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The role of biochar and organic fertilizers on the growth and yields of soybean

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ABSTRACT

The low production of domestic soybeans is due to the decreasing amount of productive land, so the cultivation of soybeans can be done by utilizing dry land. One type of dryland soil is grumusol soil, which is a less fertile soil and requires improvement through and applying biochar and organic fertilizers. Biochar is expected to increase water availability, thereby increasing nutrient absorption. The research was conducted by experiment with a randomized completed block design (RCBD) two-factor treatment. The treatments are biochar (without biochar as control, biochar of coconut shell, rice husk, and *Strobilanthes cusia* waste) and organic fertilizer (without fertilizer as control, chicken, cow, and goat manure). Each combination treatment, as an experiment unit, was replicated three times. The results showed that the types of biochar and organic fertilizer do not affect the growth and yield of soybeans. The application of types of biochar alone does not affect the soybean yield, but the various organic fertilizers alone can increase the yield of soybeans. Cow organic fertilizer was able to increase the total pods (31.68%), the number of seeds per plant (29.33%), and the stuffed pods (24.11%).

Keywords: biochar, growth, *organic fertilizer*, soybean, pods

INTRODUCTION

Soybean (*Glycine max* L.) is often used as a good source of protein for nutritional fulfilment. Soybean is one famous food legume globally (Jabborova et al., 2022). Soybeans are the second most important food crop after rice and maize. The high demand for soybeans is disproportionate to soybean production in Indonesia. National soybean productivity reaches only 1.3 tons per hectare, although in variety description it can reach 2.77 tons per hectare (Harsono et al., 2022). More than 90% of domestic soybean needs are imported from America, Brazil, and Canada. Indonesia's imported soybeans reached 2.11 million tons, or US$ 842.75 million, throughout 2020 (Statistics Indonesia, 2020).

This condition is caused by the decreasing productivity of land in Indonesia. Around 10.68 million hectares, or 6.15%, of agricultural land, is converted into non-agricultural land every year (Statistics Indonesia, 2020). The overexploitation of land causes a decline in the cultivation ability of the land becoming one of the major problems faced by humans (Li et al., 2020).The way to meet domestic soybean needs can be done by converting dry land into productive land for soybean cultivation.

One type of dryland soil is grumusol soil, which has many problems, including low fertility, poor soil structure, and being very clayey. To reduce the current soil problems, we have to improve the soil structure and soil fertility for crops (Li et al., 2020).

Increasing grumusol soil fertility using organic manure and biochar as suppliers for plant nutrients (Schulz et al., 2013). Biochar significantly improves soil structure, soil quality, plant growth, and yield (Wu et al., 2022). Biochar can increase soybean yield by improving soil nutrient levels such as N, P, and K (Han et al., 2019). Based on Khan et al., 2021), the application of biochar can promote growth by increasing chlorophyll content in wheat, thereby increasing yield. Biochar can increase the pH, soil porosity, and soil humidity, then increase the yields of crops such as soybean, rice, and sorghum (Xiu et al., 2019).

Organic fertilizers play important roles by fulfilling plants' nutritional needs as well as improving the physical, chemical, and biological properties of the soil (Altaee and Alsawaf, 2021). Organic fertilizer is a source of various types of important nutrients, such as nitrogen, phosphorus, and potassium. Nitrogen is an important nutrient that can be obtained from organic fertilizers. In addition, organic fertilizers can also be useful in reducing detrimental nutrients (toxins) for plants. In general, manure application significantly increased soil organic carbon, soil pH, total nitrogen (TN), available nitrogen (AN), available potassium, and available phosphorus (AP) (Du et al., 2020). Organic fertilizer contains various nutrients and microbiological agents that increase soil fertility (Wang et al., 2017). The application of manure has a beneficial effect on soybean yields by increasing the nitrogen available in the soil (Ghedabna et al., 2022), pH, and retaining soil organic carbon (Cai et al., 2019).

The use of biochar aims to promote the nutritional needs of plants as well as soil improvement materials. Biochar is stable in the soil, which is good for dry land (Wu et al., 2022). Biochar is a pyrolysis product that can be made from wood, straw, or other crop residues (Kätterer et al., 2019). Biochar comes from organic materials in agricultural waste such as husks, coconut shells, and sugarcane waste.

