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Research Article

THE USE OF BIOCHAR AND VERMICOMPOST COMBINATION IN INCREASING THE GROWTH AND YIELD OF RED CHILI

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Abstract
This investigation aimed to study the response of chili to the application of biochar and vermicompost, and to find the combination that produced the best growth and yield of red chili. The trial was conducted at the Teaching and Research Farm, Faculty of Agriculture, University of Jambi from May 2023 through to October 2023. The treatments tested were the application of five different soil ameliorant, i.e. 100% biochar, 75% biochar + 25% vermicompost, 50% biochar + 50% vermicompost, 25% biochar + 75% vermicompost, 100% vermicompost, and 100% NPK fertilizer. The experiment was arranged in a completely randomized block design with four replications each consisted of 14 plants (7 of them were taken as sample plants). The results showed that the application of biochar along with vermicompost could increase the growth and yield of red chili. The use of 25% biochar + 75% vermicompost resulted in the highest growth and yield, indicated by average fruit number of 58.75 per plant and fruit weight of 173.71 g per plant, or 6.95 ton·ha^{-1}. Thus, our study proved that the application of biochar and vermicompost is crucial to improve drought-tolerance of red chili cultivated in dry land.

Keywords: Capsicum Annuum, Hot Pepper, Organic Ameliorant, Soil Amendment.

INTRODUCTION

Red chili (*Capsicum annuum* L.) is one of vegetable crops need to be developed to meet market demand. However, they are very susceptible to price fluctuations, especially during weather or climate disturbances such as drought and floods that can affect chili growth production. Therefore, efforts should be done to increase and maintain stable production in order control price fluctuation due to weather or climate uncertainty. Effort to increase the production of red chili by expanding planting area and improving cultivation techniques are among the possible ways that can be implemented.

Climate change that occurs due to global warming has resulted in increasing areas of agricultural land experiencing drought. Dryland in Jambi Province which is dominated by Ultisols is also affected by this condition. As the consequence, it is necessary to apply organic materials to improve soil physical and biological fertility as well as maintain soil water availability for plants

Biochar is an organic material that can be applied to improve Ultisols' performance. Biochar is produced by burning agricultural bio-waste under an oxygen-limited and controlled environment (pyrolysis). Biochar has unique physical and chemical properties, such as high pH, high porosity, and high water-holding capacity, making it good as a soil amendment (Campos et al., 2020; Carvalho et al., 2020; Paul and Harikumar, 2022). Biochar can increase the soil's ability to store water and nutrients, improve soil looseness, reduce evaporation of water from the soil, and suppress the development of certain plant diseases, as well as create a good habitat for symbiotic microorganisms (Nurida et al., 2015; Niazi et al., 2023; Patani et al., 2023). Biochar also reduces the effects of harmful elements to plants such as Zn, Pb, Cd, and Cr in which their availability in the soil decreases with the application of biochar. In addition, biochar might reduce the need for fertilizer and increase carbon sequestration in marginal soils (Knoblauch et al., 2021; Qu et al., 2024; Tao et al., 2024).

According to Lago et al. (2021), biochar has a relatively low nutrient content as well as relatively low cation exchange capacity, and therefore, it cannot function as a long-term and sufficient nutrient source for plants (Sattar et al., 2020; Antonangelo et al., 2024). And as such, in order to maintain a sustainable agriculture, the use of biochar needs to be combined with organic fertilizer as an effective substitute for chemical fertilizer because the release of nutrients occurs slowly and continuously (Shi et al., 2020; Abbhishek et al., 2021).

Vermicompost is the result of the decomposition of organic material by utilizing earthworms. Vermicompost can be used as an organic fertilizer, which can be combined with biochar. Study by Gusain and Suthar (2020) showed that composted *Ageratum conyzoides* using earthworms resulted in increase in total-N, available-P, total-K, and total-Ca as well as increasing enzymatic activity (protease, dehydrogenase, β-galactosidase, and phosphatase) and microbial populations (bacteria, fungi, and actinomycetes). Vermicompost improves soil structure and water retention capacity and increases plant resistance to pests and diseases through higher microbial activity (Gazi et al., 2024; Mulatu & Bayata, 2024).

Studies showed that the combination of biochar and vermicompost could increase vegetable crops productivity. In cucumber, the productivity could increase by up to 56%, in addition to significantly improving soil quality (Wang et al., 2021). In carrots, the combination was found to increase plant height, number of leaves, and yields of up to 27.67 tons·ha^{-1} (Biswas et al., 2020). Meanwhile, in eggplant grown under limited irrigation conditions, the combination of biochar and vermicompost was proven to be able improve water use efficiency, plant growth, and yield (Ebrahimi et al., 2021). In red chili, Zhang et al. (2023) reported that the combination of biochar and vermicompost increased productivity by up to 88.92% and improved fruit quality, including vitamin C and soluble sugar content.

