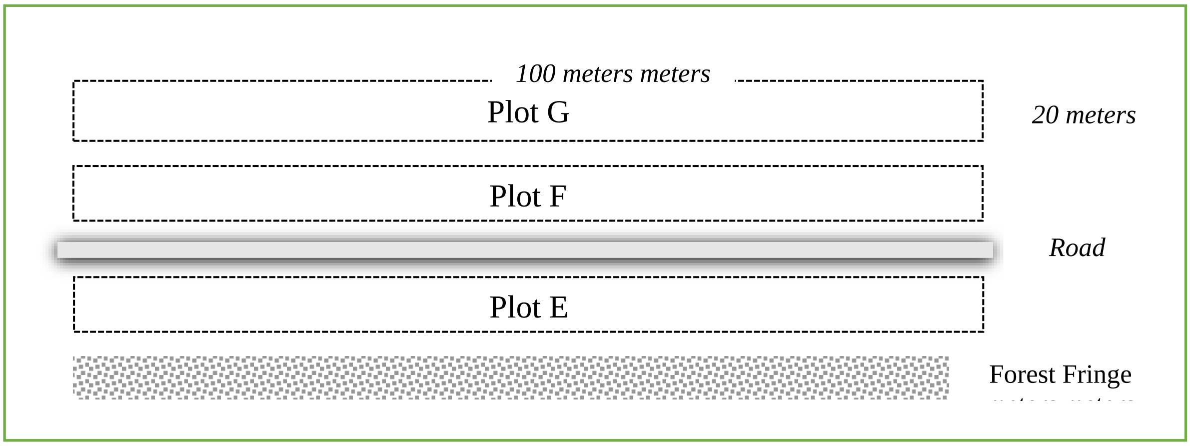

Figure 2. Illustration of different site characteristics of study Plots (E, F, and G).

RESULTS AND DISCUSSIONS

The Growth Rate of One-Year-Old *N. cadamba* at Different Elevations and Slopes

The mean diameter at breast height (DBH) of *N. cadamba* in the first year of growth is higher in the flat areas (Plots A and D) compared to the hilly areas, as indicated in Table 2. Specifically, the mean DBH for Plot A at the higher elevation is 8.746 cm, while for Plot D at the lower elevation, it is 7.635 cm. In the hilly areas (Plots B and C), where the slope exceeds 10 degrees, the mean DBH is lower, measuring 7.428 cm in Plot B and 7.005 cm in Plot C. The mean total height of *N. cadamba* is greater in Plots A and B at higher elevations than in the lower elevation plots. Plot A records the highest mean total height at 5.84 m, followed by 5.53 m in Plot B, 5.39 m in Plot D, and 4.81 m in Plot C, respectively. In terms of volume, the highest mean is observed in Plot A (0.0164 m³), followed by Plot B (0.0102 m³), Plot D (0.0094 m³), and Plot C (0.0075 m³).

Table 2. Growth of one-year-old *N cadamba* at different slopes and elevations.

	Plot (PSP)	N	Minimum	Maximum	Sum	Mean		Deviation
		Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Plot A (flat)	DBH (cm)	40	3.80	14.00	349.82	8.7455	0.4281	2.7075
	Height (Total) (Meter)	40	2.50	9.52	233.63	5.8408	0.2604	1.6471
	Volume (m³)	40	0.0011	0.0494	0.6547	0.0164	0.0018	0.0112
	Valid N (listwise)	40						
Plot B (hilly)	DBH (cm)	40	3.00	13.00	297.10	7.4275	0.3348	2.1176
	Height (Total) (Meter)	40	2.18	10.10	221.11	5.5278	0.3157	1.9965
	Volume (m³)	40	0.0010	0.0465	0.4092	0.0102	0.0014	0.0086
	Valid N (listwise)	40						
Plot C (hilly)	DBH (cm)	40	2.40	9.70	280.20	7.0050	0.2689	1.7007
	Height (Total) (Meter)	40	2.52	7.06	192.55	4.8138	0.1754	1.1095
	Volume (m³)	40	0.0007	0.0184	0.3016	0.0075	0.0006	0.0040
	Valid N (listwise)	40						
Plot D (flat)	DBH (cm)	40	2.70	12.80	305.40	7.6350	0.3524	2.2288
	Height (Total) (Meter)	40	2.20	8.93	215.70	5.3925	0.2445	1.5461
	Volume (m³)	40	0.0004	0.0284	0.3761	0.0094	0.0010	0.0065
	Valid N (listwise)	40						