Sidobiru plant (*Strobilanthes cusia*) extract waste has the potential to be used as a material for making biochar. *Strobilanthes cusia* is a material for making natural dyes in the form of indigo paste. *Strobilanthes cusia* will be extracted by soaking and boiling and will produce a blue color, which is used to make natural textile dyes. Waste from this extract can pollute the environment. Therefore, it can be used as a material for making biochar to reduce pollution from the industry.

Biochar can increase soil pH and maintain the stability of heavy metals in the soil because it is alkaline (Liu et al., 2020). The use of nutrient briquettes has the potential to increase fertilization efficiency and yield and reduce soil nutrient loss (Torane et al., 2017). Biochar has the potential to be used as an ameliorant material in the process of marginal land conservation. Biochar can improve soil physical and chemical properties (Coumaravel et al., 2011). Therefore, the objectives of the study were: i) examine the growth and yield response of soybean crops to the application of various types of biochar and organic fertilizers; ii) examine whether the biochar of *Stroblianthes cusia* waste is able to improve marginal soil structure and increase soybean growth and yield.

MATERIALS AND METHODS

Experimental site

The study was conducted from March to June 2022 at the Field Laboratory of the Faculty of Agriculture, Universitas Sebelas Maret, Jumantono District, Karanganyar Regency, Indonesia. The study site is geolocated at 7°30' S and 110°50' E, with an elevation of about 180 meters above sea level. The average temperature and relative humidity are ± 28.29 °C and ± 79.65%, respectively. The soil selected in the study was derived from dry land in Playen District, Gunung Kidul Regency, Yogyakarta Special Region, called Grumusol Soil. The soil texture is clayey, consisting of dust (48.33%), clay (31.49%), and sand (20.18%). The soil has a slightly acidic pH of 6.33 with a cation exchange capacity of 21.60%. The grumusol soil contains organic matter (1.56%), N available (0.17%), P (0.05%), and K (0.07%), which means this soil is less fertile.

Treatments and field practices

The experimental design was a randomized complete block design (RCBD) with two factors. The first factor is the types of biochar (without biochar, coconut shell biochar, rice husk biochar, and biochar of extract waste, *Strobilanthes cusia*), and the second factor is the type of organic fertilizer (without organic fertilizer, chicken manure, and cow manure, goat manure). The treatment was repeated three times and placed according to the research layout.

Biochar was made by the Kiln Traditional Method (Emrich,1985). All biochar materials are burned using a furnace or drum in conditions of minimal oxygen or air within a few hours until they become black charcoal, which is called biochar. Biochar and organic fertilizer were given to the plants at the same dose: 80 g per plant for organic fertilizer and 60 g per plant for biochar.

The research data was analyzed using ANOVA, then continued with the Duncan multiple test (5%) if there were significant differences. The variables observed were plant growth (plant height, number of branches, number of leaves), plant weight (fresh and dry weight), root nodules (number and effective root nodules), soybean pods (number of total pods, stuffed pods, and hollow pods), and soybean seeds (number of seeds, seed weight).

RESULTS AND DISCUSSION

Biochars laboratory analysis

Based on laboratory analysis (Table 1), this type of biochar has a very high organic C content, but the N, P, and K contents are still relatively low. This biochar has higher available N, P, and K contents than the other two types of biochar. Apart from that, the C/N ratio content of *Strobilanthes cusia* waste biochar has met the quality standard, namely 10.61, while the C/N ratio content of the other two types of biochar is still high. Organic material with a high C/N ratio cannot be directly available and absorbed by plants. Biochar is naturally alkaline; therefore, biochar is useful as a neutralizing agent and increases soil pH (Mandal et al., 2021). This shows that biochar is a material that plays a role as a soil improver in providing water and raising soil pH, not as a provider of nutrients for plants.

Plant growth

Plant height is the most important indicator of plant growth (Dong et al., 2019), reflected in photosynthetic and respiratory capacity (Li et al., 2020). Organic manure significantly affects the number of soybean leaves (Table 1). The application of chicken organic fertilizer gave the highest number of leaves (69.50 strands) and increased by about 16.16%.