This aims of this study were to examine the effectiveness of biochar and vermicompost application as soil amendments to increase soil fertility, which in turn increases the growth and yield of red chilies cultivated on Ultisol dryland, and to find a combination of the two that can stimulate the best growth and yield of red chilies. The findings can be used as an effective strategy to support sustainable agriculture practice in dry land by reducing the use of chemical fertilizers and minimize negative impact on the environment while increasing red chili production.

RESEARCH METHOD

The study was conducted at the Teaching and Research Farm, Faculty of Agriculture, University of Jambi at an altitude of 35 m above sea level, from May 2023 through to October 2023. The treatment tested was the combination of biochar and vermicompost, consisted of 100% biochar, 75% biochar + 25% vermicompost, 50% biochar + 50% vermicompost, 25% biochar + 75% vermicompost, and 100% NPK fertilizer. The trial was arranged in Randomized Block Design with four replications. The number of plant used in this study was 14 individuals for each treatment resulted in overall 280 plants, in which 50% of them were designated as sample plants.

The biochar and vermicompost tested were commercially available. Biochar contained 1.12% N, 0.20% P and 0.31% K, and vermicompost contained 1.37% N, 0.58% P and 0.24% K. Application of biochar and vermicompost was carried out a week before planting at dosages according to the treatment. Both biochar and vermicompost were mixed thoroughly before being applied on the soil surface, then evenly mixed with the soil. Chili seeds were sown in seedling medium. When the seeds were 7 days old, they were transferred to nursery and left for 21 days. The seeding and nursery media was a mixture of soil+compost+sand (2:1:1). One-month old seedlings were transferred to soil prepared with biochar and vermicompost at planting space of 50 cm x 50 cm.

At the time of transplanting, the seedlings were sprayed with 2 $mL \cdot L^{-1}$ foliar fertilizer Bayfolan-D, and 2 $mL \cdot L^{-1}$ insecticides (active ingredients Amabektin and Mesurol). The foliar fertilizer and insecticide were sprayed on weekly basis. Additional fertilizer in the form of NPK (16:16:16) at a concentration of 2 $g \cdot L^{-1}$ was poured around the stem at 6, 8, and 10 weeks after planting (WAP), and flushed with 100 mL water per plant. Plant maintenance including watering, weeding, and pests and diseases control was routinely conducted. Harvesting was carried out from 10 to 13 WAP (during the first flowering period), with the criteria that 80% of individual fruit skin has turned to red.

The variables observed were plant height, number of branches, stem diameter, number of fruit and fruit weight. Plant height, number of branches, and stem diameter were recorded at 8 WAP, and number of fruit and fruit weight were recorded at harvest time. Observation of plant biochemical components were made on chlorophyll content and relative water content (RWC). Chlorophyll analysis was carried out using Acetone method (Arnon, 1941), RWC was determined according to (González and González-Vilar, 2001) method. Soil volume weight, and total soil pore were also observed at the end of the study. The data were analyzed by employing an analysis of variance (ANOVA) using Microsoft Excel application (Version 16.63.1, 2022, Microsoft Corporation, USA) to see the effect of both biochar and vermicompost application. The Duncan's Multiple Range Test (DMRT) at $\alpha = 5\%$ was used to compare the difference among treatment means.

RESULTS AND DISCUSSION

The growth of red chilies in terms of plant height, number of branches, crown diameter, and stem diameter was not significantly affected by the application of various combinations of biochar + vermicompost. The application 100% vermicompost resulted in better growth compared to the combination of biochar + vermicompost, biochar without vermicompost, or 100% NPK fertilizer (Table 1).

Table1. Plant height, number of branches, crown diameter, and stem diameter of red chili at various biochar and vermicompost combination at 8 WAP.

Biochar + vermicompost combination	Plant height (cm)	Number of branches	Crown diameter (cm)	Stem diameter (cm)
100% biochar	68.86 ± 1.82	211.63 ± 24.15	55.81 ± 2.94	0.3250 ± 0.02
75% biochar+ 25% vermicompost	68.11 ± 3.32	188.00 ± 22.62	51.43 ± 1.95	0.3125 ± 0.02
50% biochar + 50% vermicompost	66.70 ± 2.16	211.13 ± 24.15	53.69 ± 1.77	0.3275 ± 0.01
25% biochar + 75% vermicompost	69.38 ± 5.48	252.25 ± 36.30	58.16 ± 2.40	0.3100 ± 0.02
100% vermicompost	75.09 ± 1.10	267.13 ± 26.60	56.49 ± 1.58	0.3475 ± 0.03
100% NPK fertilizer	71.66 ±3.58	217.50 ± 31.33	55.05 ± 2.69	0.3225 ± 0.01

Note: The plus minus sign shows standard error with n = 5.

