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Organic ameliorant and density arrangement affected the growth of *Calliandra calothyrsus* in nursery

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Abstract. *Sofyan FPM, Hartati W, Sudarmadji T, Syahrinudin. 2024. Organic ameliorant and density arrangement affected the growth of* Calliandra calothyrsus *in nursery. Asian J For 8: 107-114.* Seedling quality is crucial for forest stand development, but optimizing nursery conditions for specific species like *Calliandra calothyrsus* Meisn. needs further research. This study aims to investigate how organic ameliorants and seedling density affect *C. calothyrsus* seedling growth performance in nurseries. Three replicates of 4 levels of organic ameliorant (0%, 25%, 50%, and 100%) and 3 levels of seedling density (100, 25, and 16 seedling/m^2) were applied in a compatible arrangement with a factorial randomized design procedure. Each replication of treatment consisted of 30 seedlings for the assessment of the survival rate, diameter, height, and biomass accumulation. Ameliorant treatments and seedling density significantly influenced diameter, height, and biomass, whereas survival rate was unaffected by treatments. Only densities of 25 and 16 seedlings/m² met Indonesian quality standards (SNI 5006.2.2018) for field transplantation. This study demonstrates that improving the root environment through organic ameliorants and density management can enhance *C. calothyrsus* seedling growth in nurseries. This research offers insights for optimizing agroforestry seedling production. Identifying densities meeting national standards enhances reforestation success. The study lays the groundwork for future research on seedling quality and species-specific protocols in tropical agroforestry. Results can guide practitioners in producing high-quality seedlings, potentially improving reforestation efficiency and effectiveness.

Keywords: Biomass, energy crop, red calliandra, seedling growth, soil amendment

INTRODUCTION

Calliandra calothyrsus Meissn. (red caliandra) is a fast-growing woody shrub from the Fabaceae family, native to the tropical and subtropical Americas (Messi et al. 2020). It is locally used as fuelwood, plantation shade, and livestock forage or fodder. Since the 1970s, this species has been widely introduced and planted in agroforestry systems across approximately 30,000 hectares in Indonesia through a program by the Indonesian State Forest Corporation (Yudaputra 2020; Kosasih et al. 2022). The *C. calothyrsus* has high adaptability to local climatic conditions, especially at altitudes ranging from 250 to 1,800 meters above sea level (de Luna et al. 2020). It is readily found as a pioneer species in the forest successional stage (Binayao et al. 2021).

As a legume plant, *C. calothyrsus* can be utilized in revegetating post-mining land due to its ability to associate with Rhizobium and fix nitrogen from the air, improving soil nutrients. This allows it to cover the soil surface on rehabilitation land rapidly (Nyenda et al. 2020). Interestingly, *C. calothyrsus* has been reported as a promising energy crop, possessing a high heating value with low moisture content (Amirta et al. 2016, 2019; Yuliansyah et al. 2019). Its charcoal product also exhibits superior energy quality, with a calorific value of 7,200 kcal kg^{-1} (Saputra et al. 2022).

When cultivating *C. calothyrsus* for energy production, another benefit is the opportunity to plant it as a Short Rotation Coppice (SRC) crop due to its ability to regrow stems after harvesting (Haqiqi et al. 2018; Widyati et al. 2022). The harvested wood yield can reach 152 m^3 ha^{-1} or 76.3 tons ha^{-1} per year with a planting distance of 1×1 m^3 (Hendrati et al. 2020). These favorable characteristics have led to significant attention for *C. calothyrsus* as a promising biomass-based renewable energy feedstock, as instructed by the Government of Indonesia under Precedent Decree No.79/2014. Furthermore, Indonesia has announced the National Energy Policy, aiming to source 23% of total energy consumption in 2025 from renewable energy sectors (Bappenas 2020)

When developing large-scale plantations, producing high-quality, ready-to-plant seedlings is crucial. Providing appropriate growth media for seedlings in the nursery is one of the most essential factors. During seedling growth, the medium should contain sufficient water and oxygen to distribute to the plant roots (Krishnapillai et al. 2020). Organic fertilizers are also necessary to enrich nutrients in the media. Bokashi, a commercial organic substance frequently used as a substitute for chemical fertilizers, can improve soil fertility and restore its physical, chemical, and biological properties. It is commonly produced from agricultural wastes like straw, husk, and corn stalks, which are fermented by commercially effective microorganisms (EM-4) (Joshi et al. 2019).

