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Effects of Biochar and Organic Fertilizer Application on Soybean Growth Under *Melaleuca cajuputi* Stand

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ABSTRACT/ABSTRAK

Pengaruh aplikasi biochar dan pupuk organik terhadap pertumbuhan kedelai di bawah tegakan kayu putih

Produksi komoditas pertanian dipengaruhi oleh berkurangnya lahan produktif yang diakibatkan oleh alih fungsi lahan menjadi pemukiman dan industri. Memaksimalkan potensial lahan kering dengan menambahkan *biochar* dan pupuk organikberpotensi menjadi solusi dalam mengatasi masalah tersebut. Biochar berfungsi mengikat air dan nutrisi, sedangkan pupuk organik dapat meningkatkan kesuburan tanah. Penelitian bertujuan untuk menganalisis pengaruh pemberian *biochar* dan pupuk organikterhadap pertumbuhan kedelai pada penanaman di lahan agroforestri. Percobaan dilaksanakan diResort Pengelolaan Hutan Menggoran, Playen, Gunungkidul, Yogyakarta pada bulan Maret hingga Juni 2022. Percobaan dirancang menggunakan Rancangan Acak Kelompok Lengkap (RAKL) pola faktorialdengan dua faktor. Faktor pertama yaitu biochar (tanpa biochar, sekam padi, tempurung kelapa) dan faktor kedua yaitu pupuk organik (tanpa pupuk organik, pupuk kandang ayam, pupuk kandang sapi, pupuk kandang kambing).Variabel pengamatan yaitu indeks luas daun (ILD), bobot daun khas (BDK), nisbah luas daun (NLD), luas daun spesifik (LDS), laju pertumbuhan tanaman (LPT),laju asimilasi bersih (LAB), dan persentase N-total tanah. Data hasil dianalisis menggunakan analisis ragam (ANOVA), jika perlakuan berbeda nyata maka dilanjutkanuji Duncan's Multiple Range Test (DMRT) taraf nyata 5%. Hasil penelitian menunjukkan tidak terdapat interaksi antara jenis biochar dan jenis pupuk organik. Aplikasi jenisbiochar dan pupuk organik yang diuji tidak meningkatkan semua parameter pengamatan daun. Aplikasi pupuk organik secara mandiri memberikan pengaruh pada persentase N-total tanah, pupuk kandang sapi dan kambing memberikan hasil N-total tanahyang secara nyata lebih tinggi dibandingkan dengan tanpa perlakuan pupuk organik.

Kata Kunci:
Agroforestry, Biochar, Dry Land,Organic Fertilizer, Soybean

The production of agricultural commodities is affected by the reduction of productive land, whichis due to the land conversion into residential and industrial areas. Maximizing the potential of dry land with biochar and organicfertilizerapplication can potentiallybecome the solution to overcome it. Biochar functions to retain water and hold nutrients, while organic fertilizer can enhance soil fertility. The research aims to analyze the effects of biochar and organic fertilizers application on soybean growth in agroforestry planting areas. This research was conducted at Menggoran Forest Resort, Playen, Gunungkidul, Yogyakarta, from March to June 2022. The experiment

was designed in a factorial randomized complete block design (RCBD) with two factors. The First factor was types of biochar (without biochar, rice husk biochar, coconut shell biochar), and the second factor was types of organic fertilizer (without organic fertilizer, chicken manure, cow manure, and goat manure). The observed variables were leaf area index (LAI), specific leaf weight (SLW), leaf area ratio (LAR), specific leaf area (SLA), crop growth rate (CGR), net assimilation rate (NAR), and soil N-total percentage. The data were analyzed using analysis of variance (ANOVA), and if the treatment showed significant differences, Duncan's Multiple Range Test (DMRT) at a 5% significance level was performed. The results showed no interaction between the type of biochar and the type of organic fertilizer. The application of biochar and organic fertilizers tested did not increase any of the observed growthparameters.The application of organic fertilizer independently has an effect on the percentage of soil N-total, and cow and goat manure application resulted in significantly higher final soil N-total percentages compared to without organic fertilizer treatment.