The yield in terms of number of fruit and fruit weight was significantly influenced by the combination of biochar and vermicompost. The combination of 25% biochar + 75% vermicompost gave the highest fruit number and fruit weight. This was not significantly different from the application of 100% vermicompost but was different from other biochar + vermicompost combinations (Table 2).

Table 2. Number of fruit and fruit weight of red chili at various biochar and vermicompost combination at harvesting time.

Biochar + vermicompost combination	Number of fruit	Fruit weight (g)
100% biochar	43.50 ± 1.94 c	121.20 ± 7.19 c
75% biochar+ 25% vermicompost	47.38 ± 4.55 bc	130.73 ± 12.17c

Biochar + vermicompost combination	Number of fruit	Fruit weight (g)
50% biochar + 50% vermicompost	44.00 ± 1.80 c	134.01 ± 9.25 c
25% biochar + 75% vermicompost	58.75 ± 3.85 a	173.78 ± 14.26 a
100% vermicompost	56.38 ± 4.09 ab	166.97 ± 14.47 ab
100% NPK fertilizer	45.50 ± 1.55 c	140.64 ± 12.98 bc

Note: Numbers followed by the same lowercase are not significantly different according to the DMRT α = 5%. The plus minus sign shows standard error with n = 5.

The relative water content (RWC) and plant chlorophyll content show that the application of biochar along with vermicompost provides better RWC and plant chlorophyll content compared to biochar without vermicompost. The application of 25% biochar + 75% vermicompost resulted in higher RWC and 100% vermicompost had higher chlorophyll content than other combinations or 100% NPK fertilizer. In contrast, the use of 100% biochar resulted in the lowest RWC and chlorophyll content (Table 3). The RWC of chilies in various combinations of biochar and vermicompost ranges from 85.40% to 89.43%, while the chlorophyll content ranges from 3.59 $mg \cdot L^{-1}$ to 4.88 $mg \cdot L^{-1}$.

Table 3. Relative water content (RWC) and plant chlorophyll content of red chili at various biochar and vermicompost combination at 8 WAP.

Biochar + vermicompost combination	RWC (%)	Chlorophyll content ($mg \cdot L^{-1}$)
100 % biochar	85.40	3.58
75% biochar+ 25% vermicompost	86.70	3.96
50% biochar + 50% vermicompost	85.85	4.29
25% biochar + 75% vermicompost	89.43	4.67
100% vermicompost	87.44	4.88
100% NPK fertilizer	86.51	4.13

The results of the analysis of soil physical properties due to the application of biochar and vermicompost at the end of the study is presented in Table 4. The highest average of soil volume weight was obtained at 50% biochar + 50% vermicompost, while the highest total pore space was at 100% vermicompost applications.

Table 4. Volume weight and total pore space of soil at the end of study at various biochar and vermicompost combination.

Biochar + vermicompost combination	Volume weight ($g \cdot cm^{-3}$)	Total pore space (%)
100 % biochar	1.07	59.43
75% biochar+ 25% vermicompost	1.09	59.03
50% biochar + 50% vermicompost	1.19	55.27
25% biochar + 75% vermicompost	1.16	56.08
100% vermicompost	1.05	60.21
100% NPK fertilizer	1.13	53.67

The results presented in Table 1 through to Table 4 showed that the application of 100% vermicompost provided better plant growth than other biochar + vermicompost combinations or 100% NPK fertilizer. These results also indicated that at the beginning of plant growth vermicompost plays more important role than biochar. Application of 100% vermicompost provides better chili growth because it is rich in nutrients such as N, P, K, Ca, S, Fe, Mn, Zn, Co and B, which can increase the nutrient content of various plant components such as roots, leaves and fruit (Nawrin et al., 2020; Tammam et al., 2022). In addition, vermicompost could increase soil fertility by promoting microbial activity and enzymes such as dehydrogenase, urease, phosphatase, and invertase (Balachandar et al., 2020; Lv et al., 2020).

