

MORPHOLOGICAL RESPONSE OF *Parkia speciosa* SEEDLINGS EXPOSED TO VARIOUS AMELIORANTS, SHALLOW GROUNDWATER, AND THE EFFECTS ON MICROCLIMATE CONDITIONS

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MORPHOLOGICAL RESPONSE OF *Parkia speciosa* SEEDLINGS EXPOSED TO VARIOUS AMELIORANTS, SHALLOW GROUNDWATER, AND THE EFFECTS ON MICROCLIMATE CONDITIONS. The cultivation of stinky bean (*Parkia speciosa* Hassk.) in wetlands is significantly affected by shallow water table conditions. Therefore, this research aimed to explore the growth of stinky bean seedlings and microclimate conditions in various substrate mixtures and shallow water table levels. The experiment was conducted at the Jakabaring Research Facility (104°46'44"E, 3°01'35"S), Palembang, South Sumatra, from September to December 2023 using a factorial randomized block design. The first and second factors were an ameliorant mixture in the substrate and shallow water table depth respectively, with each treatment repeated four times. The results showed that optimal leaf growth occurred using biochar ameliorant, but no significant difference was observed among the four types of planting media. Although the conditions of air and substrate temperature and soil moisture varied, the stinky bean seedlings still grew optimally on all four planting media, including biochar, peat, cocopeat, and topsoil under shallow water table conditions. A zero-intercept linear model was considered optimal for predicting leaf area based on midrib length, leaf width, and the interaction indicated by the R^2 value. Optimal stinky bean leaf growth was observed at shallow water table SWT-12, but plant growth at three variations of SWT-20, SWT-16, and SWT-12 was not significantly different. Fluctuations in the microclimate, including air and substrate temperature, as well as humidity did not significantly affect growth, suggesting that the cultivation of stinky bean plants could be carried out in all shallow water table conditions.

Keywords: Growing media, microclimatic conditions, optimal growth, shallow water table, stinky bean

RESPON MORFOLOGIS BIBIT *Parkia speciosa* TERHADAP BERBAGAI AMELIORAN, MUKA AIR TANAH DANGKAL, DAN PENGARUHNYA TERHADAP IKLIM MIKRO SETEMPAT. Budidaya tanaman petai (*Parkia speciosa* Hassk.) di lahan basah memerlukan evaluasi tanaman terhadap kondisi muka air dangkal. Penelitian ini bertujuan untuk memahami pertumbuhan tanaman petai dan kondisi iklim mikro dalam variasi campuran substrat dan tingkat muka air dangkal. Penelitian ini dilakukan di Fasilitas Penelitian Jakabaring (104°46'44" E, 3°01'35" S), Palembang, Sumatera Selatan, dan dimulai pada bulan September hingga Desember 2023, serta menggunakan rancangan acak kelompok faktorial. Faktor pertama campuran amelioran pada substrat, faktor kedua kedalaman muka air dangkal. Setiap perlakuan diulang sebanyak empat (4) kali. Hasil penelitian pertumbuhan optimal daun tanaman petai terjadi pada media tanam dengan amelioran biochar, namun pertumbuhan tanaman pada empat jenis media tanam tidak menunjukkan perbedaan nyata secara statistik. Meskipun kondisi suhu udara, suhu substrat, dan kelembapan tanah

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bervariasi, tanaman petai tetap tumbuh baik pada keempat media tanam, termasuk amelioran biochar, gambut, cocopeat dan tanah topsoil pada muka air dangkal. Model zero-intercept linear dianggap optimal untuk memprediksi luas daun dengan mempertimbangkan panjang midrib, lebar daun, dan interaksi keduanya berdasarkan nilai R^2 . Pertumbuhan daun petai optimal terlibat pada muka air dangkal SWT-12, namun pertumbuhan tanaman pada tiga variasi muka air dangkal (SWT-20, SWT-16, dan SWT-12) tidak berbeda nyata. Meskipun iklim mikro berfluktuasi, termasuk suhu udara, suhu substrat, dan kelembaban udara pada tiga perbedaan muka air dangkal, pengaruhnya belum signifikan pada pertumbuhan tanaman petai. Ini menunjukkan budidaya tanaman petai pada permukaan air dangkal bisa dilaksanakan.

Kata kunci: Media tanam, kondisi iklim mikro, pertumbuhan optimal, muka air dangkal, petai

I. INTRODUCTION

Deforestation is known to have negative impacts on biophysical aspects, such as climate change and biodiversity loss (Lawrence et al., 2022). This phenomenon is attributed to poor forest governance, which focuses on short-term economic gains, neglecting environmental aspects (Doggart et al., 2020). Southeast Asia, which has the third largest tropical forests in the world, faces serious challenges due to high deforestation rates (Hoang & Kanemoto, 2014). In this context, conservation efforts are crucial to maintaining the sustainability of ecosystems (Matthew et al., 2019). Among the lands that require rehabilitation are degraded peatlands.

The stinky bean (*Parkia speciosa* Hassk.) plant is an appropriate choice for conservation efforts, given its popularity in various parts of the world, including India, Malaysia, Singapore, Thailand, Borneo, Madagascar, and Africa (Ahmad et al., 2019; Chhikara et al., 2018). It is rich in bioactive components such as phenolic acids, flavonoids, carotenoids, glucosinolates, isothiocyanates, and folates (Singhania et al., 2021). Aside from its contribution as a nutrient-rich plant, stinky bean fruit can be consumed both raw and after cooking. Regarding the impact of ecology, the benefits include a positive impact on preventing climate change by absorbing carbon dioxide (CO₂) from the atmosphere, which helps to reduce the concentration (Singha et al., 2021). Meanwhile, Hadi et al. (2018) reported that the stinky bean is a plant that can adapt to peatlands. Thus, it has the potential to be planted on degraded peatlands.