A Kolmogorov-Smirnov and Shapiro-Wilk test were conducted to evaluate normality, yielding a p-value greater than 0.05 ($p > 0.05$), which indicates that the distributions in the four plots are not normal. The Kruskal-Wallis test revealed significant differences in the diameter at breast height (DBH), height, and volume of *N. cadamba* trees among the plots. The results for DBH are as follows: $H(3) = 11.559$, $p = 0.009$, with mean ranks of 100.70 for Plot A, 74.58 for Plot B, 67.24 for Plot C, and 79.49 for Plot D. For height, the results are $H(3) = 8.696$, $p = 0.034$. Regarding volume, the statistics are $H(3) = 14.548$, $p = 0.002$, with mean ranks of 103.48 for Plot A, 77.16 for Plot B, 65.74 for Plot C, and 75.63 for Plot D. Spearman's correlation analysis revealed a weak significant correlation between tree height and soil compaction ($r_s = -0.412$, $n = 40$, $p = 0.000$).

The early growth of the fast-growing species *N. cadamba* is influenced by various factors. This study highlights a significant difference in the growth of *N. cadamba* based on differing site conditions, including altitude and slope characteristics. The findings demonstrate that trees planted in flat areas show higher growth rates compared to those in hilly areas. Slope is a critical factor affecting tree growth; often, steeper slopes can hinder growth due to increased soil erosion in these areas. This erosion typically removes the nutrient-rich topsoil, especially during rainfall events. As the slope degree increases, the potential for soil erosion also rises. Previous research by Nguyen *et al*. (2012) suggested that trees on lower slopes tend to grow faster than those on steeper gradients. Additionally, a study by Hui *et al*. (2012) indicated a strong correlation between slope and DBH ($r = 0.912$). The significant negative correlation ($r = -0.634$) between slope and height observed in this study suggests an inverse relationship, indicating that a lower slope degree is associated with improved tree growth.

Study the Growth of *N. cadamba* Under Various Site Conditions.

The study investigated the impact of various environmental conditions on the growth of five-year-old *N. cadamba* trees, specifically in Plot E with 118 trees, Plot F with 100 trees, and Plot G with 84 trees, as detailed in Table 3. The mean DBH was highest in Plot E at 17.36 cm, followed by Plot F at 13.57 cm and Plot G at 9.20 cm. In terms of total height, Plot E also recorded the greatest mean at 14.53 m, while Plot F measured 10.050 m and Plot G had the lowest mean at 7.30 m. Consequently, Plot E exhibited the highest mean volume at 0.3899 m^3, followed by Plot F at 0.1826 m^3 and Plot G at 0.0729 m^3.

Table 3. Growth of 5-year *N cadamba* at five different site conditions.

Plot		N	Minimum	Maximum	Mean		Std.
		Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
E (Flat)	DBH (cm)	118	6.60	26.30	17.3568	0.4327	4.7005
	Height (Total) (m)	118	5.16	27.43	14.5341	0.3245	3.5248
	Total Volume (m^3)	118	0.0200	0.9080	0.3899	0.0208	0.2264
	Valid N (listwise)	118					
F (Hilly)	DBH (cm)	100	4.70	21.60	13.5650	0.4282	4.2824
	Height (Total) (m)	100	3.14	19.09	10.0501	0.3393	3.3931
	Total Volume (m^3)	100	0.0050	0.6870	0.1826	0.0146	0.1462
	Valid N (listwise)	100					
G (Hilly)	DBH (cm)	84	2.00	19.20	9.2024	0.4283	3.9255
	Height (Total) (m)	84	1.10	16.98	7.3048	0.3343	3.0639
	Total Volume (m^3)	84	0.0010	0.4920	0.0729	0.0093	0.0856
	Valid N (listwise)	84					

The Shapiro-Wilk test ($p > 0.05$) (Shapiro & Wilk, 1965), along with a visual inspection of the histograms and normal Q-Q plots, indicates that the diameter at breast height (DBH) and height of the trees across the three plots do not follow a normal distribution. The Kruskal-Wallis test conducted on total height revealed a statistically significant difference among the plots ($p < 0.000$), with mean ranks of 220.53 for Plot E, 132.53 for Plot F, and 77.12 for Plot G. Additionally, there was a statistically significant difference in DBH among the plots as well ($p < 0.000$), with mean ranks of 207.14 for Plot E, 148.29 for Plot F, and 77.15 for Plot G.