INTRODUCTION

One of the causes of agricultural yield decline is the reduction of productive land in Indonesia. Most of the productive land reduction isdue to land conversion for building construction. Population increases in Indonesia also cause less productive land(Harini & Ariani, 2019). Implementing an intercropping system by cultivating soybeans between perennial crops, such as eucalyptustrees, presents a feasible agricultural strategy. Cultivation in agroforestry areas can improve people's income because the revenues can be obtained from soybean cultivation and eucalyptus trees. Cultivation of annual crops, such as soybean, in aeucalyptus intercropping system can be carried out in several seasonal crop rotations because the leaves of eucalyptus trees are regularly harvested (leaf pruning). Therefore, the light limitation that usually occurs in the agroforestry intercropping system can be avoided.

Agroforestry can be applied to various types of land, including dry land. Dry land has limited water availability and low fertility (Heryani & Rejekiningrum, 2019). However, dry land can be utilized for Indonesian agricultural development(Fauzan, 2020). Organic matter can be added to dry land to maximize its potential. The organic matter that can be added to dry land is livestock manure as organic fertilizer and biochar. Due to its low fertility, dry land requires the input of organic matter like biochar and organic fertilizer to improve soil fertility.

Biochar is made of organic plant residues such as rice husks, coconut shells, corn cobs, wood chips, peanut shells, and other organic materials, which can be used as a water-retaining material in the soil. The application of rice husk biochar showed the highest plant growth in soybeans (Nurmalasari *et al.*, 2022). Biochar can prevent soil water loss and bind the nutrients, preventing them from disappearing due to surface runoff and leaching.

Increased soil moisture due to biochar application makes it difficult for the soil to lose water (Suryakencana *et al.*, 2023). Organic fertilizers are made of organic materials, such as plant residues and livestock manure(Marian & Tuhuteru, 2019). Organic matter application to soil impacts increasing soil pH(Hartati *et al.*, 2022)due to its function in neutralizing the soil pH, which helps plant nutrient absorption.

The application of organic matter, such as biochar and organic fertilizers, is considered to increase plant growth because they have good benefits for the soil. However, the combined use of these two materials is rarely applied among farmers. This research aims to study the growth of soybean plants with the application of various biochar and organic fertilizers in the Eucalyptus intercropping system, which can provide information on its potential application.

MATERIALS AND METHOD

Place and time of research

The research was conducted at Menggoran Forest Resort, Playen District, Gunungkidul Regency, Special Province of Yogyakarta,between

March and June 2022.The research location is geographically situated at 7°57'40.0''S and 110°29'48.8''E, with an altitude of 215 meters above sea level.

Experimental design and treatment

The experiment was arranged in afactorial Randomized Complete Block Design(RCBD)with two factors. The first factor is the type of biochar with three levels, without biochar, rice husk biochar, and coconut shell biochar.

The dose of each biochar treatment appliedwas 15 tons/ha. The second factor is the type of organic fertilizer with four levels, which consisted of a control treatment (without organic fertilizer), chicken manure, cow manure, and goat manure. The dose of each organic fertilizer was 20 tons/ha.In total, therewere 12 treatment combinations repeated three times, resultingin 36 experimental units.

Land preparation and planting of the Grobogan Soybean

Grobogan variety was selected as a soybean tested, due to its short harvest life (Nilahayati*et al.*, 2021). The distance between the plots was 50 cm, and between blocks bordered by eucalyptus trees. The plot had a length of 3.6 m and a width of 0.9 m. Each plot contained 48 soybean crops with a planting distance of 40 cm x 15 cm (Figure 1). Two seeds were sown per planting hole to ensure germination success. Following seedling emergence, thinning was conducted to retain a single healthy seedling per hole, optimizing plant spacing and resource utilization.

Figure 1. Experimental plots

The first inorganic fertilizers application was carried out at one week after planting(WAP) using a dose of 25 kg/haof Urea (0.15g/plant), 75 kg/haof SP-36 (0.45 g/plant), and 100 kg/haof potassium chloride (0.60 g/plant). Thefertilizer was applied bymaking a hole beside the plant, and the hole was covered immediately after all the inorganic fertilizers were put in each hole. The second inorganic fertilizer application was carried out at 25 days after planting using 25 kg.ha^{1}of urea.