Before developing stinky bean cultivation in peatlands, it is necessary to assess the adaptation to shallow water table conditions. Waterlogging has a negative impact on seedling growth in species that prefer both wet and dry conditions (Chong et al., 2021). The effect on forests causes plant roots to face significant hypoxia conditions, affecting growth and overall function (Fujita, Noguchi, & Tange, 2021). Among the five forestry plant species, including *Eucalyptus camaldulensis*, *Populus deltoides*, *Syzygium cumini*, *Dalbergia sissoo*, *Salix tetrasperma*, and *Eucalyptus camaldulensis* shows a higher level of tolerance to the duration of waterlogging compared to other tree species (Shaheen et al., 2021).

The addition of ameliorants has been proposed as an effective strategy for improving soil fertility to obtain positive results for the growth of stinky bean plants (Saputra & Sari, 2021). Based on agronomic tests, biochar possesses strong alkaline properties, which improve the rooting and growth of *Rosmarinus officinalis* cuttings (Fornes & Belda, 2019). The use of biochar also affects the properties of the growing medium, leading to an increase in pH and changes in nutrient levels. As stated in previous research, this material increases seed germination success (Chrysargyris et al., 2020). Furthermore, sand mixed with peat as an essential planting medium can increase the growth of *Argania spinosa* at the seedling stage due to its significant water-retaining capacity (Farhoun & Cherkaoui, 2022). Peat soil supplemented with manure positively affected plant growth (Susilawati et al., 2022). Previous research reported that the combination of

32.5% cocopeat, 17.5% manure, and 50% soil significantly affected the growth of ketapang (*Terminalia catappa*). These results provide valuable insights for coastal forest rehabilitation practices and can be cited as a guide in the development of ecosystem sustainability (Felle et al., 2023). Trees grown in cocopeat substrate showed better water status and increased vegetative growth compared to control (Parra et al., 2022). Therefore, this research aimed to determine the growth of stinky bean plants and the microclimate status in different substrate mixtures and shallow groundwater levels.

II. MATERIAL AND METHOD

A. Research location and climatic characteristics

This research was conducted at the Jakabaring Research Facility (104°46'44"E, 3°01'35"S), Palembang, South Sumatra from September to December 2023. The site is classified as a tropical lowland ecosystem, located within an urban area. A mixture of topsoil with decomposed peat, biochar, and cocopeat was used as the growing substrate. The monthly rainfall and humidity during research activities are presented in Figure 1.

B. Research procedure

This research used stinky bean seedlings aged 12 weeks after sowing with a height of about 15–18 cm. Seedlings were planted in

pots measuring 27.5 cm (height) x 27.5 cm (diameter). The pots were equipped with holes at the bottom and sides for access to water from or to the substrate. Several variations of substrate mixture were used including topsoil; peat + topsoil mixture (1:3 v/v); cocopeat + topsoil mixture (1:3 v/v); and biochar + topsoil mixture (1:3 v/v). These substrate mixture variations were designated as treatments, with the symbols M0, M1, M2, and M3 respectively. Topsoil was soil originating at 0-15 cm layer from Indralaya, Ogan Ilir, South Sumatra. The soil used in the study is Alluvial. Peat was obtained from local land, Sepucuk, Ogan Komering Ilir, South Sumatra. Meanwhile, the cocopeat was pulverized coconut husk. The biochar used was rice-husk biochar produced through the pyrolysis method. The biochar used was obtained from a commercial store.

The pots were arranged in an experimental pond measuring 4.0 m (length) x 2.0 m (width) x 0.3 m (depth). Inside the pond, the position of the pots was adjusted according to the water depth treatment, namely 20 cm (SWT-20), 16 cm (SWT-16), and 12 cm (SWT-12) from the surface (Figure 2). The pond was equipped with a valve to maintain the water level. Although watering was not carried out, the plants obtained water through capillary movement from the bottom to the rhizosphere through the holes at the bottom of the pot.