Rehman et al. (2023) stated that vermicompost promotes plant growth based on its enrichment with all important nutrients, beneficial microbes, and plant growth hormones. Study on tomato showed that the application of vermicompost could improve soil fertility by increasing the content of soil organic matter and soil nutrients (nitrogen, phosphorus, and potassium). Application of vermicompost could promote tomato yields by up to 32.6% (Liu et al., 2022).The application of vermicompost significantly increased the activity of sucrase and catalase, the abundance of bacteria and actinomycetes, and reduced the abundance of fungi in the soil (Zhao et al., 2020; Ahmad et al., 2025). Further, vermicompost increased root activity and leaf photosynthesis, increasing the leaves' chlorophyll, nitrogen, and potassium content. In strawberry, (Zuo et al., 2018) proved that the use of vermicompost did not only increase photosynthesis but also increase antioxidant activity and fruit quality, including the content of soluble sugar and vitamin C. Vermicompost is rich in many nutrients including calcium, nitrate, phosphorus, and soluble potassium, which are required for plant growth. Various plant growth hormones such as gibberellins, auxins, and cytokinins which come from microbes, are found in vermicompost (Kumar et al., 2021). Gusain and Suthar (2020) added that the presence of earthworms in the composting process could increase soil aeration, structure, porosity, nutrient cycling, and water infiltration, as well as accelerate mineralization and humification of organic materials through feeding and burrowing activities.

Over time, biochar will improve soil fertility, increase soil nutrient availability, and eventually increase plant growth and yield. This can be seen from the results of this study which show that the application of 25% biochar + 75% vermicompost resulted in average chili yield that was better than the application of 100% vermicompost. According to Nurida et al. (2015), biochar has relatively low nutrients and cation exchange capacity (CEC), so it cannot function as a long-term and sufficient nutrient source for plants (Sattar et al., 2020). Biochar is not a fertilizer, but functions as a soil conditioner, so at the beginning of plant growth the role of biochar in increasing plant nutrient availability is not yet visible. The results of this study are confirmed by Schmidt et al. (2021) who claimed that biochar is very porous and resistant to decomposition. With this character, biochar has a high adsorption capacity for nutrients, and when applied to the soil in the form of a mixture of biochar and organic fertilizer, biochar acts as a nutrient catcher and slow-release fertilizer. Therefore, to maintain sustainable agricultural development, the use of biochar needs to be combined with organic fertilizers as an effective substitute for chemical fertilizers, due to the sustainable release of nutrients (Shi et al., 2020; Zhang et al., 2023)

Liu et al. (2022) claimed that the application biochar along with compost showed a positive synergistic effect on soil nutrient content and water-holding capacity under field conditions. In addition, the combination of biochar and compost allowed the reduction of fertilizer input, stabilized soil structure as well as improved its nutrient content and water retention capacity (Schmidt et al., 2014; Al-Omran et al., 2019). The results of the RWC analysis shows that the combination of 25% biochar + 75% vermicompost produce a higher RWC and chlorophyll content compared to other treatments (Table 3). This indicates the role of biochar in promoting soil capability to hold water, thereby increasing the RWC of chili plants. An increase in plant chlorophyll content resulted in better ability of plant to carry out photosynthesis, which ultimately increases photosynthetic rate, plant growth and yield. Further, the results of the analysis of the physical properties of the soil showed that the combination of 25% biochar + 75% vermicompost had a balanced volume weight and total pore space (Table 4). This made chili plants grown on medium enrich with combination of 25% biochar + 75% vermicompost to produce higher number of fruit and fruit weight than other treatments.

The application of 100% NPK fertilizer also resulted in relatively better growth of chili plants compared to 100% biochar. However, the use of 100% NPK fertilizer to increase the growth and yield of chilies needs to be reconsidered, since the residual effects of NPK fertilizer might reduce soil fertility. The results of soil physical analysis show that soil treated with 100% NPK fertilizer had a high soil volume weight with relatively low total pore space, a soil physical status that is not recommended for sustainable agriculture.

CONCLUSION

Our study revealed that biochar and vermicompost shared better effects on growth and yield of chili (*Capsicum annum* L.). Best growth and yield were achieved in the application of 25% biochar + 75% vermicompost which produced the highest fruit number (58.75 fruits per plant) and fruit weight (173.71g per plant). In addition, providing growing medium with biochar and vermicompost could improve soil physical fertility by reducing the volume weight and increasing the total pore space of the soil. Thus, the combination of 25% biochar + 75% vermicompost is worth considering for the sustainable use of red chili cultivation in dry land.

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AUTHOR CONTRIBUTIONS

Conceptualization by B.I; Methodology by E; Software by Z; Validation by B.I; Formal Analysis by B.I; Investigation by B.I, I.A.M and S; Resources by B.I, I.A.M and S; Writing – Original Draft Preparation by B.I, I.A.M and S; Writing – Review & Editing by B.I.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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