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The Performance of Legume and Non-legume Trees under Dry Karst Areas

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Abstract

Karst areas in Indonesia are arid landscapes with water-use limitations because of dissolved carbonates. Long-term water scarcity stunts plant growth and often kills them. For tropical karst forestry-greening, the three best legume and three best non-legume species from a previous trial comprising 20 species were compared. Since October 2011, seedlings of the top three non-legume, species Aleurites mollucana, Sterculia foetida, and Alstonia scholaris, and three legume species, Acacia auriculiformis, Cassea seamea, and Acacia mangium, have been grown for four months. In January 2012, field trials were established at two dry karst locations, i.e., Pracimantoro, Central Java, and Bunder, Gunung Kidul Yogyakarta. A randomized block design was used to raise 1.764 seedlings at the two sites with 7×7 plots, 3×3 spacing between trees, and three blocks. After 10 months, legumes and non-legumes differed greatly in all growth parameters. These disparities lasted up to 30 months, when trees should have adapted to their new surroundings. After seven years of planting, legume trees raised the soil's organic matter concentration from low to medium, making it more fertile, similar to soil from intensive agricultural regions. Thus, early or mixed legume plantings on tropical karst sites may aid in better re-greening than the establishment of non-legumes.

Keywords: *drought, growth, legume, non-legume, karst area*

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Introduction

Karst is a distinctive and dry landscape characterized by limestone geology. Karst aquifers, therefore, have a high dissolved carbonate content. Approximately 25% of the global population relies on karst aquifers for their drinking water (Ford & Williams, 2007). The distinctive geographical environment and seasonal fluctuations of karst regions can pose challenges to plant growth and circumstances. Dehydration of plants is a prominent feature of karst regions (Liu et al., 2021). Plant water availability is common in karst environments due to the limited water storage capacity and significant seasonal fluctuations in the thin and rocky karst soils resulting from the presence of double-layer hydrogeological structures (Ford & Williams, 2007). Drought or water stress is a major limitation that significantly impacts plant photosynthesis, growth, and survival in karst environments (McCole & Stern, 2007; White et al., 1985). Karst terrain has a high degree of susceptibility to alterations in the environment and human intervention (Ford & Williams, 2007), and the act of planting trees serves as a favorable measure for preserving the landscape. It is anticipated that the current water stress experienced by plants in karst regions might significantly worsen in the future because karst terrain is extremely vulnerable to anthropogenic environmental changes, particularly climate change. This is due to the fact that climate change, by elevating temperatures and reducing both the amount and distribution of precipitation, leads to drought conditions in karst regions (Harmoni, 2005). The primary cause of declining water storages in the ground and water shortage on the soil surface is the reduction in precipitation, leading to hydrological and agronomical droughts (Sujinah & Jamil, 2016). There is empirical data indicating that climate change-induced droughts lead to widespread plant mortality across all age groups (Allen et al., 2010; Chenchouni, 2010). Hence, it is imperative to select trees for plantation in karst regions with optimal growth to provide land coverage, enhance soil quality, and adapt to climate change.

Drought is the primary abiotic factor that limits plant growth by disrupting normal physiological processes (Fathi & Barari, 2016). The impact of drought on plants is multifaceted, leading to both dehydration and overheating. The impact of drought on plants varies due to the absence of a universally applicable mechanism for plants to adjust to dry conditions. Drought tolerance also differs across different life stages. Plants, particularly trees, offer greater advantages

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in restoring vegetation to marginal regions compared to agricultural crops. When water is scarce, plants with deeper and larger root systems are more advantageous than those with shallower roots. Furthermore, studies have proven that implementing forest conservation and restoration enhances the ecosystem's water utilization (Zhao & Wu, 2023).