Application of biochar and organic fertilizer

Organic fertilizer was applied after planting and spread over the soil. The type of organic fertilizer used was chicken manure, cow manure, and goat manure, with a recommended dose of 20 tons/ha for each manure (120 g/plant), which in total was5.76 kg/plot of organic fertilizer.The type of biochar used was rice husk and coconut shell. Similar to the application of organic fertilizer, biochar applicationwas given to the plots after planting the seeds (Figure 2). Biochar was spread on the soil surface according to the recommended dose of 15 tons/ha(90 g/plant), which in total was 4.32 kg/plot.

Figure2. Application of biochar

Observation and data analysis

The observations were made on the soil, including initial soil analysis, final soil analysis, biochar, and organic fertilizer analysis.Soil sampling was conducted on three plots (front, middle, and rear) within each experimental block. In each plot, samples were collected from three points arranged in a zigzag pattern, composited at the plot level, and subsequently combined to form a representative sample for each block. Plant growth observations were carried out at 3 WAP, includingleaf area index (LAI), specific leaf weight (SLW), leaf area ratio (LAR), specific leaf area (SLA), while crop growth rate (CGR), and net assimilation rate (NAR) were observed in two phases.Phase 1 was measured at 3-5 WAP, while data in phase 2 were measured at 5-7

WAP.Leaf area measurement was obtained using a leaf area meter. Calculations for leaf area index (LAI; leaf area per unit ground area), specific leaf weight (SLW; dry leaf weight per unit leaf area), leaf area ratio (LAR; leaf area per unit total dry weight), specific leaf area (SLA; leaf area per unit dry leaf weight), while crop growth rate (CGR) and net assimilation rate (NAR) were performed using standard presented formulas.The observed data were analyzed using analysis of variance (ANOVA), and if significant differences were found, the analysis was followed by Duncan's Multiple Range Test at the 5% significance level.

The NAR and CGR parameters were calculated using the formula as follows:

$$NAR = \frac{(W2-W1)(\ln A2 - \ln A1)}{(t2-t1)(A2-A1)}$$

$$CGR = \frac{W2-W1}{t2-t1}$$

Remarks:
W1 = Dry weight1 (g)
W2 = Dry weight2 WAP (g)
A1 = Leaf area1 (cm^2)
A2 = Leaf area2 (cm^2)
t1 =Time 3-5 WAP (week)
t2 = Time 5-7 WAP (week)

RESULTS AND DISCUSSION

Initial soil analysis

The initial soil analysis was conducted before planting, andthe results showed that the soil has a clay content of 31.49% (Table 1). According toFitria *et al.* (2024),soil is categorized as grumusol when the clay content is > 30%. Grumusol soil contains a significant amount of montmorillonite clay, resulting in high absorption capacity (50-100 me/gram of clay) and a soil pH of 6,0-8,2. In addition, Ganesiska *et al.* (2020) reported that this type of soil has the property that the deeper it goes, the more alkaline it becomes. This causes water movement and the state of harmony to deteriorate. The Grumusol soil also has few aeration pores, and very low permeability(Zuhdi *et al.*, 2022). Based on Table 1, the levels of C-organic and N total are categorized as low, while the levels of P_2O_5 and K_2O are very low. It is an early indication thatfertilizer application to support plant growth is a necessity. Suitable soil acidity for soybean growth ranges from 5.5-7 (Hartati *et al.*, 2023).Based on Table 1, the pH at the research location (6.33) is suitable for soybean growth.

Table 1.Initial soil analysis

Soil chemical properties	Unit	Result	Determination
C-Organic	%	1.56	Low
N total	%	0.17	low
P_2O_5	%	0.05	very low
K_2O	%	0.07	very low
pH		6.33	Acid
CEC	me%	21.60	Low
BV	g/cm^3	1.15	-
BJ	g/cm^3	2.15	-
Porosity	%	46.51	-
Texture			
(Dust, Clay, Sand)	%	48.33 ; 31.49 ; 20.18	clayey

Source: Laboratory of Chemistry and Soil Fertility Analysis, Faculty of Agriculture, UNS (2021). The determination is according to the Soil Research Institute (Soil Research Institute, 2009)