An ameliorant like biochar, a carbon-rich solid material formed by low-oxygen combustion (pyrolysis) and utilized as a soil improvement agent (Mulinari et al. 2021), can improve soil quality (Dariah et al. 2019, 2021), increase soil retention of water and nutrients (Oni et al. 2019), increase pH and soil organic matter content (Cooper et al. 2020), boost nutrient usage efficiency (Hossain et al. 2020; Azman et al. 2023), and promote soil microorganism activity (Egamberdieva et al. 2021; Liu et al. 2021). Additionally, biochar application to soil reduced runoff by 25% and erosion by 16% (Gholamahmadi et al. 2023).The use of biochar has been widely observed to increase plant growth and production (Sarfraz et al. 2019; Dai et al. 2020; Zhang et al. 2021; Ji et al. 2022). Based on research conducted by Simiele et al. (2022) showed that biochar and/or compost applications improved growing medium physicochemical characteristics by increasing electrical conductivity, cation exchange capacity, and nutrient concentrations.

Implementing appropriate seedling density arrangements is also crucial to achieving the best conditions. According to Larijani et al. (2019), plant spacing is considered one of the significant management strategies to minimize space competition, which reduces the potential for diseases, especially during the rainy season. The adjustment of density or population is strongly related to the level of competition and growth factors of the plants.

Based on the above description, a study was conducted to determine the effect of providing soil amendments in the planting medium, as well as a polybag spacing treatment, on the growth of *C. calothyrsus* seedlings in the nursery to support its utilization as an energy crop.

MATERIALS AND METHODS

Study area

The research was carried out in the nursery of the Silviculture Laboratory, Faculty of Forestry, Universitas Mulawarman, East Kalimantan, Indonesia. It took six months to complete, with the last three months dedicated to growth observations.

Procedures

Seedling and media preparation

The selected seedlings of *C. calothyrsus* used in this study were three months old. The growing media applied in the research experiments was a combination of subsoil and organic ameliorants. The percentage of those growing media depended on the treatment generated from used experimental design. The subsoil was prepared at the Soil Sciences and Forest Nutrition Laboratory, Faculty of Forestry, Universitas Mulawarman. The organic ameliorant is made from a mixture of bokashi and biochar which has been enriched with 2% NPK fertilizer, with a bokashi:biochar ratio of 9:1 (v:v). This organic ameliorant is a product of the Forestry Faculty Silviculture Laboratory's Compost House.

Experimental design

The 3-month-old *C. calothyrsus* seedlings used in this study were transferred into polybags measuring 10×15 cm. These polybags were filled with four different levels of organic ameliorant (which then became treatment A). The other treatment is density per square meter (treatment B). Both treatments are made in three repetitions and consist of 30 units for each treatment dose. The observation units total 1,080 plants. The *C. calothyrsus* seedlings were grown on each treatment in a greenhouse for 6 months. Growth occurs under controlled water regimes, natural humidity, and temperature, and the plants were arranged in a randomized, complete design. The polybags were watered to prevent water stress (once a day, as required), and a suspended net was used to reduce exposure to sunlight.

The four treatments of soil ameliorant dose were 0%, 25%, 75%, and 100%. The three treatments of density were 100 seeds per square meter, 25 seeds per square meter, and 16 seeds per square meter. Table 1 states the factors of the experiment and their combination (level of organic ameliorant and seedling density).

Data analysis

Diameter, height, and biomass accumulation

From the beginning (T0) to the end of the experiment (T12), plant growth was monitored weekly by measuring the morphological traits. The major parameters observed in this study were the survival rate of seedlings, diameter, height, biomass potential, and seedling quality index. The temperature and humidity inside and outside the nursery were also measured. The calculation of the survival rate was done at the end of experiments using an equation as follows:

$$\text{Survival rate (\%)} = \frac{\textit{Accumulation of live seedlings}}{\textit{Total seedlings observed}}$$

The qualification of the ready-to-plant seedlings was evaluated based on the morphology of the *C. calothyrsus* seedlings, such as the height, root-shoot ratio, and seedling quality index. The aboveground (leaves and stems) and belowground (roots) dry weight, at time T12, were also determined after two days of drying in an oven at 80°C, and stem/root ratio (S/R ratio) was calculated in terms of dry weight. The root-shoot ratio was calculated according to an equation as follows:

$$\text{Root-shoot ratio} = \frac{\textit{Dry weight of shoot } (g)}{\textit{Dry weight of root } (g)}$$