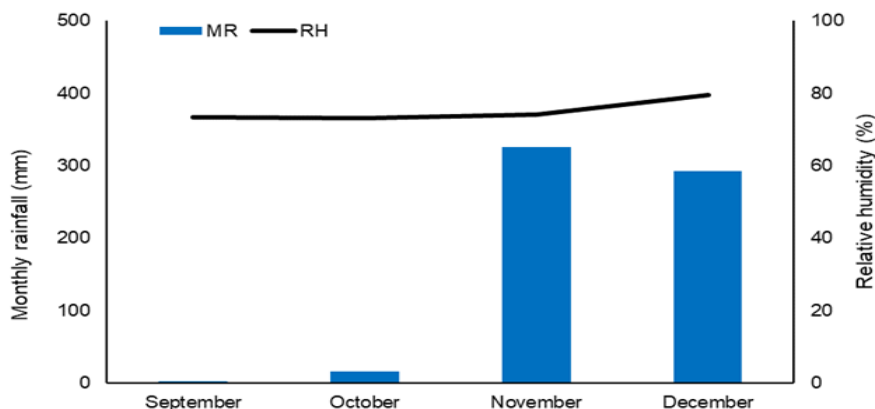


Figure 1. Map of the study site

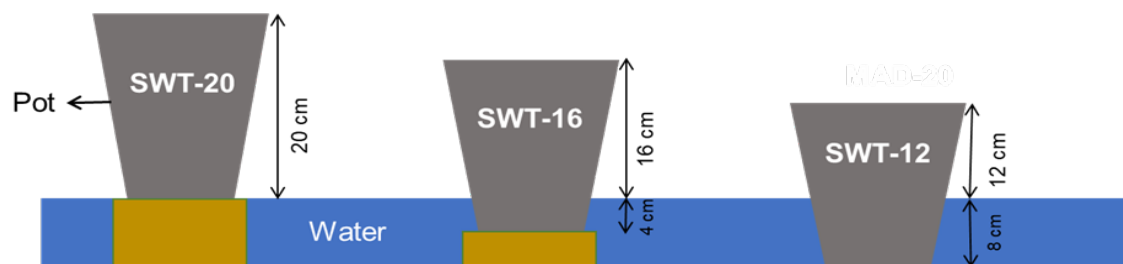


Figure 2. The difference in groundwater level was adjusted by positioning the bottom of the pot. Bottom part of the pot in direct contact with the water surface (SWT-20), bottom of the pot is partially submerged to 4 cm under water surface (SWT-16) and submerged to 8 cm below the surface (SWT-12)

C. Data collection

The data collected comprised stinky bean plant growth and microclimate conditions. Specifically, data related to the plant growth consisted of individual leaf growth rates (midrib length, leaf width, and petiole length), weekly vegetative growth (plant height, number of leaves, canopy width, and stem diameter), and growth at the end of observation (fresh and dry weight of each organ). Meanwhile, data related to microclimate included soil moisture and temperature, as well as air temperature.

Measurement of individual leaf growth started when the leaves opened completely until they stagnated. Soil moisture was measured for five days, while substrate and atmospheric temperature were taken for 10 days. Microclimate measurements were carried out when there was no rain, and at the end, destructive observations were made at 13 weeks after treatment (WAT).

Canopy width was measured at the widest dimension of the canopy. The number of leaves was calculated based on the number of petioles. Midrib length was measured from the beginning of the leaflet to the leaf tip, while leaf width was measured at the widest dimension of the leaf.

Leaf area estimation was carried out by taking 120 leaves as samples with varied sizes, while direct measurement was achieved using an image scanner. LIA32 (Nagoya University, Japan) software for Windows 10 was used to measure leaf area. Meanwhile, each leaf

was measured for midrib length, width, and number of leaflets as predictors of area. These predictors were then examined for the strength of the relationship with leaf area using simple regression to determine the reliability of the predictors.

Soil moisture measurements were conducted using a soil moisture meter (PMS-714, Lutron Electronics Canada, Inc., Pennsylvania, USA). Meanwhile, substrate and atmospheric temperature measurements were carried out with a digital thermometer (Pen Thermometer KW0600308, Krisbow, Inc., Jakarta, Indonesia). The dry weight of each plant organ was obtained by drying in a 100°C oven for 24 hours.

D. Research design and statistical analysis

The research used a factorial randomized group design with two factors: shallow water table depth and the addition of ameliorant mixture to the substrate. The treatments were repeated up to four times.

All data collected were analyzed by analysis of variance (ANOVA), and significance levels between treatments were tested by least significance difference (LSD) at $P < 0.05$. Meanwhile, each selected variable was tested for the strength of the relationship by simple regression through linear, exponential, polynomial, logarithmic, zero intercept linear, and zero intercept exponential models. All analyses were conducted using Rstudio (v2023.06.0+421) for Windows 10.

III. RESULTS AND DISCUSSION

A. Result

Growth of stinky bean plant in different planting media

The petiole and midrib length and the leaf width of stinky bean plant in all planting media tended to increase. Optimal petiole length growth occurred in topsoil growing media (M0) compared to biochar (M1), peat (M2), and

cocopeat ameliorant (M3). The midrib length and leaf width growth is optimal in biochar planting media (M1). The growth in shape was assessed by dividing the midrib length by the width of the leaves. The results showed that the seedlings on all planting media experienced significant growth from the first to the seventh day. However, after the seventh day, leaf growth was relatively stagnant (Figure 3).

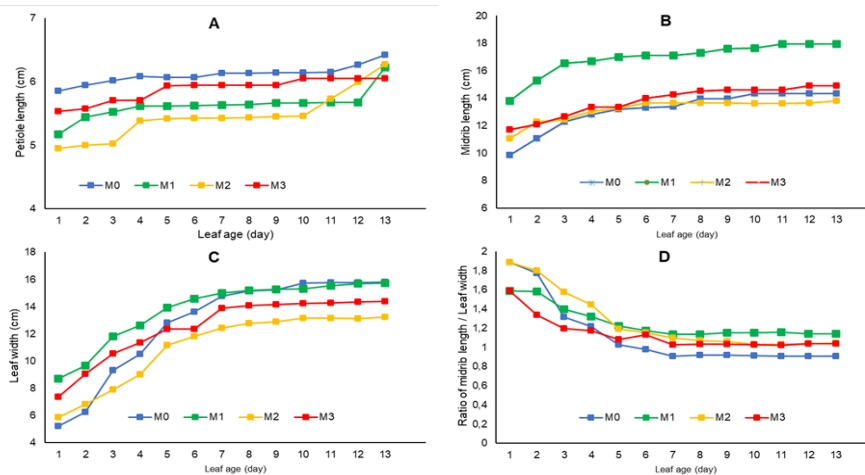


Figure 3. Daily leaf enlargement in stinky bean treated with different ameliorants. Measured leaf components are petiole length (A), midrib length (B), leaf width (C), and ratio of midrib length/leaf width (D). Measurements were taken starting after the young leaf was fully unfolded. Ameliorants used include topsoil (M0), biochar (M1), peat (M2), and cocopeat (M3).