Legumes serve as a dependable means of fulfilling the nitrogen need by utilizing Rhizobium bacteria to convert atmospheric nitrogen into a usable form within nodules on their roots (Akça et al., 2022; Baskorowati et al., 2024). Legume species are commonly used for land rehabilitation due to their rapid growth, multifunctionality, and ability to fix nitrogen, which accelerates their development and enhances soil nutrient fixation. Nitrogen is the costliest, most energy-demanding, and if applied inappropriately, the most ecologically detrimental of the essential fertilizers for plant development. It has been suggested that the integration of crops with nitrogen-fixing trees (NFTs) can help maintain the diversity and long-term viability of tropical ecosystems. For the purpose of rejuvenating degraded soil, legume tree species have the potential to contribute 12 tons of dry organic matter and 190 kg of nitrogen per hectare annually (Franco & de Faria, 1997). Cultivating legumes can be a highly successful strategy for decreasing land degradation and mitigating climate change in various soil types and geographic situations (Akça et al., 2022). Although non-legume trees generally have a slower growth rate compared to legumes, some of them also have the ability to thrive under drought conditions (Hendrati, 2016). Among the requirements for species selection, plants that rapidly cover large areas are beneficial for land reclamation due to their ability to mitigate soil erosion, enhance soil biodiversity, and promote carbon sequestration. Enhancing growth in dry regions is essential for achieving increased biomass through improved speed and quality. This study examines the success of growing legume and non-legume trees in the fields of two karst sites. This can assist in selecting the appropriate tree species for initial planting or mixed planting in karst areas.

Methods

Time and locations The experiment commenced in October 2011 by cultivating seedlings of three legume species and three non-legume species, which were among the 20 arid species studied in two different locations. Two field trials were initiated in January 2012 in two arid karst locations.

Seedlings were raised for up to four months in the Centre for Forest Biotechnology and Tree Improvement nursery in Yogyakarta. Plantation trials were established in Pracimantoro, Wonogiri, Central Java, and Bunder, Watu Sipat, Yogyakarta, Indonesia (Figure 1). Those areas were selected to meet different requirements. The plantation site at Pracimantoro was expected to experience dry annual conditions, and is positioned in a karst tourism area where the Karst Museum could be used to promote the results of the project. The second trial site at Bunder was chosen to test the r species appropriate to the hilly karst area in Gunungkidul, Yogyakarta. Both sites are parts of the karst range of Java Island's karst range, Gunung Sewu . Table 1 contains detailed information on both trial sites. Soil analyses were conducted in the soil laboratory of the Faculty of Agriculture, Gadjah Mada University.

Materials The six species were chosen based on their superior performance among 20 species that were previously evaluated under karst conditions (Hendrati, 2016). The seedlings were chosen for uniformity after a period of four months in the nursery. The selected legume species were *Acacia auriculiformis, Cassea seamea*, and *Acacia mangium*, while the top three non-legume species are *Aleurites mollucana, Sterculia foetida*, and *Alstonia scholaris*. A total of 1,764 seedlings, encompassing all six species, were cultivated for field testing at the two sites.