The seedling quality index is a comparison between the total dry weight with seedlings' robustness and root-shoot ratio. This index can be the most important parameter since it can conclude the seedling quality based on the morphology and physiology characteristics of the observed seedlings. It was calculated using a Dickson''s index as follows (Grossnickle and MacDonald 2018):

$$\text{Seedling quality index} = \frac{\textit{Total dry weight } (g)}{\left(\frac{\textit{Height } (cm)}{\textit{Diameter } (mm)}\right) + \left(\frac{\textit{Dry weight of shoot } (g)}{\textit{Dry weight of root } (g)}\right)}$$

Table 1. Experiment used in this study

No	Treatment	Composition of organic ameliorant (%, w/w)	Density (seedlings/m^2)
1	A0B0	0	100
2	A1B0	25	100
3	A2B0	50	100
4	A3B0	100	100
5	A0B1	0	50
6	A1B1	25	50
7	A2B1	50	50
8	A3B1	100	50
9	A0B2	0	16
10	A1B2	25	16
11	A2B2	50	16
12	A3B2	100	16

All obtained data were then statistically analyzed by an F-test with significant levels of 0.05 and 0.01. The Analysis of Variance (ANOVA) followed by the Least Significant Difference (LSD) method was used.

RESULTS AND DISCUSSION

Survival rate

According to our observation, the growth of the *C. calothyrsus* seedlings revealed a survival rate higher than 93%. All the treatments showed a great contribution to the survival rate of the seedlings tested. For all treatments, the survival rate of seedlings was higher than 75%. However, the results of the statistical analysis demonstrated that the organic ameliorant additions did not affect the survival rate of *C. calothyrsus* in the nursery. The details of the survival rate can be seen in Table 2.

Plant diameter and height

The results of the ANOVA at a significant level of 0.05 showed that the dose of organic ameliorant (A) and density (B) had a significant contribution to the increase in diameter of the *C. calothyrsus* seedlings. The treatment of organic ameliorant loading producing the highest diameter was A1 (25% of organic ameliorant addition) with a different diameter value of 1.39 mm. On the other hand, the lowest diameter increase was obtained from A3 (100% organic ameliorant addition), with a gap in diameter value of 0.98 mm.

Conversely, the treatment of A0 (0% of organic ameliorant addition) showed the lowest height with a different value of 11.02 cm. The treatment of density revealed that the highest contribution to the plant height was obtained on B0 (100 seedlings/m^2) with a different value of 18.21 cm. On the other hand, B2 (16 seedlings/m^2) achieved the lowest height with a different value of 13.06 cm. The effect of ameliorant (A) and the effect of density arrangement (B) on the mean diameter and height increment can be seen in Tables 3 and 4.

Table 2. The measurement results of the survival rate of *Calliandra calothyrsus* seedlings

Treatment	Planted seedlings			Total	Live seedlings			Total	Survival rate (%)
	B0	B1	B2		B0	B1	B2		
A0U1	30	30	30	270	30	26	25	252	93.33
A0U2	30	30	30		30	28	25		
A0U3	30	30	30		30	30	28		
A1U1	30	30	30	270	30	28	30	265	98.15
A1U2	30	30	30		30	29	29		
A1U3	30	30	30		30	30	29		
A2U1	30	30	30	270	30	29	29	256	94.81
A2U2	30	30	30		30	30	26		
A2U3	30	30	30		30	28	24		
A3U1	30	30	30	270	29	29	29	261	96.67
A3U2	30	30	30		30	30	28		
A3U3	30	30	30		29	29	28		

Table 3. Effect ameliorant on the mean diameter and height increment of *C. calothyrsus* seedling during 6 month period of study (mean values followed by different letters are significant at $p<0.05$)

Treatment	Mean diameter increment (mm)	Mean height increment (cm)
A0	1.11^{a}	11.02^{a}
A1	1.39^{b}	19.91^{c}
A2	1.18^{ab}	16.13^{b}
A3	0.98^{a}	13.15^{ab}

Table 4. Effect of density arrangement on the mean diameter and height increment of *C. calothyrsus* seedling during 6 month period of study (mean values followed by different letters are significant at $p<0.05$)