Biochar and organic fertilizer analysis

The biochars and organic fertilizers used in this study wereanalyzed to obtain the basic information related to C-organic, N total, P_2O_5, K_2O, and C/N ratio (Table 2). The analysis results showed that rice husk biochar has higher C-organic and N total contents, while coconut shell biochar has betterP_2O_5 and K_2Ocontents (Table 2). Biochar has pores that can absorb nutrients and retain water in the soil (Kabir *et al.*, 2023). The main contents of biochar include carbon, hydrogen, and silica. Silica plays a role in increasing the availability of P elements(Anggraeni *et al.*, 2022). Coconut shell biochar contains nitrogen, water, lignin, cellulose, ash, and pentosan(Ajien *et al.*, 2023).

The organic fertilizers used for treatment were cow manure, chicken manure, and goat manure.It showed that chicken manure has better

C-organic, N total, P_2O_5, and K_2O contents compared to the two other organic fertilizers used in this study (Table 2).Manure is a type of organic fertilizer that has been reported can improve the chemical, physical, and biological properties of soil (Walida & Harahap, 2020). Organic fertilizer can also increase the pH of acidic soil, which is related to plant nutrient absorption. Nutrient absorption occurs well when the soil pH is close to normal (Ferrarezi *et al.*, 2022).

Table2. Biochar and organic fertilizer analysis

Parameters	Units	Type of biochar		Type of organic fertilizer			Quality standard
		Rice husk	Coconut shell	Chicken manure	Cow manure	Goat manure	
C-Organic	%	61.18	54.51	57.23	48.85	46.17	Min. 15
Ntotal	%	1.13	0.28	2.78	2.24	2.5	
P_2O_5	%	0.45	2.81	2.81	2.08	1.91	Min. 2
K_2O	%	1.36	2.81	2.5	1.63	1.9	
C/N ratio	-	54.04	197.29	20.56	21.85	18.48	≤ 25

Source: Yogyakarta Agricultural Technology Assessment Laboratory Testing Laboratory. Qualitystandards areaccording to the Soil Research Institute (Soil Research Institute, 2009)

The effect of biochar and organic fertilizer treatment on the N soil content

The nitrogensoil content analysis was conducted after harvesting.There is no interaction between the type of biochar and organic fertilizer in influencing the N total soil content. However, there weresignificant differences among the types of organic fertilizers tested in this study, whilethe type of biochar did notsignificantly affect theN content of the soil (Table 3). In this study, biochar was spread over the layer of organic fertilizer on the plot surface.According to Singh *et al.* (2018), rice husk biochar can contribute nutrients and bind the nutrients provided by organic fertilizers when mixed into the soil. The results showed that the application of biochar by spreading on the surface of the plot did not have the same effect as if biochar were mixed into the soil.

Table 3. Effect of biochar and organic fertilizer on nitrogen soil content.

Treatments	N Soil Content (%)
Biochar	
Control	0.16
Rice husk	0.21
Coconut shell	0.16
Organic fertilizer	
Control	0.12 a
Chicken manure	0.16 ab
Cow manure	0.20 b
Goat manure	0.21 b
Average	0.18

Note: The numbers followed by the same letter indicate that there is nodifferencebased on DMRT test at 5% significant level.

Providing organic fertilizer types gave significantly different results to the final N soil content (Table 3). Even though chicken manure showed better C-organic, N total, P_2O_5, and K_2O contents (Table 2), application of goat manure and cow manure gave the soil anN content yield of 0.20% and 0.21%, which arehigher than the control treatment (Table 3).Thura (2010)reported that goat manure can improve the physical, chemical, and biological properties of soil.

The effect of biochar and organic fertilizer treatment on the leaf and plant growth parameters

Theleaf parameter indicates the ability of plants to participate in the process of photosynthesis. Leaf area index (LAI) is the leaf area per land area or plant spacing. The higher the leaf area value, the greater the LAI value (Dahu, 2022). The results show that there is no significant difference in the type of biochar in the LAI parameter at 3 WAP. Although not significant, there was an increase in the rice husk biochar treatment of 21.42% compared to the control treatment (Table 4). Biochar has the ability to retain nutrients and water,which can enhance soil fertility(Kabir *et al.*, 2023). However, in this study, the application of biochar was done only by spreading it on the soil surface, which limited its ability to significantly affect the plants. Additionally, the effect of the biochar and organic fertilizer treatments might not be observed yet at 3 WAP.