Table 1. The content of nutrients in various types of biochar

Parameters	Unit	Types of biochar		
		Rice husk	Coconut Shell	*Strobilanthes cusia* waste
C Organik	%	61.18	54.51	36.61
N total	%	1.13	0.28	3.45
P_2O_5	%	0.45	0.28	1.44
K_2O	%	1.36	0.74	1.40
pH	-	7.20	9.60	8.70
KTK	cmol(+)kg-1	18.60	4.80	15.00
C/N ratio	-	54.04	197.29	10.61

Source: Analysis of the Yogyakarta Agricultural Technology Assessment Laboratory Testing Laboratory. Information: Quality Standards According to the Soil Research Institute (2009)

Chicken manure plays an important role in promoting plant growth, potential nutrient input, and microbial decomposition activity (Cai et al., 2019). Nitrogen plays an important role in the number of leaves (Azeem et al., 2019), which plays the main role in plant photosynthesis and transpiration (Budiastuti et al., 2022). Applying organic matter with a low C:N ratio and high N can sustain microorganisms and plant growth (Masunga et al., 2016). The C:N:N ratio of organic materials markedly influences the decomposition rate and the mineralization of N (Wolf and Snyder, 2003). Nitrogen is one of the primary nutrients that plants need to improve their growth and productivity (Li et al., 2021).

The rice husk biochar treatment is better than the control on the fresh weight (Table 2). Rice husk biochar increased fresh weight by about 25.73% compared to control. Fresh weight higher than control indicates that the use of rice husk biochar increases the ability of the soil to hold water (Nurida et al., 2017), meaning the groundwater content increases (Wu et al., 2022). Rice husk biochar has the ability to retain water and nutrients available to plants and is able to increase dry weight (Nurmalasari et al., 2022). High-rate biochar (12t/ha) significantly increases the water holding capacity, available N (Fall et al., 2016), soluble P (Huang et al., 2018), and reduces N losses in the rhizosphere zone (Li et al., 2021). Biochar can increase plant growth and yield by increasing water holding capacity (Hagner et al., 2016), fertilization efficiency, and soil nutrient loss (Torane et al., 2017).

In addition, rice husk biochar can reduce nitrogen loss in the soil and providing an important source of nitrogen for soybean growth (Xiu et al., 2021). Application of biochar can promote the crop growth (Liu et al., 2020), root nodulation, and legume yield (Sun et al., 2020). In addition, applying biochar can improve the soil's structure, which has positive benefits for the growth of young roots and biological nitrogen fixation (Li et al., 2020).

Table 2. Plant growth response to providing various types of biochar and organic fertilizer

Treatment	Plant height (cm)	Number of branches	Number of leaves	Fresh weight (g)	Dry weight (g)	Number of root nodules	Number of effective root nodules
				Types of biochar			
Control	51.33±6.51^{a}	4.50±1.09^{a}	62.50±11.47^{a}	129.91±52.50^{a}	27.16±9.88^{a}	45.58±23.90^{a}	19.92±11.49^{a}
Coconut shell	53.01±5.79^{a}	5.00±0.85^{a}	68.58±8.36^{a}	156.25±36.34^{ab}	33.87±8.12^{a}	44.42±26.66^{a}	26.33±18.70^{a}
Rice husk	50.33±3.49^{a}	4.50±0.80^{a}	67.17±10.92^{a}	163.33±41.86^{b}	35.14±8.88^{a}	48.33±24.95^{a}	28.00±12.81^{a}
S. cusia	49.47±7.15^{a}	4.33±1.30^{a}	62.58±9.49^{a}	147.14±38.07^{ab}	32.39±10.92^{a}	41.33±21.96^{a}	20.08±11.07^{a}
				Types of organic fertilizers			
Control	52.58±5.76^{a}	4.17±1.30^{a}	59.83±13.88^{a}	128.21±53.76^{a}	28.91±11.30^{a}	39.17±24.96^{a}	17.50±14.67^{a}
Chicken	49.28±6.93^{a}	4.58±0.90^{a}	69.50±6.61^{b}	154.73±40.13^{ab}	32.74±7.03^{ab}	48.42±23.23^{a}	27.67±11.24^{a}
Cow	52.90±5.56^{a}	4.83±1.19^{a}	67.00±9.86^{ab}	171.43±33.55^{b}	37.25±10.09^{b}	43.83±26.55^{a}	24.92±17.16^{a}
Goat	49.37±4.67^{a}	4.75±0.97^{a}	64.50±7.33^{ab}	142.25±35.07^{ab}	29.67±8.72^{ab}	48.25±22.01^{a}	24.25±11.36^{a}
Average	51.03±5.86	4.58±1.03	65.21±10.18	149.16±43.17	32.14±9.70	44.92±23.77	23.58±13.90
Interaction	-	-	-	-	-	-	-

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT (α = 0.05)
(-): No interaction

The application of cow manure has a significant effect on soybean fresh weight of about 33.71% (Table 2). Fresh weight is strongly affected by the water content in the tissues, nutrients, and the products of the plant's metabolism (Budiastuti et al., 2021). Application of organic fertilizers increases the water content of the soil (Panda et al., 2021).