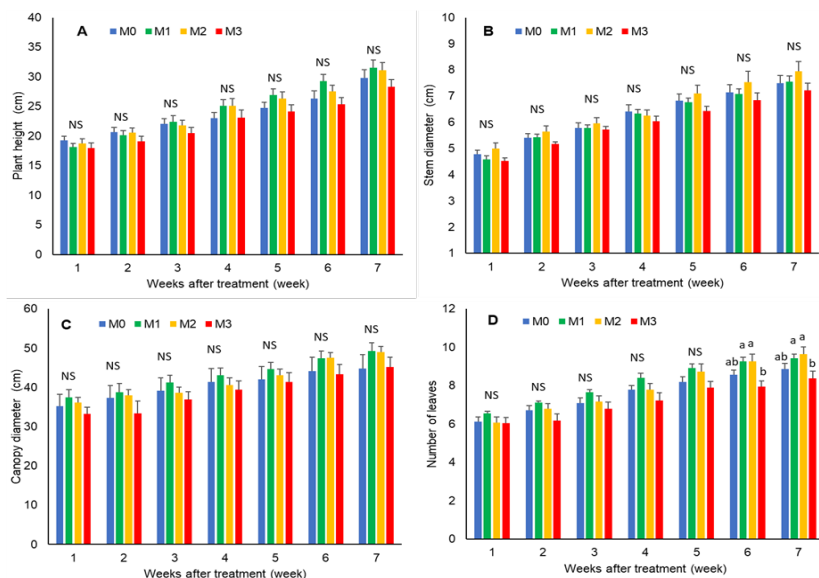


Figure 4. Plant height (A), stem diameter (B), canopy width (C), and number of leaves (D) of stinky bean plants in different planting media. Each bar followed by a different letter means significantly different at LSD0.05. Meanwhile, NS is not significantly different at LSD_{0.05}. Ameliorants used include topsoil (M0), biochar (M1), peat (M2), and cocopeat (M3).

ANOVA analysis of all planting media showed that from weeks 1 to 7, no significant differences were observed in height, stem diameter, and leaf width growth between treatments from the first to the seventh week. Based on the results, it was concluded that the planting media had no significant effect on the growth of height, stem diameter, and leaf width of stinky bean plant. However, there were significant differences in the number of leaves in the fourth, sixth, and seventh weeks between the different treatments (Figure 4).

Based on the results of the data analysis, there were no significant differences in leaf, petiole, stem, and root fresh weight between the four types of growing media used. This indicated that the variation in the use of planting media had no significant effect on the growth and development of the stinky bean observed. The Least Significant Difference (LSD) assessment of each variable provided insights into the extent of differences required between treatments to be considered significant. However, since no significant differences could be identified, the growing media used in this experiment did not produce a statistically different impact on

the measured growth parameters. This result suggested that the growing media used did not play a different role in supporting the growth of the stinky bean (Table 1).

Based on the R^2 values, the zero-intercept linear model was considered the best for all three components, including midrib length, leaf width, and Midrib length x Leaf width, in estimating the leaf area accurately. This model provided a high level of accuracy and could explain most of the variability in leaf area based on each of the observed components (Table 2).

Microclimate in different growing media

The air temperature consistently surpassed the substrate temperature because the stinky bean plant substrate was constantly kept moist by exposure to water. When the air temperature increased, an upward trend in soil temperature occurred in various growing media, although this change was not significant. The pattern and rate of increase in soil temperature tended to be similar across all growing media. When the air temperature decreased, the soil temperature also reduced, although this change was not significantly different (Figure 5).

Table 1. Fresh and dry weight of stinky bean plant organs in different growing media.

Treatment	Leaf fresh weight (g)	Petiole fresh weight (g)	Stem fresh weight (g)	Root fresh weight (g)
Growing media				
M0	13.744±2.241	1.624±0.289	15.180±2.044	21.778±3.240
M1	17.796±2.908	1.967±0.283	18.652±2.373	25.432±3.677
M2	18.623±2.004	2.044±0.264	16.966±1.801	22.969±2.750
M3	14.422±1.840	1.347±0.170	12.445±1.323	17.152±1.417
Significance	NS	NS	NS	NS
LSD _{0.05}	6.688	0.710	5.708	7.357
Treatment	Leaf dry weight (g)	Petiole dry weight (g)	Stem dry weight (g)	Root dry weight (g)
Growing media				
M0	5.371±0.895	0.547±0.115	5.672±0.816	4.980±0.723
M1	6.761±1.166	0.655±0.098	7.648±1.043	5.676±0.687
M2	7.210±0.796	0.662±0.089	6.287±0.662	5.082±0.513
M3	5.545±0.683	0.499±0.067	4.838±0.523	4.078±0.352
Significance	NS	NS	NS	NS
LSD _{0.05}	2.599	0.274	2.355	1.612