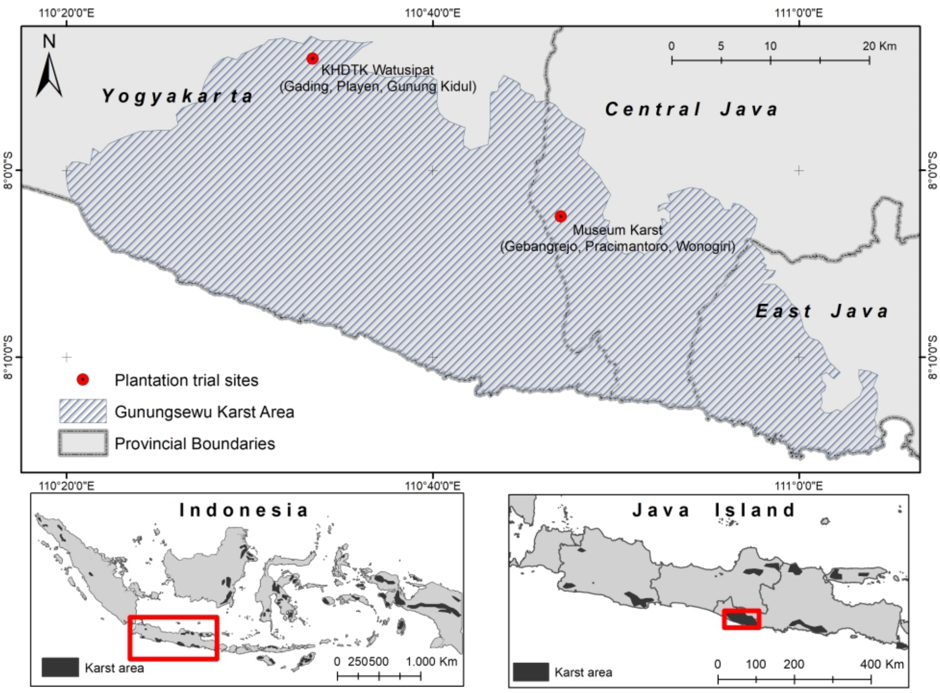

Figure 1 Map of the trial sites.

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Table 1 The conditions of of the dry karst field areas in Pracimantoro, Wonogiri, Central Java, and Bunder, Gunungkidul, Yogyakarta, Indonesia

Location	Topography	Position	Climate	Soil characters	Character
Pracimantoro, Wonogiri, Central Java, Indonesia	290 m asl. Hilly terrain. It makes it challenging to locate uniform places for trials in the karst tourist region near the Pracimantoro national karst museum.	S8°02′33″ E110°46′59″	Precipitation = 1,500 mm year^{-1} Average temperature = 25.1 °C	Mediterranean that developed from limestone. The soil is red to yellowish red in color, loamy in texture, granular to cloddy in structure, firm in consistency and very sticky when wet, slow in permeability and classified as having low to medium fertility.	Due to the karst soil's porous nature and inability to retain water in the surface soil, water is scarce throughout the dry season. The neighboring river and the majority of the water sources that are becoming depleted and even dry during the dry season are indicators of a scarcity of water.
Bunder, Gunungkidul, Yogyakarta, Indonesia	160 m asl. A slight hilly with some flat relief to hilly.	S7°54′02″ E110°33′27″	Precipitation = 1,788 mm year^{-1} Average temperature = 26.4 °C	Grumosol with intermediate napal and tuff parent material. Heavy clay texture, granular structure in the upper layer and clumpy to solid in the lower layer. Montmorillonite clay, alkaline, high base saturation and adsorption capacity, slow permeability and erosion sensitive.	The Oyo river forms fluvial terraces and limestone outcrops are found.

Source: Kabupaten Wonogiri Dalam Angka (Wonogiry Regency in Figures), 2021

Experimental design The trials were conducted using a randomized complete block design, with three complete block replications at each site. Every seedling was planted into a hole of 30 cm × 30 cm × 30 cm, and the hole was filled with 2 kg of compost derived from cow manure. Each species was planted in a 49-tree rectangular plot consisting of 7 rows and 7 columns of trees, with a spacing of 3 m × 3 m between each tree. In order to mitigate any potential bias in the data collected from the periphery of each 7 × 7 plot, only the inner net plot 25 of trees (arranged in 5 × 5 trees) within each plot were subjected to measurement.

Measurement At the age of 10 months, the height, diameter (20 cm above ground), number of branches, and crown diameter of trees in the 25-tree net plots at the two locations were measured. The trials were assessed again at 30-months post planting, however, due to low survival at Bunder (<50%), only the Pracimantoro site was assessed for height, diameter (diameter at breast height), and crown diameter. Soil samples were gathered from the Pracimantoro site after a period of seven years post-establishment. The samples were taken from the individual tree plots of each species, namely from underneath the tree stands. The soil was collected at depths of 0–20 and 20–40 cm. The organic and moisture contents of the three replicated soil samples were subsequently assessed. For contrast, agricultural plots in the karst region that had undergone extensive cultivation and had been treated with cow manure compost before each initial crop were also included.