The type of organic fertilizer alsoresulted in no significant differencein the soybeanLAI at3 WAP. Although not significant, there was an increase in the cow manure treatment of 26.67% compared to the control treatment (Table 4).Manure

can help improve the availability of nitrogen elements in the soil(Wulandari *et al.*, 2021). However,manure is a slow-release fertilizer, so plants cannot immediately absorb the nutrients as it takes time for the manure to decompose and release them(Gharib *et al.*, 2024).

The specific leaf weight (SLW) shows leaf thickness and the ratio between leaf weight per unit of leaf area (Agustiani *et al.*, 2019).The higher the SLW, the greater the leaf thickness(Anhar et al., 2022). The type of biochar and organic fertilizer had no significant difference in theSLW trait of soybean at 3WAP (Table 4).The SLW can be influenced by LAI. Leaf area index is positively related to photosynthesis. The higher the LAI, the more leaves participate in the photosynthesis process, leading to increased biomass accumulationTanaka *et al.* (2022), including leaf weight.Leaf area index in the research results showed insignificant differences, which in turn caused the SLW to be not significantly affected.

Table 4. Average value of leaf area index (LAI), specific leaf weight (SLW), leaf area ratio (LAR), specific leaf area (SLA).

Treatments	LAI	SLW (g/cm^2)	LAR (cm^2)	SLA (g)
Biochar				
Control	0.11	0.0029	102.396	352.668
Rice husk	0.14	0.0026	125.693	416.793
Coconut shell	0.13	0.0025	1113.240	411.351
Organic fertilizer				
Control	0.11	0.0028	110.746	371.356
Chicken manure	0.13	0.0028	110.292	370.772
Goat manure	0.10	0.0027	108.581	393.264
Cow manure	0.15	0.0025	125.487	439.024
Average	0.12	0.0027	256.633	393.604
Interaction	-	-	-	-

(-): no interaction.

Leaf area ratio (LAR) is a measurement related to leaf area and the number of leaves (Indriana, 2020).The results show that there was no significant difference in the type of biochar in the soybean inLARat3 WAP.There was an increase in the rice husk biochar treatment of 18.53% compared to the control treatment (Table 4). Rice husk biochar can retain water in the soil, helping to maintain water availability for plants(Singh *et al.*, 2018). However, in this study, the biochar was only spread on the soil surface, limiting its ability to maintain water availability.

Similar to the effect of biochar in LAR, the type of organic fertilizer treatment was not significantly different for soybeans at 3 WAP. Although no significant difference was observed, there was an increase in the cow manure treatment of 11.74% compared to the control treatment (Table 4).Manure fertilizer contains a variety of nutrients, but it is a slow-release fertilizer. The nutrients are released gradually, and this results in insufficient nutrients in the early stages of growth, as they do not receive sufficient nutrients immediately.Further observationsare needed in order to evaluate the effect of the organic fertilizers tested. However, over time, organic fertilizers decompose and continuously release nutrients(Gharib *et al.*, 2024).

Specific leaf area (SLA) is the ratio of leaf area to the dry weight of the leaf. SLA is affected by light intensity (LI), which means that if the LI is low, it causes the specific leaf area to decrease(Humoen *et al.*, 2020). This trait is positively correlated with nitrogen nutrients. Plant growth is better in conditions of sufficient nitrogen (Barbosa *et al.*, 2021). There is no significant difference among thetypes of biochar and types of organic fertilizer evaluated in this study in SLA at 3 WAP soybeans,but there was an increasein SLA in the rice husk biochar treatment (15.38%) compared to the control treatment and an increase in cow manure treatment (15.41%) (Table 4). Biochar can retain nutrients in the soil, preventing them from easily leaching and facilitating the absorption of nutrients by plant roots(Hossain *et al.*, 2020). Based on the analysis of organic fertilizers, cow manure contains nitrogen that meets quality standards (Table 2). However, in this study, biochar and organic fertilizer application wereonly by spreading on the soil surface, limiting their effectiveness and resulting insuboptimal nutrient absorption by the plant roots.