Remark: The data represent the mean ± standard error. NS means each treatment is not significantly different at LSD_{0.05}*

Table 2. Relationship of leaf area with Midrib length, Leaf width, and Midrib length x Leaf width

Leaf part	Regression type	Equation	R ²
Midrib length	Linear	$y = 13.319x - 47.733$	0.8487
	Exponential	$y = 28.965e^{0.0947x}$	0.8175
	Logarithmic	$y = 170\ln(x) - 288.76$	0.7317
	Polynomial	$Y = 0.0349M^2 + 7.9612M - 17.349$	0.8757
	Power	$y = 3.6922x^{1.343}$	0.8665
	Zero-intercept linear	$y = 10.668x$	0.9408
	Zero-intercept polynomial	$y = 0.2238x^2 + 6.0188x$	0.8727
Leaf width	Linear	$y = 22.102x - 132$	0.7449
	Exponential	$y = 14.187e^{0.1661x}$	0.6368
	Logarithmic	$y = 246.03\ln(x) - 464.1$	0.6580
	Polynomial	$y = 0.6089x^2 + 5.8451x - 32.945$	0.7630
	Power	$y = 0.7941x^{2.0044}$	0.7607
	Zero-intercept linear	$y = 12.617x$	0.8752
	Zero-intercept polynomial	$y = 0.6089x^2 + 5.8451x - 32.945$	0.763
Midrib length x Leaf width	Linear	$y = 0.6416x + 15.56$	0.9363
	Exponential	$y = 48.352e^{0.0043x}$	0.5523
	Logarithmic	$y = 114.29\ln(x) - 430.14$	0.7976
	Polynomial	$y = -0.0001x^2 + 0.7279x + 6.5013$	0.9392
	Power	$y = 1.1439x^{0.9137}$	0.9387
	Zero-intercept linear	$y = 0.6907x$	0.9778
	Zero-intercept polynomial	$y = -0.0002x^2 + 0.7688x$	0.9389

Remark: R² stands for the strength level of relation between leaf area and predictors.

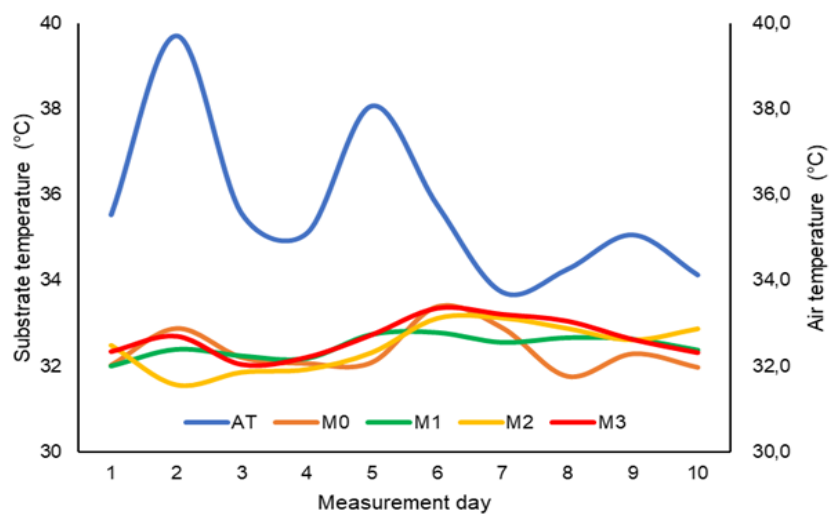


Figure 5. Status of air temperature and substrate temperature in different growing media. AT = air temperature; M0 = topsoil; M1 = biochar; M2 = peat; and M3 = cocopeat

ANOVA of soil moisture showed significant differences between different growing media, attributed to the high water retaining capacity. Based on the results, the cocopeat ameliorant

planting medium was the best at storing water efficiently, resulting in the highest soil moisture (Figure 6).

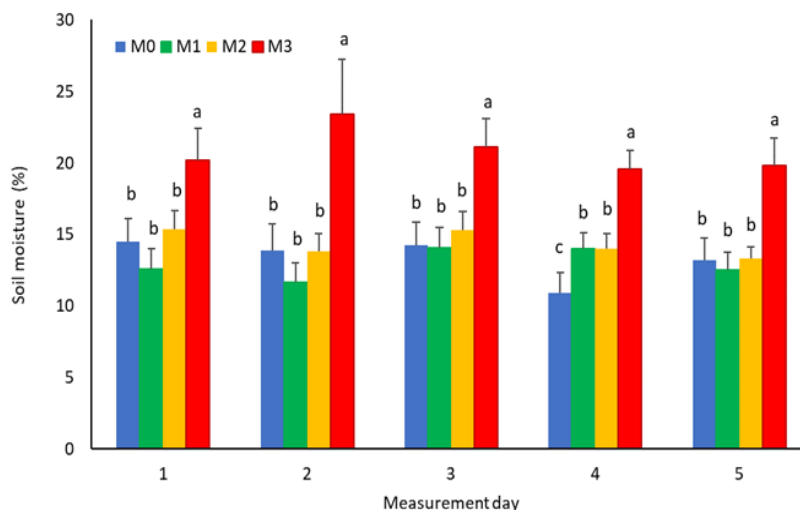


Figure 6. Soil moisture measurement based on growing media. Ameliorants used include topsoil (M0), biochar (M1), peat (M2), and cocopeat (M3)