These findings align closely with previous research conducted in South Kalimantan, which indicated that *N. cadamba* trees younger than five years have a diameter ranging from 6.0 cm to 16.4 cm, with an average of 25.3 cm, and heights varying from 4.1 m to 14.6 m, reaching a maximum of 17.1 m (Krisnawati *et al*., 2011). A Spearman's rho correlation test was performed to examine the relationships between DBH and slope, DBH and distance from the road, DBH and distance from the forest fringe, distance from the road and total height, distance from the forest fringe and DBH, and distance from the forest fringe and total height. All correlation coefficients were highly significant ($p < 0.001$) at the 0.01 level (2-tailed). There was a moderate negative correlation between DBH and slope (rs = -0.511, n = 302, p = 0.000), as well as between DBH and distance from the road (rs = -0.529, n = 302, p = 0.000) and distance from the forest fringe (rs = -0.598, n = 302, p = 0.000). The relationship between total height and slope was also significantly correlated (rs = -0.634, n = 302, p = 0.000), as was the relationship between total height and distance from the road (rs = -0.530, n = 302, p = 0.000) and distance from the forest fringe (rs = -0.678, n = 302, p = 0.000).

The findings reveal that trees located near the road exhibit a higher growth rate compared to those situated farther away. Fast-growing species planted close to the road demonstrate superior growth compared to their counterparts planted at a greater distance from the roadside. *N. cadamba*, being a light-demanding species, thrives and adapts well to degraded lands, particularly in logged forests, making light a crucial factor for its growth. The more sunlight these trees receive, the larger their diameter and height. In this study, the distance from the road shows a moderate negative correlation with DBH (rs = - 0.529). Fox (1971) noted that Laran trees prominently contribute to the initial growth in secondary forests, especially in open areas post-logging and in moist sites. This indicates that trees receiving adequate sunlight are likely to grow better than those with limited exposure. Supporting this, Kocher and Harris (2007) observed that light-demanding trees thrive in environments with ample light penetration, while they struggle when overshadowed by other trees. Additionally, a study by Naghdi *et al*. (2017) confirmed that trees near the road exhibit greater diameter increments compared to those planted farther away.

The forest fringe, or edge, serves as a transitional zone between open and closed landscapes, acting as a boundary for living spaces (Tripathi *et al*., 1993). It functions as a protective barrier against the wind. In addition to providing a habitat that supports a wide variety of fauna, the forest fringe also supplies vital nutrients to the surrounding ecosystem. A study by McDonald *et al*. (2004) found that the forest edge does not significantly influence tree growth when compared to topographical and soil factors. However, this study revealed a substantial correlation between the forest fringe and both the diameter at breast height (DBH) (rs = - 0.598) and height (rs = - 0.678) of *N. cadamba*. This can be attributed to the interactions and competition for sunlight among various tree species at the forest fringe, particularly affecting the light-demanding *N. cadamba*. Ajik (2005) also noted similar observations regarding the early growth performance of *N. cadamba* in Segaliud Lokan, Sabah.

CONCLUSION

A crucial aspect of research is to analyze the growth patterns of trees in different site settings to evaluate their potential for thriving in varying soil types, climatic conditions, and elevations. This information is instrumental in determining optimal planting sites and maximizing tree growth potential. By investigating the growth of *N. cadamba* under various conditions, one can identify the ideal requirements for soil, climate, and elevation for its optimal development. Such data can lead to improved cultivation techniques and enhanced tree productivity. *N. cadamba* is highly valued for its timber, medicinal properties, and ability to improve soil fertility while reducing erosion. Studying its growth across different environmental conditions helps pinpoint the best locations for planting the tree and maximizing its economic benefits. Additionally, while *N. cadamba* is recognized for its invasive tendencies in some areas, analyzing its growth patterns can help identify regions where the tree is less likely to exhibit invasive behavior, thus reducing potential ecological impacts.

Understanding the growth of *N. cadamba* in various site conditions is key to optimizing its growth, enhancing its economic advantages, and minimizing ecological consequences. This study will provide insights into tropical forest dynamics and the management of specific forest species by offering empirical data on the site factors influencing the growth and health of *N. cadamba*, thereby addressing gaps in knowledge about the growth responses of this species. Such understanding is vital for identifying strategies to effectively conserve and control *N. cadamba* in timber plantations, contributing to enhanced reforestation and sustainable forest management. It involves determining site conditions that improve resilience to climate variations, leading to a better comprehension of how this species can aid in managing climate change. Moreover, it will shed light on the tree's interactions with other plant species and wildlife within and around the plantation, as well as *N. cadamba* role in influencing species richness within the plantation system. Ultimately, the data gained from this study can be utilized by policymakers and land managers in making informed decisions regarding land use and conservation strategies in forest reserves, particularly in plantation areas. Furthermore, additional studies focusing on the growth performance of fast-growing species are recommended, especially concerning any treatments applicable during the early growth phase that consider different site conditions. The research should also be expanded to encompass various age stages of the planted trees.

ACKNOWLEDGEMENT

This research was carried out under the Universiti Malaysia Sabah Grant, project GUG0252-1/2018. We extend our gratitude to the research group team who contributed to this study, as well as to Universiti Malaysia Sabah and Jawala Plantation Sdn. Bhd. for their support and resources throughout the research process.