Treatment	Mean diameter increment (mm)	Mean height increment (cm)
B0	1.31^{b}	18.21^{b}
B1	1.03^{a}	13.89^{a}
B2	1.16^{ab}	13.06^{a}

Table 5. Biomass potential of *Calliandra calothyrsus* seedlings under various treatment

Treatment	Dry weight (g)			Density (N/m^2)	Biomass potential (g/m^2)
	Root	Stem	Total		
A0B0	0.09	0.55	0.65	100	65.00
A1B0	0.22	1.05	1.27	100	127.00
A2B0	0.14	1.05	1.19	100	119.33
A3B0	0.11	0.67	0.78	100	78.33
A0B1	0.40	0.59	0.98	25	24.58
A1B1	0.95	1.85	2.80	25	69.92
A2B1	0.53	1.61	2.14	25	53.42
A3B1	0.36	0.64	1.00	25	25.08
A0B2	1.11	1.62	2.73	16	43.68
A1B2	0.78	1.52	2.30	16	36.80
A2B2	0.75	2.18	2.93	16	46.93
A3B2	0.38	0.83	1.22	16	19.47

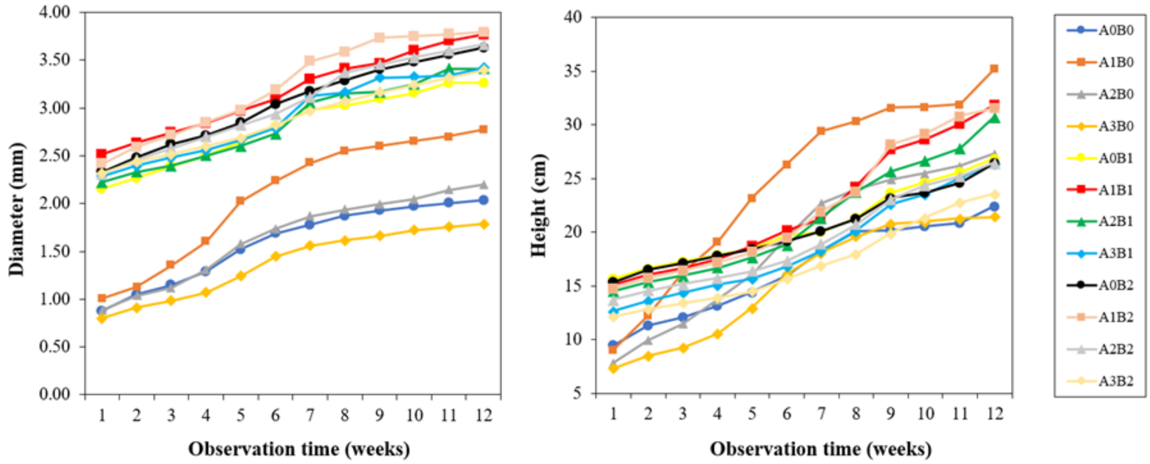

Figure 1. The diameter and height of *Calliandra calothyrsus* during the observation time used

Plant biomass

The results of the *C. calothyrsus* biomass calculation are shown in Table 5. It could be observed that after adding organic ameliorant at a concentration of 25%, the treatments of 100 seedlings/m^2 (A1B0) and 25 seedlings/m^2 (A1B1) showed their highest biomass production at 127.00 g/m^2 and 69.92 g/m^2, respectively. On the other hand, at the treatment of 16 seedlings/m^2, the highest biomass was produced by 50% of the organic ameliorant addition (A2B2) with a value of 46.93 g/m^2. It indicated that the use of the organic ameliorant concentration of 25% positively contributed to seedling growth, which could enhance biomass production compared to other concentrations used. The potential biomass results from each treatment can be seen in Table 5.

Quality index

One of the important indicators for the seedlings before they are planted is the quality index. Seedlings with a seedling quality index value of at least 0.9 had a high survival rate after being planted in the field (Posse et al. 2018). Based on the SNI 5006.2.2018 regarding the quality of seedlings for forest rehabilitation and forest plantations, the ideal height and diameter of *C. calothyrsus* seedlings were >30 cm and >4 mm, respectively. In this study, four *C. calothyrsus* seedlings possessed those qualifications. However, only two seedlings were evidently qualified according to the SNI standard. The first one was achieved by the treatments of A1BI (addition of 25% organic ameliorant with 25 seedlings/m^2), with a quality index of 0.29 and a root-shoot ratio of 1.95. The second one was obtained from the A2B1 treatment (addition of 25% organic ameliorant with 16 seedlings/m^2) with a quality index of 0.22 and a root-shoot ratio of 3.06.