Data analysis With species nesting into the plant groups of legume and non-legume, analyses of variance were conducted to statistically test the data from the field experiment. The Tukey test was then used to further evaluate the results. The formula used for analysis of each trait at age 10-months (1) and for single sites at age 30-months (2) was as shown in Equation *[1]* and Equation *[2]*. The model was implemented in R Studio V.4.3.1 statistical software.

$$Y_{ijklm} = \mu + B_i(S_j) + S_j + G_k + Sp_l(G_k) + S_i{*}G_k + S_j{*}Sp_l(G_k) + B_i{*}S_j{*}Sp_l(G_k) + \varepsilon_{ijklm} \qquad [1]$$

$$Y_{ijklm} = \mu + B_i + G_k + Sp_l(G_k) + \varepsilon_{ijklm} \qquad [2]$$

Note: Y_{ijklm} = individual observation on each tree, μ = mean value, $B_i(S_j)$ = effect of i^{th} block within site j^{th}, S_j = effect of j^{th} site, G_k = effect of k^{th} group (legume/non-legume), $Sp_l(G_k)$ = effect of l^{th} species nested within k^{th} group, $S_j{*}G_k$ = interaction between j^{th} site and k^{th} group, $S_j{*}Sp_l(G_k)$ = interaction between j^{th} site and l^{th} species nested into k^{th} group, $B_i{*}S_j{*}Sp_l(G_k)$ = interaction between i^{th} block and j^{th} site and l^{th} species nested into k^{th} group (plot), ε_{ijklm} = residual (error).

Results

At the age of 10 months in two locations Significant variations were observed among treatments across locations, among groupings of legume and non-legume plants, and among species. Table 2 reveals the discovered interactions between sites and groups, as well as between sites and species. The Bunder trial (Table 3) outperformed

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Pracimantoro in all traits, except for survival, which was higher in Pracimantoro. Legumes exhibited superior performance compared to non-legumes at both locations, with a roughly 70% higher height and 31% higher diameter and a twofold increase in both the number of branches and crown diameter. *A. auriculiformis* consistently exhibited superior performance compared to other species. Non-legume species typically occupy lower rankings for each trait.

At the age of 30 months in Pracimantoro Due to the significant decrease in survival rate (<50%) in the Bunder area, the evaluation at 30 months was only examined for the Pracimantoro site. The Pracimantoro analysis (Table 4) revealed considerable variations in the characteristics of groups, species, and interactions, except for the number of branches. At this particular age, *A. auriculiformis* has superior performance in all characteristics, as indicated in Table 5. Legume species were superior in terms of height,

Table 2 ANOVA of field trials between legume and non-legume at two karst field sites at 10 months post-planting

Source of variation	MS of height (cm)	Pr > F	MS of diameter (mm)	Pr > F	MS of number of branches	Pr > F	MS of crown width (cm)	Pr > F
Block	34,395*	0.045	178.67ns	0.11	97.96*	0.036	23,236**	0.00468
Site	1,466,059***	<2e-16	6,387***	<2e-16	2,935.7***	< 2e-16	407,860***	<2e-16
Group (Legume vs non-legume)	1,129,787***	<2e-16	3,839***	1.8e-12	3,109.3***	<2e-16	553,475***	<2e-16
Species (Group)	544,765***	<2e-16	2,122***	<2e-16	1,236***	<2e-16	194,441***	<2e-16
Site*Group	988,708***	<2e-16	4,072***	<2e-16	2,382***	<2e-16	347,806***	<2e-16
Site*Species (Group)	462,230***	<2e-16	2,192***	<2e-16	1,011.1***	<2e-16	141,383***	<2e-16
Block*Site*Species (Group) (plot)	173,947***	<2e-16	942.8***	<2e-16	373.6***	<2e-16	60,432***	<2e-16
Error	8,233,775		26,859		8,788.8		1,105,274	