The application of cow organic fertilizer has a significant effect on the dry weight compared to the control, namely 37.25±10.09 g, and increased by about 28.85% (Table 2). The dry weight of the plant, or biomass, is mostly photosynthetic before partitioning into the generative part occurs. The difference in biomass due to organic fertilizers shows the role of nutrient content in fertilizers. Nitrogen and potassium play a role in the formation of amino acids, which are converted into proteins, and are also required for the formation of compounds such as nucleic acids, enzymes, and chlorophyll (Rahayu et al., 2021). Nitrogen content in leaves, chlorophyll, and chlorophyll content index are closely related in influencing photosynthesis.

Meanwhile, P is a compound that makes up energy, ATP, which is needed in all biosynthesis (Fathi, 2022). Furthermore, nitrogen increases plant photosynthetic capacity and rapidly converts the synthesized carbohydrates into proteins and protoplasm, which allows the plant to grow faster (Om et al., 2014). While P as a constituent of energy compounds, ATP, is required in all biosynthesis (Thuy, 2023),

The number of nodules and active nodules does not increase with the application of biochar and organic fertilizers. Soil nitrogen derived from organic fertilizers becomes relatively high, resulting in the formation and activity of root nodules that are not optimal (Lagunas et al., 2023). The high nitrogen concentration in the soil will cause the root nodules to form fewer because it requires more carbon (Minamisawa, 2023). Rhizobia is a saprophytic lifestyle in the soil and forms nitrogen-fixing nodules on legume roots (Lipa and Janczarek, 2020). Rhizobium is influenced by nitrogen and phosphorus in the soil. Nitrogen and phosphor nutrients can stimulate N-fixing bacteria, which are symbiotic with soybean root nodules. P-fertilizers promote rhizobia growth, nodulation, and nodule function, as well as biological nitrogen fixation (Ulzen et al., 2020).

Soybean yield

The biochar's ability to hold soil water has no impact on increasing the soybean yield. Cow manure showed the best yields compared to the control, which increased the total pods by about 31.68% and stuffed pods by about 24.11% (Table 3). Cow manure with a low C:N ratio can encourage microbial activity in the soil, which can increase soybean yields (Ulzen et al., 2020) and crop yield quality (Diacono and Montemurro, 2010). Manure can restore degraded soils by maintaining organic matter and sustaining soil fertility for agricultural production in the long-term by slowly releasing nutrients. The total and stuffed pods are formed by the high supply of important nutrients such as nitrogen, phosphorus, and potassium. Soybeans require a high amount of nitrogen during the grain filling stage (Ulzen et al., 2020). The soybean yield can increase due to the high availability of N in the soil, nutrient use efficiency, high cation exchange capacity, soil structure, and water-holding capacity (Oladele, 2019). The addition of organic matter can induce changes in nutrient availability and may provide additional nutrients such as N, P, K, Mg, Na, and Ca (Prendergast-Miller et al., 2011). Based on an 8-year field experiment, organic fertilizer can influence crop yields due to the soil total nitrogen, available N and P nutrients, and maintaining the soil pH balance (Cai et al., 2019).

Application of cow organic fertilizer shows the highest result on the total number of seeds per plant. Cow manure gave the highest results on the number of seeds (85.58±27.40), which was significantly different from the control, and increased the number of seeds by about 29.33% (Table 3). Cow manure was reported to have a significant effect on the total weight of seeds, the weight of 100 seeds, and the productivity of the plants (Sebayang and Fatimah, 2019). This is because cow manure has a high content of nitrogen and phosphorus in the soil (Ghedabna et al., 2022).