In this study, the crop growth rate (CGR) observation is carried out in two phases. The first phase (V1) is the growth rate of the plant at 3-5 WAP, and the second phase (V2) is the growth rate of the plant at 5-7 WAP(Figure 3).The plant growth rate describes the speed of plant growth over a specific period during the plant's growth per unit area of land(Hilty *et al.*, 2021). The results showed thatthere was no significant effect on the application of biochar and organic fertilizer.The growth rate of plants is influenced by the leaf area index and net assimilation rate. An optimal leaf area index and a high net assimilation rate can enhance plant growth(Faisal *et al.*, 2024). However, research

results indicated that the LAI (Table 4) and net assimilation rate(Figure 4)are not significant, leading to an insignificant plant growth rate.

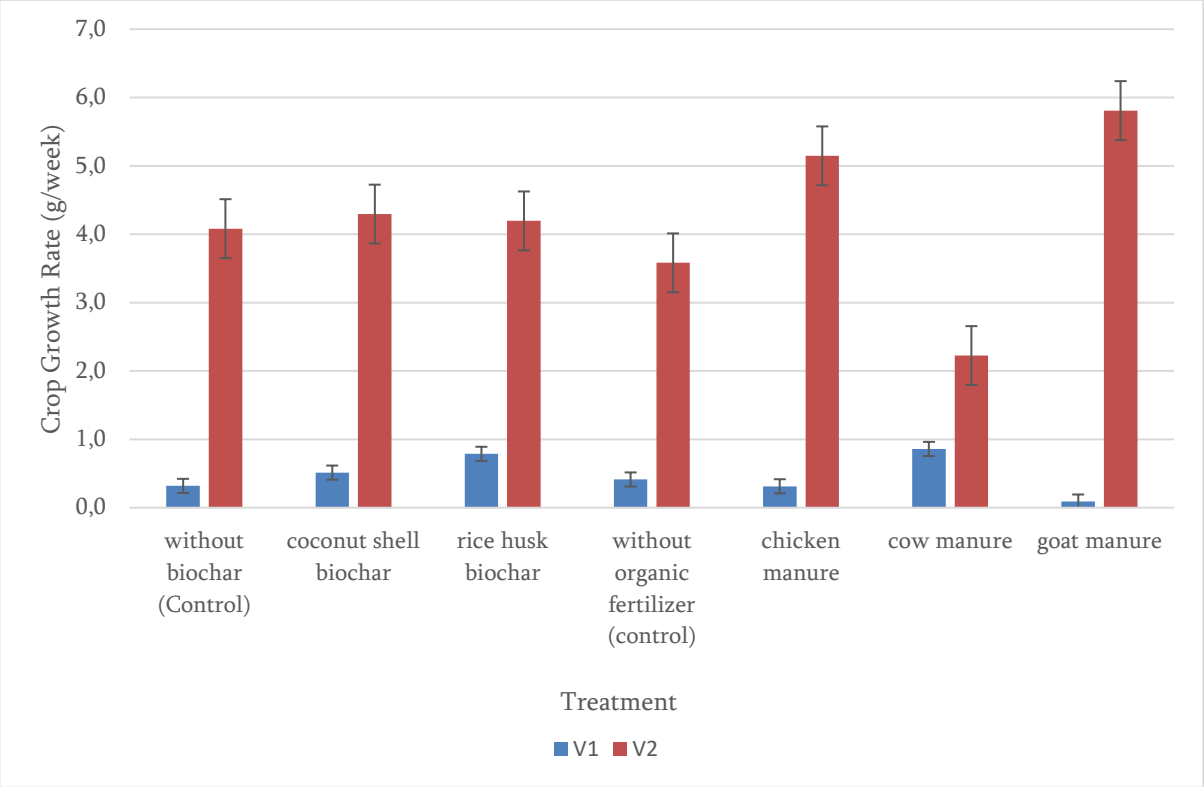

Figure3. Diagram of crop growth rate.