Table 3 Tukey test results based on site, group, and species at 10 months old between 2 karst sites

Treatments	Site/Group/Species	Survival (%)	Height (cm)	Diameter (mm)	Number of branch	Crown width (cm)
A. Site	Pracimantoro	93.1 a	109.08 b	14.3 b	2.9 b	60.4 b
	Bunder	71.6 b	198.81 a	20.2 a	6.9 a	107.8 a
B. Group	Legume	80.2 a	188.13 a	19.2 a	6.7 a	109.0 a
	Non-legume	84.4 a	110.01 b	14.6 b	2.6 b	54.4 b
C. Site*Group	Pracimantoro*Legume	92.4 a	131.2 b	15.1 b	4.0 b	80,4 b
	Pracimantoro*Non-legum	93.8 a	88.5 c	13.3 c	1.8 c	40.7 c
	Bunder*Legume	68.0 b	265.5 a	24.7 a	10.5 a	147.9 a
	Bunder*Non-legum	75.1 ab	138.4 b	16.4 b	3.7 b	71.4 b
D. Species	*A. auriculiformis*	86.0 a	261.7 a	23.6 a	10.1 a	143.7 a
	A. mangium	65.3 b	177.9 b	16.4 bc	5.1 b	81.9 b
	C. seamea	89.3 a	124.8 cd	17.1 b	4.8 b	95.5 b
	A. mollucana	74.7 a	147.7 bc	18.6 b	2 4 c	49.8 c
	A. scholaris	89.3 a	115.6 d	14.0 cd	4.5 b	81.0 b
	S. foetida	89.3 a	72.9 e	11.9 d	1.0 c	31.5 c

Table 4 ANOVA between legume and non-legume in Pracimantoro karst field trial at 30 months

Source of variation	MS of height (cm)	Pr > F	MS of diameter (mm)	Pr > F	MS of number of branch	Pr > F	MS of crown width (cm)	Pr > F
Block	413,532**	0.00153	52.90**	0.00172	2.49 ns	0.81	23,710 ns	0.249
Group (Legume vs non-legume)	8,400,621***	<2e-16	451.9***	2.89e-14	40.29 ns	0.0641	1,549,443***	<2e-16
Species (Group)	2,823,589***	<2e-16	213.46***	<2e-16	154.70***	4.53e-14	495,888***	<2e-16
Block*Species (Group)	1,136,686***	<2e-16	122.78***	<2e-16	125.37***	<2e-16	253,690***	<2e-16
Error	470,227		1,040.9		2,243.0		2,020,860	

diameter, and crown diameter, with legumes surpassing non-legume species by about 150% to double the amount in each of these categories.

Soil samples after 7 years Significant differences in moisture content are seen among legume groups, non-legume groups, and intensively cropped soil, as shown in Table 6. The legume and crop cultivated soil exhibits the capacity to generate organic matter (Table 7). Meanwhile, the legume organic matter tends to be higher at a depth of 20–40 cm compared to the non-legume ones after 7 years.

Discussion

Effects of location The Pracimantoro and Bunder karst areas are included in the Pegunungan Sewu Karst array, which stretches to Pacitan in East Java (Haryono et al., 2017). However, it seems that the planting performances at the two places are clearly different in some aspects (Table 2). Various factors, including the administration of site upkeep, drove these disparities. Working with diverse contributors in several locations can have a substantial influence. The Karst museum in Pracimantioro Wonogiri was intentionally selected due to its popularity among tourists and its nomination for global heritage classification as a karst area in 2010; it was planned to be encircled with scenic surrounds (Rafi & Danardono, 2024). In contrast, the Bunder region is characterized by its steep karst topography. The primary objective for this region is ecosystem restoration through reforestation efforts. The Pracimantoro site received greater care, as indicated by enhanced survival (Table 3), despite the location being considerably drier and hillier. Bunder experiences a higher annual precipitation rate of approximately 1,800 mm year^{-1} compared to Pracimantoro's 1,500 mm year^{-1}. Consequently, the adoption of the contour strategy for constructing terraces to cultivate temporary rainy-season crops has gained popularity in this Bunder area as a means of preserving soil fertility. The combination of precipitation and soil fertility likely influenced the growth parameters of height, diameter, branch count, and crown