Regarding the value of the quality index, most of the combinations of B1 (25 seedlings/m^2) and B2 (16 seedlings/m^2) met the qualification as ready-to-plant seedlings since they had values greater than 0.9. At the same time, the treatment of B0 (100 seedlings/m^2) was not qualified since its value was still low. It was probably due to the fact that the used *C. calothyrsus* seedlings in B1 and B2 were considered seedlings at the age of three months when transferred to the new media. Hence, at the end of the measurement, they were six months old. It was different from the treatment of B0 in that the seedlings were still three months old at the end of the measurement. The details of the seedling quality index can be seen in Table 6.

Table 6. Seedling quality index of *Calliandra calothyrsus* seedlings under various treatment

Treatment	Height (cm)	Diameter (mm)	Dry weight (g)			Robustness	Root-shoot ratio	Quality index
			Stem + leave	Root	Total			
A0B0	29.33	2.63	0.55	0.09	0.65	11.15	5.93	0.04
A1B0	40.40	3.20	1.05	0.22	1.27	12.61	4.77	0.06
A2B0	42.80	2.71	1.05	0.14	1.19	15.77	7.33	0.05
A3B0	28.03	2.14	0.67	0.11	0.78	13.10	5.91	0.05
A0B1	23.80	3.41	0.59	0.40	0.98	6.97	1.48	0.11
A1B1	30.30	4.52	1.85	0.95	2.80	6.70	1.95	0.29
A2B1	31.77	4.06	1.61	0.53	2.14	7.82	3.06	0.22
A3B1	25.90	4.01	0.64	0.36	1.00	6.46	1.76	0.13
A0B2	26.93	4.61	1.62	1.11	2.73	5.84	1.47	0.35
A1B2	29.97	4.10	1.52	0.78	2.30	7.30	1.94	0.23
A2B2	27.23	4.23	2.18	0.75	2.93	6.44	2.89	0.34
A3B2	25.53	3.65	0.83	0.38	1.22	7.00	2.17	0.17

Table 7. The result of temperature measurements inside and outside the nursery

Observation time (weeks)	Inside nursery (ºC)				Outside nursery (ºC)			
	Morning*	Afternoon**	Evening***	Average	Morning*	Afternoon**	Evening***	Average
1	28.7	31.8	29.8	29.8	29.8	33.2	32.7	31.9
2	28.1	30.5	29.3	29.0	30.2	33.5	32.3	32.0
3	28.2	29.8	28.8	28.7	29.3	34.2	30.7	31.4
4	27.2	30.0	28.0	28.1	28.2	32.1	29.0	29.8
5	29.7	30.1	27.9	29.3	32.6	31.8	28.5	31.0
6	29.2	29.8	27.9	29.0	31.2	30.5	28.7	30.2
7	29.3	30.1	27.8	29.1	30.4	33.2	29.5	31.1
8	24.8	25.7	28.6	25.9	26.3	26.6	29.9	27.6
9	28.7	31.8	29.8	29.8	30.0	33.3	32.6	32.0
10	29.1	31.0	28.8	29.5	31.6	32.0	30.3	31.3
11	29.0	32.1	29.8	30.0	30.3	34.2	33.4	32.6
12	29.1	31.0	28.8	29.5	31.6	32.0	30.3	31.3
Average	28.4	30.3	28.8	29.0	30.1	32.2	30.7	31.0

Note: *measured at 8.00 a.m.; **measured at 0.00 p.m.; ***measured at 04.00 p.m.