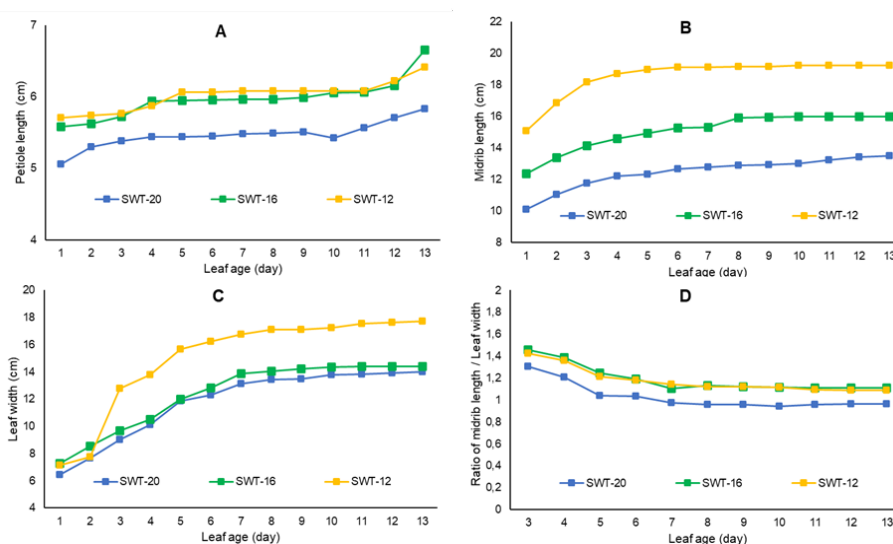


Figure 7. Petiole length (A), midrib length (B), leaf width (C), and ratio of midrib length/leaf width (D) of the stinky bean plants at different shallow water tables. Measurements were taken starting from fully open leaves to stagnant. The shallow water table consists of SWT-20 = shallow water table 20 cm from the surface of the planting media; SWT-16 = shallow water table 16 cm from the surface of the planting media; and SWT-12 = shallow water table 12 cm from the surface of the planting media

Individual leaf growth of stinky bean plant at a shallow water table

The growth of petiole length, midrib length, and leaf width of stinky bean under various shallow water table conditions, including SWT-20, SWT-16, and SWT-12, showed an increasing trend. Optimal growth occurred at a shallow water table condition of 12 cm from

the surface of the planting media (SWT-12). To evaluate leaf shape, the ratio of midrib length to leaf width was used, and the results in SWT-20, SWT-16, and SWT-12 showed a similar increase. From the first to the seventh day, there was significant leaf expansion, but after the seventh day, leaf growth tended to stagnate (Figure 7).

Weekly vegetative growth of stinky bean plant

Based on the ANOVA of height growth, stem diameter, canopy width, and number of leaves in the shallow water table of 20 cm (SWT-20), 16 cm (SWT-16), and 12 cm (SWT-12) there were no significant differences between the different treatments. This result implied that the stinky bean could be planted at various shallow water table conditions (Figure 8).

The ANOVA results showed no significant differences in the leaf fresh, petiole fresh, stem wet, and root fresh weight between SWT-20, SWT-16, and SWT-12. This implied that variations in shallow water table conditions did not significantly impact the observed growth

and development. Furthermore, there were no significant differences in leaf dry, petiole dry, stem dry, and root wet weight between the three shallow water table conditions. Based on the result, variations in shallow water table conditions had no significant effect on the growth and development of the observed stinky bean plant. The LSD assessment of each variable offered insights into the extent of differences required between treatments to be considered significant. However, since no significant differences could be identified, the results indicated that the various shallow water table conditions used in the experiment had no significant impact on the measured growth parameters of the stinky bean plant (Table 3).