Table 5 Tukey test results based on group and species at 30 months in Pracimantoro karst site

Treatments	Group	Survival (%)	Height (cm)	Diameter (mm)	Number of Branch	Crown width (cm)
a. Group	Legume	84.9 a	567.8 a	6.1 a	5.5 a	304.1 a
	Non-legume	80.9 a	267.6 b	3.9 b	4.8 a	175.1 b
b. Species						
- Legume	*A. auriculiformis*	81.3 a	729.4 a	7.5 a	6.1 ab	344.5 a
	A. mangium	78.7 a	595.4 b	6.0 bc	4.4 c	289.2 b
	C. seamea	94.7 a	406.2 c	4.9 c	5.9 abc	281.7 b
- Non-legume	*A. mollucana*	72.0 a	434.5 c	6.1 b	7.3 a	276.1 b
	A. scholaris	81.3 a	170.1 d	2.8 d	4.9 bc	132.0 c
	S. foetida	89.3 a	221.9 d	2.9 d	2.7 d	133.0 c

Table 6 Pracimantoro karst field trial after 7 years of planting: ANOVA of organic matter and moisture content between soil depth and legume, non-legume, and crop-cultivated soil groups

Sorce of variation	Organic matter		Moisture content	
	Mean square	Pr > F	Mean square	Pr > F
Depth	0.1387 ns	0.3190	0.3042 ns	0.4840
Group	0.3119 ns	0.0859	1.7046 *	0.0404
Depth*Group	0.3348 **	0.0025	0.8169 ns	0.2050
Error	0.5608		5.7096	

Group: 1 = legume, 2 = non-legume, 3 = crop cultivated
Depth: soil depth at 1-20 cm and >20-40 cm

Table 7 Pracimantoro karst site Tukey test results of organic materials between groups and depth interaction after 7 years of planting

Treatment	Organic material mean (%)
a. Group	
Intensively crop cultivated	2.42 a
Legume	2.21 a
Non-legume	1.96 a
b. Depth*Group	
20–40 cm * Intensively crop cultivated	2.64 a
1–20 cm * Legume	2.39 ab
1–20 cm * Non-legume	2.28 ab
1–20 cm * Intensively crop cultivated	2.20 abc
20–40 cm * Legume	2.05 bc
20–40 cm * Non-legume	1.65 c

breadth. However, imited maintenance efforts and human disturbance during the dry season, when leaf collection for livestock fodder occurs, significantly lower the overall survival rate (Table 3). This is confirmed by the fact that only 20 months after planting Bunder's survival rate had drastically declined from above 70% to below 50%.

Water scarcity is a crucial element contributing to the mortality of seedlings during the establishment of an artificial forest, particularly under drought (Villar-Salvador et al., 2004). In this study, in seasonally dry conditions, there were noticeable differences in plant growth between the legume and non-legume plants in all growth characteristics after only 10 months in the field (Table 3). This occurs for up to 30 months, as indicated in Table 5. This befalls at the stage when trees are expected to have begun adjusting to the new environment after a period of 2 years (Setiadi et al., 2021). In standard forestry procedures, the maintenance of young plants usually continues up to approximately 2 years of age. This is because seedlings need time to acclimate and adapt to their new field habitat (Hendrati, 2016). The ensuing plant's survival would then be greatly impacted by its vigor, and a decrease in vigor could potentially lead to a reduction in survival and yield (Snider et al., 2014). However, the impact of microorganisms in the soil, such as rhizobia, on the growth and health of legume plants has been proven to help legume survival (Biswas et al., 2000). After a period of 30 months, obvious variations were observed, suggesting a cumulative impact of the environment. The variations seen within each plant group in this study highlight the benefits of carefully selecting legume plants for planting in arid karst regions, at least as pioneers.