Table 8. The result of humidity measurements inside and outside the nursery

Observation time (weeks)	Inside nursery (%)				Outside nursery (%)			
	Morning*	Afternoon**	Evening***	Average	Morning*	Afternoon**	Evening***	Average
1	80.1	66.7	72.0	73.0	69.6	71.4	72.6	71.2
2	86.3	67.0	74.3	75.9	79.3	71.7	70.3	73.8
3	85.4	71.7	83.4	80.2	73.3	75.9	77.7	75.6
4	95.6	79.6	88.6	87.9	92.7	76.3	86.1	85.0
5	83.9	73.4	84.4	80.6	75.9	68.0	84.0	76.0
6	87.4	79.0	86.9	84.4	77.0	72.4	83.3	77.6
7	86.0	74.7	82.4	81.0	77.1	68.0	80.3	75.1
8	74.9	69.3	81.7	75.3	68.6	66.9	85.1	73.5
9	79.7	64.3	72.7	72.2	76.9	67.0	71.4	71.8
10	83.6	69.1	76.1	76.3	81.4	70.4	77.9	76.6
11	81.9	60.9	70.4	71.0	76.4	63.1	65.7	68.4
12	81.6	67.7	72.7	74.0	80.3	68.1	74.6	74.3
Average	83.9	70.3	78.8	77.7	77.4	69.9	77.4	74.9

Note: *measured at 8.00 a.m.; **measured at 0.00 p.m.; ***measured at 04.00 p.m.

Temperature and humidity

The measurement of temperature and humidity has been conducted inside and outside the nursery, using a thermohygrometer for as long as twelve weeks every 8.00 a.m., 0.00 p.m., and 04.00 p.m. (see Tables 7 and 8). The results demonstrated that the average temperature obtained from those measurement times inside the nursery was 28.4°C, 30.3°C, and 28.8°C, respectively. The weekly average ranged from 25.9°C to 30.0°C. On the other hand, the temperatures outside the nursery were 30.1°C, 32.2°C, and 30.7°C, respectively.

According to the measurement of humidity during the twelve weeks of observation, it could be seen that the average humidity inside the nursery in the morning, afternoon, and evening was 83.9%, 70.3%, and 78.8%, respectively. Their weekly average ranged from 71.0% to 87.9%. Whereas, in the outside nursery, the humidity was 77.4%, 69.9%, and 77.4%, respectively. The results of the weekly measurement indicated ranges of humidity from 68.4% to 85.0%. The detailed measurement of temperature and humidity inside and outside the nursery can be seen in Table 7 and Table 8.

Discussion

The most important factors affecting the increase in seedling survival rate in the nursery are media and other environmental factors, including light, temperature, air humidity, and lighting duration (Syahrinudin et al. 2018). Data was analyzed by ANOVA to determine the effect of the addition of soil organic ameliorant in the media and seedling density in the nursery on the survival rate of the *C. calothyrsus* seedlings.

The treatment of density showed that the highest increase in diameter was reached by B0 (100 seedlings/m^2) with a different value of 1.31 mm. In comparison, the smallest diameter was produced by B1 (25 seedlings/m^2) with a different value of 1.03 mm. The significant value was also obtained from the statistical analysis of the measurement of the seedling height after being treated with a varied dose of organic ameliorant (A) and density (B). The treatment with the organic ameliorant addition obtained the highest increase in height at A1 (25% of the organic ameliorant addition) with a different value of 19.91 cm.

Similar to the increase in diameter, it could be seen that the application of a soil organic ameliorant with a concentration of 25% produced the greatest height compared to other concentrations. In line with the research conducted by Salsabila et al. (2023), the use of soil amendments such as compost and paclobutrazol can assist in maintaining the panicle weight and grain yield of rice plants, including the Sigupai Abdya and Tangse varieties, under environmental stress conditions in a Greenhouse through the nutrients present in the soil.

The treatment of the density arrangement also significantly affected the seedling height. It was due to the fact that the treatment of B0 placed the seedling closely compared to the treatments of B1 and B2, in which each seedling had a wider space. The density is related to the growth competition among seedlings, including the interception of light, air, and nutrients. The high density will increase the competition among seedlings. When the density of the seedling is low, the level of competition is also lower (Tataridas et al. 2022). This phenomenon was in accordance with the report of Bastos et al. (2020) that high density will enhance the plants' growth since they try to get more sunlight. As reported by Demisie and Tolessa (2018), Amalfitano et al. (2019), and Sopha (2020), planting distance and density significantly influence the weight and diameter of the bulbs.

The increase in plant height and diameter observed in this study can be attributed to the role of growth regulators, such as gibberellic acid, in promoting cell elongation and division (Chiranjeevi et al. 2018). Additionally, the application of organic ameliorant may have enhanced the availability of essential nutrients, leading to improved seedling growth (Alfandi et al. 2019).