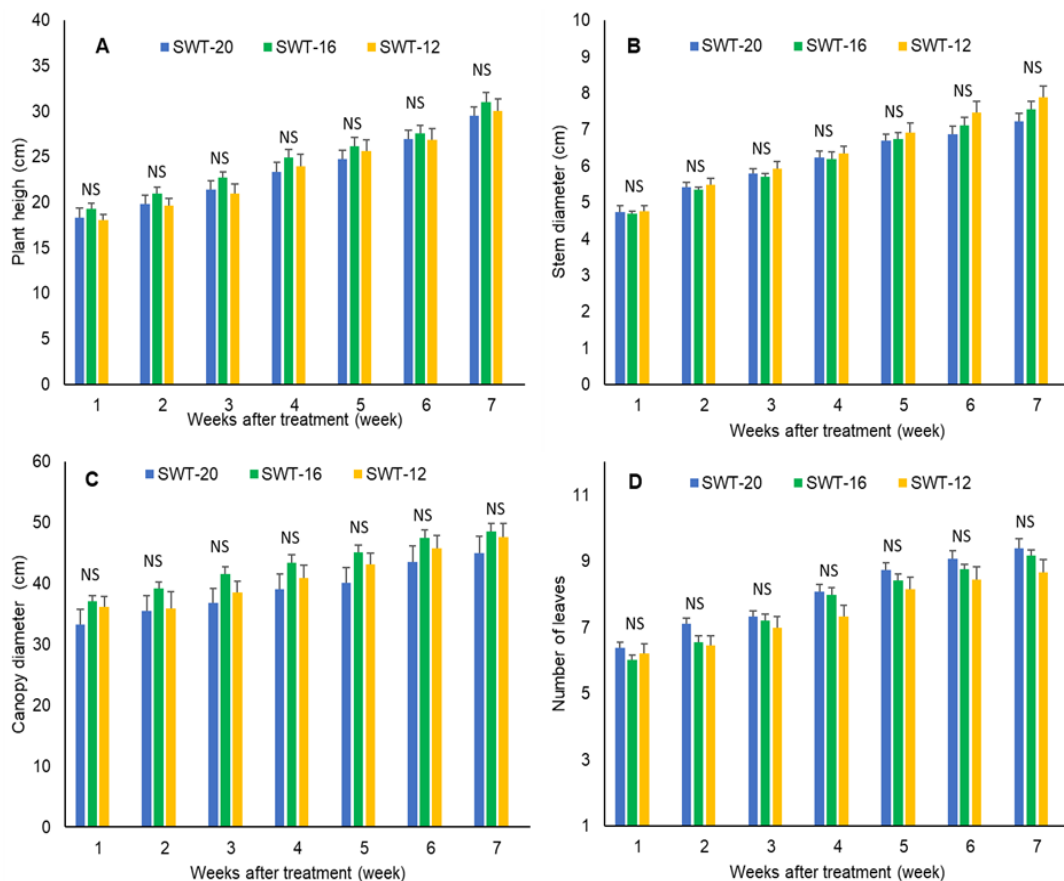


Figure 8. Plant height (A), stem diameter (B), canopy width (C), and number of leaves (D) of stinky bean plants at different shallow water tables. Each bar followed by a different letter means significantly different at LSD0.05. Meanwhile, NS is not significantly different at LSD0.05. The shallow water table consists of SWT-20 = shallow water table 20 cm from the surface of the planting media; SWT-16 = shallow water table 16 cm from the surface of the planting media; and SWT-12 = shallow water table 12 cm from the surface of the planting media

Table 3. Fresh weight and dry weight of stinky bean plant organs at different shallow water table conditions.

Treatment	Leaf fresh weight (g)	Petiole fresh weight (g)	Stem fresh weight (g)	Root fresh weight (g)
Shallow water table				
SWT-20	15.008±1.646	1.628±0.198	13.958±1.541	22.384±3.054
SWT-16	16.792±1.832	1.760±0.187	16.585±1.506	21.957±1.901
SWT-12	16.638±2.483	1.849±0.290	16.889±2.052	21.157±2.700
Significance	NS	NS	NS	NS
LSD _{0.05}	5.792	0.614	4.944	6.371
Treatment	Leaf fresh weight (g)	Petiole fresh weight (g)	Stem fresh weight (g)	Root fresh weight (g)
Shallow water table				
SWT-20	5.629±0.616	0.537±0.062	5.411±0.680	5.076±0.610
SWT-16	6.431±0.738	0.592±0.079	6.165±0.591	5.007±0.443
SWT-12	6.605±0.978	0.643±0.100	6.757±0.833	4.780±0.504
Significance	NS	NS	NS	NS
LSD _{0.05}	2.251	0.237	2.040	1.396

Remark: The data represent the mean ± standard error; NS means each treatment is not significantly different at LSD_{0.05}.

Microclimate at shallow water table differences

ANOVA analysis of the differences in soil moisture showed significant differences between the different levels of shallow water table. The differences could be attributed to variations in the ability of the substrate to capitalize on various types of submergence. Based on the results, the shallow water table at 12 cm depth (SWT-12) had the highest soil moisture level because it received the most water (Figure 9).

B. Discussion

Growth of stinky bean plant on different planting media

Leaf growth, such as midrib length and leaf width of stinky bean plant showed differences between various planting media. Positive results of leaf growth were observed in growing media that used biochar ameliorants, namely the growth of midrib length and leaf width.

This was consistent with several research reports related to the advantages of biochar planting media. Biochar promoted early growth in African mahogany (*Khaya senegalensis*). Therefore, this material has potential as a growth medium capable of improving the quality of tree seedlings in the northern Ghana region with generally low nitrogen and organic matter content (Baatuuwie, Nasare & Tefuttor, 2020). Based on this study, the application of ameliorant mixtures was not significantly different, as shown through several growth parameters of stinky bean plants. This was caused by the ameliorant used not being classified as nutrient-rich ameliorant, thus taking a longer time to have an impact on the plant growth. This was in line with Muda et al. (2023), who reported that non-fertilizer ameliorants may not effects on plant growth.

In another research, the citrange-carrizo citrus plant produced optimal rootstock growth by adding 25% biochar. The treatment

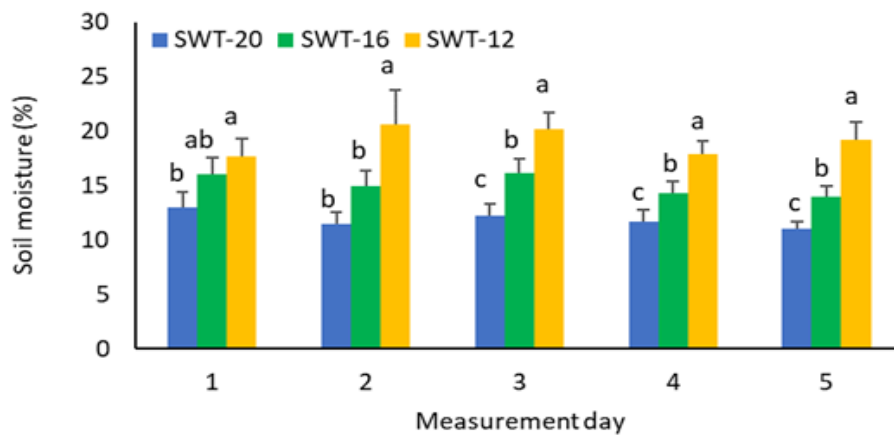


Figure 9. Soil moisture measurement at a shallow water table difference. The shallow water table consists of SWT-20 = shallow water table 20 cm from the surface of the planting media; SWT-16 = shallow water table 16 cm from the surface of the planting media; and SWT-12 = shallow water table 12 cm from the surface of the planting media