Impacts of groups and species The legumes exhibited superior development and a wider crown, measuring 30% to almost twice as much as the non-legumes in this study (Table 3, Table 5). Rapid provision of canopy cover to reduce erosion is an important function of planted forests in karst regions; thus, when choosing species for plantations in dry locations, the crown should also be taken into account. This also impacts the role of trees in efficiently attenuating heat, facilitating heat dissipation through evaporation, reducing temperatures by providing shade, and regulating air circulation. In addition, it was discovered that the width of the crown of trees effectively reduces the presence of undesirable gases such as NO_2, SO_2, and CO. Further, the presence of living trees enhances the aesthetic appeal and provides a more comfortable environment compared to places devoid of trees (Coder, 1996). Unfortunately, this study does not evaluate crown density, which is a feature that should also be considered when considering shade for the tourism regions. Additionally, legumes with greater crown biomass are likely to accumulate soil organic matter more rapidly (Thiffault et al., 2011).

Plants typically exhibit a significant demand for nitrogen. Nitrogen becomes a crucial limiting factor as a macronutrient in natural ecosystems due to its intermittent scarcity in its readily available form, making it one of the most limiting mineral components for plant growth and productivity (Turnbull, 2003). In contrast to non-legume trees, legume trees have the potential to fix nitrogen from the atmosphere into a usable form. They are therefore more desirable for rapid land coverage. However, in dry environments, the nitrogen-fixing capacity of plants may decrease by 30% (Larrainzar et al., 2007; Larrainzar et al., 2009). In this study, the legume trees consistently outperformed the non-legume trees in both the rainy season (10 months) and the dry season (30 months).

Legumes have superior leaf features for soil improvement compared to non-legumes, as their leaves are more easily decomposed and contain a substantial amount of nitrogen, which enhances soil nutrients. Even slow-degrading leaf-like thick phyllodes found in the legumes *A. auriculiformis* and *A. mangium* still provide significant benefits by protecting microbial life in the soil, shielding it from direct sunlight, and preventing erosion and nutrient loss (Huong et al., 2020). According to Xiong et al. (2008), research conducted on the *A. mangium* stand after 1 year found that 75.2% of the litter had decomposed when left undisturbed. The quantity of litter deposited on the ground leads to increased decomposition, resulting in the production of organic matter. Additionally, acacia litter is very helpful for keeping the soil moist and making it more fertile by raising the levels of organic matter (OM), alkali-hydrolyzable nitrogen (N), and accessible phosphorus (P) (Xiong et al., 2008). Furthermore, (Ngoran et al., 2006) found a positive relationship between the dry weight of litter in *A. auriculiformis* and *A. mangium* and the concentration of nitrogen. Therefore, it may be inferred that the leaves from the legume crown would offer better protection, more litter, and a higher nitrogen content (Gei & Powers, 2013; Niu et al., 2003). Hence, the trials corroborate the notion that legumes are more suitable for cultivation in arid areas, such as karst, for the purpose of soil coverage compared to non-legumes.

Effect of legume on soil organic matter After a period of 7 years after planting, the observations made in this study demonstrate that legume trees tend to improve the soil quality by increasing the amount of organic matter present in the soil (Table 7). This improvement has resulted in the soil's transformation from a state of low fertility to a state of medium fertility (as defined by the BPT 2005 standards). In addition to nitrogen fixation, the decomposition of plant material by legumes may also contribute to the build up of organic matter. Further, the presence of soil organic matter is also recognized for its significant function in promoting favorable soil structure, providing essential nutrients, and enhancing ion exchange capacity, particularly in tropical soils. This trial has received minimal maintenance, with only a limited application of fertilizer and periodic removal of weeds over the initial two years following planting. At this time of observations, the organic matter content of crop-cultivated soil tends to be larger than that of legumes, as seen in Table 7. except on the surface. However, since the organic matter will build up over time, the following three beneficial effects could happen: physically, an improvement in soil structure and water holding capacity; chemically, better cation exchange capacity, buffering, and pH; and biologically, an improved source of energy and nutrients and soil resilience (Krull et al., 2004). With these benefits, in the long run, legume trees would tend to be better than non-legume trees in improving karst soil in terms of organic matter and expected soil moisture, and can be used as pioneers before introducing non-legume trees.