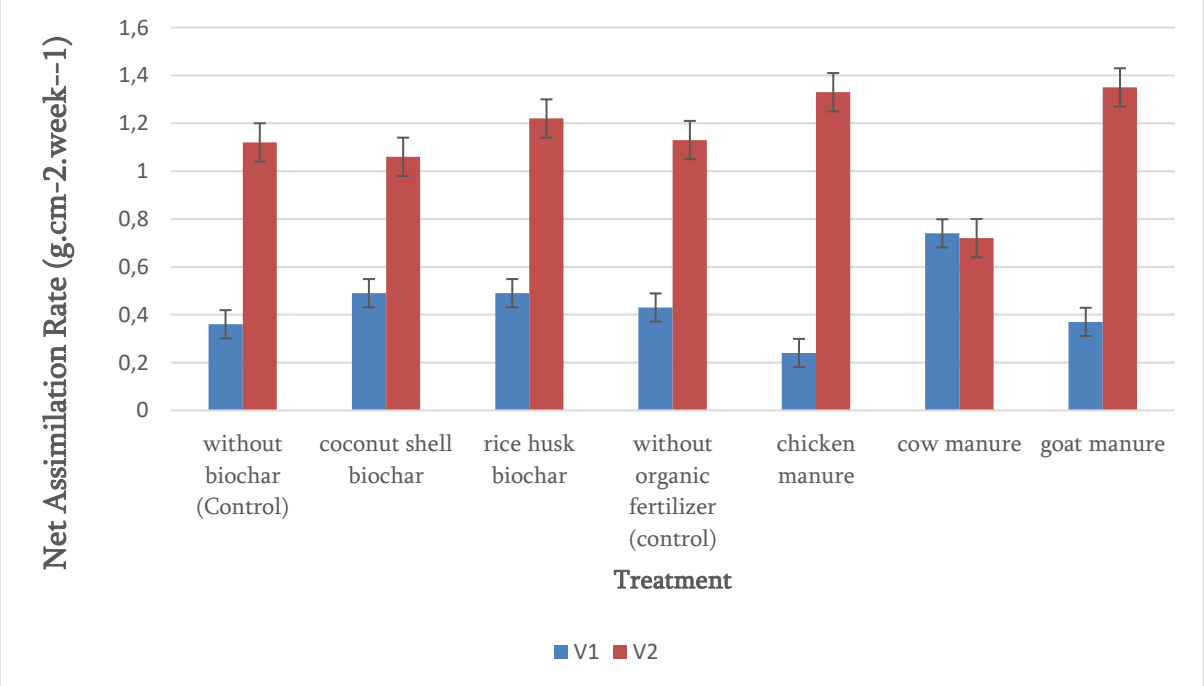

Figure4. Diagram of net assimilation rate.

The net assimilation rate (NAR) is the dry weight accumulation rate per unit area and per unit time and shows the ability of plant leaves to produce photosynthesis per week. The dry matter at the net assimilation rate is assumed to be mostly composed of CO_2 (Musrif & Sriasih, 2019).The type of biochar

and organic fertilizer has no significant effect on the net assimilation rate of soybean plants. The net assimilation rate is influenced by leaf area, which can be expressed through LAI. A high leaf area results in a higher production of assimilates from the photosynthesis process(Faisal *et al*., 2024). The net assimilation rate is optimal when the leaf area index is optimal. However, the observations of the leaf area index in this study showed that the leaf area index was not significant, which in turn affects the net assimilation rate, making it insignificant.

CONCLUSION

This study aimed to analyze soybean growth with the application of different types of biochar and organic fertilizers. Based on the research results, the types of biochar and organic fertilizersdid not have any significant effect on soybean growth, in particular on leaf parameters observed at 3 WAP. The application of different types of organic fertilizer only succeeded in increasing the N total in the soil, with the cow manure (0.20%) and goat manure (0.21%)showing higher values compared to the control treatment (0.12%).The results from this study suggested that the method of applying biochar and organic fertilizers by merely spreading them on the soil surface did not allow for optimal distribution into the plant root zone. For future research, it is recommended to use more efficient application methods, such as incorporating the materials into the soil.

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