Table 3. Soybean yield response from the application of various types of biochar and organic fertilizer

Treatment	Total pods	Stuffed pods	Number of seeds per plant	Seed weight per plant (g)
		Types of biochar		
Control	52.17±14.48[a]	48.08±13.31[a]	76.58±24.80[a]	13.56±5.19[a]
Coconut shell	56.25±14.65[a]	51.00±10.30[a]	81.75±22.50[a]	13.39±4.50[a]
Rice husk	57.92±11.78[a]	53.17±13.90[a]	86.42±20.84[a]	14.28±4.80[a]
S. cusia	61.17±14.92[a]	47.75±9.86[a]	76.17±21.08[a]	12.55±4.50[a]
		Types of organic fertilizers		
Control	49.17±14.32[a]	43.17±11.91[a]	66.17±15.74[a]	10.83±3.70[a]
Chicken	55.75±12.59[ab]	53.33±11.67[b]	85.00±20.71[b]	14.93±4.34[b]
Cow	64.75±13.20[b]	53.58±11.00[b]	85.58±27.40[b]	13.63±5.83[ab]
Goat	57.83± 12.97[ab]	49.92±10.92[ab]	84,17±19.00[b]	14.41±3.83[ab]
Average	56.88±14.03	50.00±11.80	80.23±22.05	13.45±4.64
Interaction	-	-	-	-

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT (α = 0.05)
(-): No interaction

Chicken organic fertilizer has a significantly different seed weight from the control and has increased by about 37.86%. This is due to the high content of essential nutrients in chicken organic fertilizers, especially P (phosphorus) elements. Poultry droppings contained much higher levels of nitrogen, calcium and magnesium than other organic manure.The increase in the supply of P nutrients (phosphorus) for plants can optimize plant metabolism so that the seed filling process is better and increases seed weight. Poultry manure significantly affects crop yield by increasing soil nutrients also soil pH (Cai et al., 2019). Poultry manure gave the highest values for plant height, leaf area, pod weight and number of pods (Adekiya et al., 2020).

The final soil analysis

The final soil analysis in this study was carried out to determine the residue of nitrogen (N) content in the soil that had been given various treatments. Nitrogen is an essential micro-element needed by plants to stimulate growth (vegetative phase). Here are the results of the analysis of the final soil nitrogen content (Table 4).

Table 4 shows the results of the nitrogen analysis on the final soil after harvest. The combination of treatments that showed the highest final N residue was *Strobilanthes cusia* waste biochar with bovine organic fertilizer, which showed a final soil N content of 0.319%, which was significantly different from the other treatments. This shows that the nitrogen content in *Strobilanthes cusia* waste biochar and cow organic fertilizer is quite high, but it is not well absorbed by plants. This causes the residual N content in the final soil to be high. Liu et al., (2022) showed that the total N of the final soil in treatment without biochar is lower than the total N of the soil with biochar treatment. According to Tian et al., (2020), biochar significantly increases nutrient supply, soil quality, crop yield, and quality for soil pH improvement, activated carbon components, soil aggregation, total soil porosity, and soil microbial biomass.

Table 4. Interaction of biochar type and organic fertilizer on the final soil N content (%)

	Treatment	Types of *biochar*				Average
		Control	Coconut Shell	Rice husk	*Strobilanthes cusia* waste	
Types of organic fertilizer	Control	0.1310^{ab}	0.1253^{a}	0.1477^{abc}	0.2520^{d}	0.1640
	Chicken manure	0.1660^{abc}	0.1807^{c}	0.1717^{bc}	0.2303^{d}	0.1872
	Cow manure	0.1740^{bc}	0.1653^{abc}	0.1657^{abc}	0.3193^{e}	0.2061
	Goat manure	0.1473^{abc}	0.1643^{abc}	0.1463^{abc}	0.1650^{abc}	0.1558
	Average	0.1546	0.1589	0.1578	0.2417	(+)

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT (α = 0.05)
(+): Significant interaction

CONCLUSIONS

a. The use of *Strobilanthes cusia* biochar and cow manure is the best treatment for increasing the final soil nitrogen content.
b. Rice husk biochar is able to increase soybean growth by 25.72%, as seen in the fresh weight parameter of the plant compared to without biochar,
c. Cow manure can increase the yield of soybeans in the number of pods, stuffed pods, and number of seeds per plants respectively, by 31.68%, 24.11%, and 29.3% compared to without fertilizer.

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