Planting legumes, exemplified by the *L. leucocephala* tree, has a positive impact on soil characteristics by increasing porosity from 64.22% to 69.20%, enhancing the infiltration rate from 0.43 cm min^{-1} to 1.66 cm min^{-1}, and improving particle density from 2,220 kg m^{-3} to 2,680 kg m^{-3}. Further, legumes have a crucial role in minimizing planting costs by preserving soil fertility through their use of their green manure (Youkhana & Idol, 2008; Hendrati et al., 2022). This helps promote plant growth and decreases the need for additional nitrogen fertilizer (Rose et al., 2019). Because there is a significant likelihood that trees growing in soil with low nutrient content will produce a greater number of roots (Helliwell, 1986). Therefore, it would be interesting to study more the growth of roots in legume and non-legume plants over a period of time in karst environments.

Other considerations for selecting trees for karst To enhance soil fertility, legumes can be initially cultivated in karst regions requiring restoration, or they can be intercropped with non-legume crops to establish advantageous and beneficial conditions. Implementing agroforestry through the integration of intercropping with legumes is a management strategy used to preserve and enhance soil organic matter levels, particularly in tropical agriculture (Ross, 1993), and this should be applicable in tropical karst. Given the typically poor economic conditions of the karst community, it is important to select species for planting in dry areas that not only possess suitable biomass and crown width and the ability to improve the soil and environment, but also have the ability to fulfill the needs of the local community through their by-products (Franzel et al., 1996). These encompass by-products generated during the manufacturing of pharmaceuticals, foliage utilized as livestock fodder, blossoms for apiculture, biofuel, etc.

However, for food purposes, the secondary products of the tree can be collected from the karst environment, even when the main tree is still alive and undisturbed, such as its fruits, flowers, or specific insects that live seasonally. Nevertheless, a significant hindrance to the survival of trees in karst environments is the reliance of impoverished individuals on fuel wood as a fundamental requirement. Hence, it is imperative to provide trees that can adequately satisfy the need for fuel wood. Opportunely, many legumes possess robust coppicing capabilities, and therefore they can be employed as an alternative to primary trees for continuous fuel wood production from the coppice while leaving the cut stem attached to the ground.

In the initial rainy season, the yearly coppice can be harvested, allowing the surviving trunk to produce new shoots in response to the next rain. Consequently, the trunk can remain in the soil for an extra 10 to 15 years, promoting the preservation of soil structure, stimulating root development, and preventing erosion and nutrient loss. The leguminous plants *A. Auriculiformis, L. leucocephala, Calliandra callothyrus,* and *C. seamea* have been proven to generate coppices that can be used as a renewable source of fuelwood biomass (Hendrati 2015; Hendrati 2016; Hendrati and Nurrohmah 2018). Although the ability to produce extensive root systems is not as widespread among non-legume plants, legumes are a more suitable option for initial cultivation in karst landscapes**.**

Conclusion

Legumes outperformed non-legumes in terms of growth. At the age of 10 months, the plants in Bunder outgrew those in Pracimantoro, but the management was suboptimal, resulting in a significant decrease in the percent survival rate. Although legumes generally grow better, species selection is because of the variety found among legume species. It is critical to prioritize the needs of disadvantaged local communities, particularly those that provide valuable by products.

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Contributors

The primary author of this study is RLH, LB, ILG and M, who performed the field research, gathered data, analyzed the data, composed the initial text, and edited the publication. The other authors contributed to the acquisition of field data.

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