REFERENCES

Ajik, M. 2005. Early growth performance of Laran (*Neolamarcia cadamba*) in Segaliud Lokan, Sabah. Sepilok Bulletin. Vol. 5 2 June 2005.

Binkley, D. 2003. Seven decades of stand development in mixed and pure stands of conifers and nitrogen-fixing red alder. *Canadian Journal of Forest Research*, 33(11), 2274-2279 https://doi.org/10.1139/x03-158.

Dieler, J., & Pretzsch, H., 2013. Morphological plasticity of European beech (*Fagus sylvatica L.*) in pure and mixed-species stands. *Forest Ecology and Management*, 295, 97-108 https://doi.org/10.1016/j.foreco.2012.12.049.

Fox, J. E. D. 1971. *Anthocephalus Chinensis*, the Laran tree of Sabah. Economic Botany, 25(3), 221-233. https://www.jstor.org/stable/i389382.

Hashim, M.N., Hazim, M. & Syafinie, A.M. 2015. Strategic forest plantation establishment in Malaysia for future product development and utilisation. *International Journal of Agricultural Forestry and Plantation*, 1, 14-24.

Hodge, G.R., Dvorak, W.S. & Romero, J. L. 2001. Growth and provenance variation of *Pinus caribaea* var. hondurensis as an exotic species. *The Southern African Forestry Journal*, 190(1), 43-51.

Kanowski, J., Catterall, C.P. & Wardell-Johnson, G.W. 2005. Consequences of broadscale timber plantations for biodiversity in cleared rainforest landscapes of tropical and subtropical Australia. *Forest Ecology and Management*, 208(1-3), 359-372.

Kocher, S.D., & Harris, R. 2007. Tree Growth and Competition. University of California. Agriculture and Natural Resources. Oakland, California, 3-5. At: https://anrcatalog.ucanr.edu/pdf/8235.pdf.

Kozlowski, T.T. 1999. Soil compaction and growth of woody plants. *Scandinavian Journal of Forest Research*, 14(6), 596-619.

Krisnawati, H., Kallio, M. & Kanninen, M. 2011. *Anthocephalus cadamba* Miq. Ekologi, Silvikultur, dan Produktivitas. CIFOR. Bogor. Indonesia.

Lee, Y.F., Chia, F.R., Anuar, M., Ong, R.C. & Ajik, M. 2005. The Use of Laran and Binuang for Forest Plantations and Intercropping With Oil Palm in Sabah.

Lebourgeois, F., Gomez, N., Pinto, P. & Mérian, P. 2013. Mixed stands reduce *Abies alba* tree-ring sensitivity to summer drought in the Vosges Mountains, Western Europe. *Forest Ecology and Management*, 303, 61-71.

McDonald, R.I. & Urban, D.L. 2004. Forest edges and tree growth rates in the North Carolina Piedmont. *Ecology*, 85(8), 2258-2266.

M Khatta, A.N., Mekai, M.H.A., Kadir, A.M., Suhinin, O.A., Suhaidi, H., Abdullah, N., Nyen, K.P.K., Kimjus, K., Terhem, R, & Hassan, A. 2023. Acclimatisation of White Laran (*Neolamarckia cadamba* Roxb. Bosser) and Binuang (*Octomeles sumatrana* Miq.) seedlings to water-logged and water-stress conditions. *Forests*. 2023; 14(3):500. https://doi.org/10.3390/f14030500.

Naghdi, R., Bonyad, A. & Mobasher Amini, A. 2017. Road effect on diameter growth of trees in Caspian forests of Iran. *Caspian Journal of Environmental Sciences*, 15(1), 47-55.

Poorter, H., Niklas, K.J., Reich, P.B., Oleksyn, J., Poot, P. & Mommer, L. 2012. Biomass allocation to leaves stems and roots: meta-analyses of interspecific variation and environmental control. *New Phytologist*, 193(1), 30-50.

Skovsgaard, J. P. & Vanclay, J.K. 2008. Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands. *Forestry: An International Journal of Forest Research*, 81(1), 13-31.

Tripathi, A.K., Srivastava, A.K. & Pandey, S.N. 1993. *Advances in environmental sciences*. APH Publishing, 9.

Walker, W., Baccini, A., Nepstad, M., Horning, N., Knight, D., Braun, E. & Bausch, A. 2011. *Field Guide for forest biomass and carbon estimation*. Woods Hole Research Center, Falmouth, Massachusetts, USA.

Yulianti, Y. & Sudrajat, D.J. 2016. Morphological responses, sensitivity and tolerance indices of four tropical tree species to drought and waterlogging. *Biodiversitas Journal of Biological Diversity*, 17(1).