increased the inner layer substrate density, providing stable mechanical support for plant growth. Although growth was limited in the shallow potting layer, this indicated a tendency for roots to grow near the surface, possibly due to better nutrient availability or the physical characteristics of the substrate (Ferlito et al., 2020). The high porosity of biochar facilitates efficient absorption and storage of water. This capability plays an important role in improving water use efficiency, specifically in drought-prone areas. Furthermore, the pore structure also functions as a nutrient storage, effectively reducing the need for additional mineral fertilizers (Medyńska-Juraszek & Ćwieląg-Piasecka, 2021). Rice husk charcoal biochar application had a significant effect on plant height and fresh weight parameters (Walianggen, 2022). Based on the results, the height, canopy width, stem diameter, and number of leaves on different planting media, including biochar, cocopeat, peat ameliorants, and topsoils, showed no significant difference.

The microclimate analysis showed an increase in air temperature followed by elevated substrate temperature. This was consistent with previous research (Kropp et al., 2021), where an increase in air temperature corresponded to high soil temperature in tundra vegetation

ecosystems. According to a recent report, higher air temperatures increase plant growth in the mountains (Wang et al., 2020). Soil moisture also plays an important role in controlling vegetation growth because changes in this parameter can affect the composition of plants in the environment (Zhang et al., 2022). Although increased air and substrate temperature were found in the four growing media, this did not significantly affect the growth of the stinky bean plant. The significant differences in soil moisture across four growing media also did not significantly affect the growth. This showed that stinky bean plants could be planted in four planting media of biochar, peat, and cocopeat ameliorants, as well as topsoil at different shallow water table conditions.

Estimation of leaf area of stinky bean plant

Estimation of leaf area was conducted according to research by Lakitan et al. (2022). Accurate estimation was achieved using 120 leaves with a regular shape, covering various sizes. Based on the R^2 value, the zero-intercept linear model was considered the best and most effective choice for the three components: midrib length, leaf width, and the interaction between the two in predicting leaf area estimation. This was consistent with the

research of (Muda et al., 2023), which estimated leaf area of citrus plants by multiplying leaf length and width using a regression having a zero intercept.

Growth of stinky bean plant at different shallow water table conditions

Plant species have varying survival strategies when experiencing waterlogging (Zhou et al., 2020). A strong root system, high seedling vigor, and large collar diameter can make plants more resistant to waterlogging in the environment (Nabloussi et al., 2019). Optimal leaf growth of stinky bean plant occurred in shallow water table condition of 12 cm from the surface of the planting media (SWT-12). This was in line with the research by Shaheen et al. (2021), stating that *Eucalyptus camaldulensis* demonstrated optimal waterlogging tolerance and strong physiological performance, including photosynthesis rates. Ma, Rao, and Chen (2019) also reported that cypress plants with good waterlogging tolerance could develop new leaves quickly when experiencing waterlogging stress.

The growth of stinky bean plant in three different shallow water table variations, namely 20 cm (SWT-20), 16 cm (SWT-16), and 12 cm (SWT-12), showed no significant difference. This result confirms the plant's ability to grow optimally in wetland conditions with a shallow water table. According to Tata et al. (2022), *Shorea balangeran* and *Cratogeomys arborescens* demonstrated relatively high survival rates, tolerating 13 weeks of saturation by developing additional roots to adapt to inundation conditions and grow better in full sun. Fujita, Noguchi, and Tange (2020) also reported that *Fraxinus mandshurica*, a teak tree species originating from the Mandshuria region in East Asia, showed the highest level of tolerance because existing roots were not damaged by waterlogging conditions, indicating effective adaptation to waterlogged environments.

Microclimate dynamics related to increasing air and substrate temperature, and soil moisture were significantly different at three variations of shallow water table. Although these dynamics enhanced growth, the result was not significantly different across the three variations of shallow water table. This implied that the stinky bean plant could be planted at three shallow water table variations of 20 cm (SWT-20), 16 cm (SWT-16), and 12 cm (SWT-12).

IV. CONCLUSION

In conclusion, optimal leaf growth of stinky bean plant occurred in biochar ameliorant planting media, but plant growth in four different planting media was not significantly different. Although the conditions of air, substrate temperature, and soil moisture varied, the stinky bean seedlings still grew optimally across all planting media in shallow water table conditions. Based on the R^2 value, the zero-intercept linear model was considered the best for predicting leaf area estimation by considering midrib length, leaf width, and the interaction between the two. The leaf growth increased in shallow water table SWT-12, but the result was not significantly different from other conditions, namely SWT-20 and SWT-16, suggesting stinky bean cultivation could be carried out in wetlands with shallow water table. Although microclimate dynamics, such as changes in air and substrate temperature, and soil moisture, varied across the three shallow water table variations, the results had no significant impact on growth. This indicated that the stinky bean plant could grow optimally on SWT-20, SWT-16, and SWT-12.

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