According to Figure 1, it can be seen that the use of soil organic ameliorant at a concentration of 25% in all density treatments (A1B0, A1B1, and A1B2) resulted in better seedling height and growth compared to others. These results were in line with a study previously reported by Suita and Sudrajat (2018), which found that the relatively high compost composition (30%) in the seedling media could increase the survival rate (52%) and the growth of *Tamarindus indica* seedlings (89%), compared to the agricultural soil media. Seedling growth improvement by the incorporation of organic ameliorant (biochar) has also been reported (Syahrinudin et al. 2019, 2021).

The addition of soil amendments such as biochar, compost, and organic fertilizers plays a crucial role in plant growth and production. These amendment materials can help improve the physical properties of the soil and enhance its water-holding capacity, ensuring an adequate water supply for plants. Additionally, the increase in plant growth and yield is also attributed to the improvement of soil moisture conditions and the availability of sufficient nutrients. Overall, this supports plant growth and enhances crop yields (Sukartono et al. 2019).

According to research, some soil ameliorants can improve the survival and growth of seedlings in controlled situations, but when plants are moved to the field, their effectiveness may decrease (Nurida and Rachman 2020). Significant obstacles may arise from the availability and accessibility of the resources needed to produce soil supplements. The efficacy of the modifications may vary depending on the reliance on particular raw resources. Research has demonstrated, for example, that the effects of amendments like compost, charcoal, and mycorrhizal inoculants can vary based on their composition and source. Overall, soil supplements have shown promise in improving plant development; nevertheless, in order to achieve consistent and successful results, their field application requires careful consideration of local environmental conditions and material availability.

The utilization of bokashi as an organic ameliorant is targeted to improve the biomass accumulation in the topsoil (Iqbal et al. 2019). Thus, it will enhance the biological activities in the soil and also the water availability. Sufficient water in the soil will also increase nutrient absorption (Liang et al. 2018), which affects the better photosynthesis process to enhance the carbohydrate content for increased plant growth and fruit production.

The temperature range of 27.6°C to 32.6°C was obtained from the weekly average measurement. *C. calothyrsus* has been reported to grow better in daily temperatures from 24°C to 28°C (Kosasih et al. 2022). Another report informed the ability of *C. calothyrsus* grown in Majalengka, West Java, to adapt well in the temperature range of 22.6°C to 37.3°C (Widyati et al. 2022). Therefore, since this study revealed the temperature that is suitable for *C. calothyrsus* growth based on the literature published by those authors, it was also evidence that the nursery provided the optimum temperature conditions for the *C. calliandra* seedlings.

Finally, we concluded that our study on the effects of soil organic ameliorant addition and seedling density arrangement on *C. calothyrsus* seedlings yielded significant insights. The addition of organic ameliorants to the growth media and manipulation of planting density, both individually and in combination, significantly influenced seedling diameter and height. However, these treatments did not significantly affect seedling survival rates. The optimal treatment combination was found to be 25% organic ameliorant addition with a density of 100 seedlings/m² (A1B0), which resulted in the most substantial increases in both height and diameter.

Biomass potential was highest for the 25% organic ameliorant treatment (A1) when combined with densities of 100 seedlings/m² (B0) and 25 seedlings/m² (B1). Interestingly, the 50% organic ameliorant treatment (A2) showed high biomass productivity when combined with the lowest density of 16 seedlings/m² (B2). The nursery conditions, including temperature and humidity, were found to be optimal for *C. calothyrsus* seedling growth. Notably, the combination treatments A1B1 and A2B1 produced seedlings that met the quality standards set by SNI 5006.2.2018 for forest rehabilitation and industrial forest plantation purposes.

Future perspectives: Long-term studies: Conduct follow-up studies to assess the performance of these seedlings after out planting, evaluating their survival, growth, and productivity in various field conditions. Nutrient analysis: Investigate the specific nutrient contributions of the organic ameliorant and how they interact with native soil conditions to influence seedling growth. Microbial interactions: Explore the effects of organic ameliorants on soil microbial communities and their potential role in enhancing seedling growth and health. Organic ameliorant composition: Investigate the effects of different types and sources of organic ameliorants to identify the most effective and sustainable options.

These recommendations and future research directions aim to further optimize nursery practices for *C. calothyrsus* and potentially other species, contributing to more successful reforestation and agroforestry initiatives.

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