Rice Husk Biochar, Mycorrhizae and NPK Fertilizer Increase Soil Chemical Properties and the Sweetness of Edamame in Inceptisol Tempuran, Magelang, Indonesia

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Abstract. Edamame is food commodity that has high cultivation. Edamame can be grown in both highlands and lowlands. Edamame cultivation is limited by the low fertility based on the low content of soil organic matter, Cation Exchange Capacity (CEC), and availability of the N, P, and K nutrients. This research aims to determine the effect of rice husk biochar and mycorrhizae on soil chemical properties and sweetness of edamame. The study was carried out using a Completely Randomized Design (CRD) based on 12 treatments and 3 replications. The treatments were 0 and 2 tons/ha of rice husk biochar, 100 gr/30 kg of mycorrhizal seeds, and 0, 50, and 100% recommended doses of TSP, KCL, Urea, and ZA fertilizers. The sampling method of soil and plant tissue was carried out during the harvest period. The research data was processed with anova test and DMRT with a level of 5% to produce information about the suitability the treatment being studied. The addition of the treatments could increase and improve soil chemical properties such as CEC, available P and K, and increase sweetness of edamame. The addition rice husk biochar increases CEC from 7,63 to 9,49 $\text{Cmol}\cdot\text{kg}^{-1}$, available P from 63,39 to 98,56 $\mu\text{g}\cdot\text{g}^{-1}$, and available K to 0,31 $\text{Cmol}\cdot\text{kg}^{-1}$. The highest sweetness of edamame was 12,2 g/100 g pods.

Keywords: edamame · rice husk · mycorrhizae · soil chemical properties · the sweetness

1 Introduction

Land is a natural resource that can be utilized several sectors of human life, such as the agricultural sector. Soil in the agricultural sector is used as a medium for growing and developing plants. The cultivated land used in this study is Inceptisol according to the soil map of the Center for Agricultural Land Resources (BBSDLP). The distribution of this land extends throughout Indonesia. According to the Center for Soil and Agroclimate Research (Puslittan) in 2004, the Inceptisol land area is about 37.5% or 20.75 million ha of land area.

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Inceptisol can be used as agricultural land, but there are soil limiting factors that must be modified. The limiting factors in this soil include the CEC (Cation Exchange Capacity), organic matter, and few available macronutrients. This content makes the soil less able to support plant growth and development. Low organic matter will affect soil microbial activity and can indirectly affect soil aggregation.

Modification of agricultural cultivation land is carried out by adding soil improvement materials in the form of rice husk biochar and biological fertilizers in the form of mycorrhizae. Rice husk biochar can help the soil bind water so that the soil is able to provide sufficient water for plant growth and development. The addition of 2 tons/ha of biochar can increase the production of corn, beans, and sweet potatoes, as well as increase soil pH [1]. The addition of this biochar can increase the number of leaves, plant height, and corn cobs [2]. Meanwhile, the added mycorrhizae can help plants absorb more nutrients through plant roots. The addition of mycorrhizae can reduce the use of inorganic fertilizer doses to increase fertilization efficiency [3]. The addition of 0.65 tons/ha of mycorrhizae and 2 tons/ha of biochar can have a positive effect on plant growth by increasing the chlorophyll content in the leaves [4].

Edamame is one type of Japanese soybean that can be an indicator of soil fertility. Edamame was chosen because it has a high prospect to be developed compared to ordinary soybeans. The average productivity of edamame is greater than soybeans, which is 3.5 tons/ha of edamame and 1.7–3.2 tons/ha of soybeans [5]. Edamame requires the main nutrients, namely Nitrogen (N) helps the process of forming chlorophyll and amino acids and Phosphorus (P) helps the formation and filling of pods [6], and Potassium (K) helps fill pods and helps the photosynthesis process [7].

Soils with low fertility status need additional materials that can provide nutrients quickly. Inorganic fertilizers such as Urea, ZA, KCL, and TSP can be added to nutrients in the soil. The addition of inorganic fertilizers must be carried out in a balanced manner so as not to produce excess residue on cultivated land. The use of soil amendments, biological fertilizers, and inorganic fertilizers in a balanced way will provide a sustainable increase in productivity and maintain soil health [8].

2 Materials and Methods

The research was carried out in August-November 2021 on agricultural land located in Tempurejo Village, Tempuran District, Magelang Regency, Central Java Province. Figure 1 illustrated the location of the research. The land in this study has an Inceptisol soil type with a sub group of Typic Epiaquepts found around the river flow (Fig. 2). The research area is in the middle of other agricultural cultivation areas and is located on the banks of the Progo River. The research area is located between the valleys of Mount Merbabu, Mount Sumbing, and Mount Merapi.

This research went through two stages, namely observation in the field and analysis in the laboratory. Observations in the field are agronomic observations of plants carried out until the maximum vegetative period. Furthermore, laboratory analysis was carried out in the form of analysis of chemical and physical properties of the soil as well as plant tissue analysis carried out at the General Soil, Chemistry and Soil Fertility Laboratory, and Soil Physics, Department of Soil, Faculty of Agriculture, Gadjah Mada University in December 2021-February 2022.

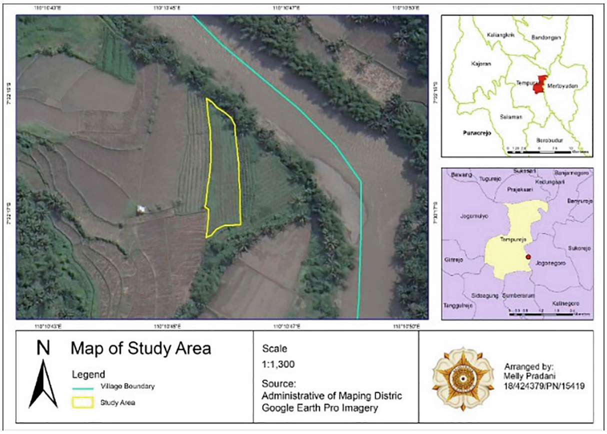

Fig. 1. Map of research locations in Tempurejo, Tempuran, Magelang, Central Java.

2.1 Preparation

2.1.1 Biochar Production

Rice husk agriculture residue were used in this research. Rice husk derived biochar were produced under pyrolysis reactor, temperature 500 °C. Biochar was sieved with 2 mm sieve. Rice husk biochar labeled by B consists of B0 (0 tons/ha) and B1 (2 tons/ha).

2.1.2 Mycorrhizae

The types of Mycorrhizae Arbuscular Fungi (AMF) powder, *i.e., Glomus manihotis*, *Glomus intaradices*, *Glomus agregatum*, *Acaulospora* sp, and *Gigaspora* sp were used in this research. Mycorrhizae was used symbolized by M consists of M0 (without the addition of mycorrhizae), and M1 (addition 100 gr mycorrhizae/30 kg edamame seeds).

2.1.3 N, P, and K Fertilizers

Fertilizers were used in this research, i.e., Urea, ZA, KCL, and TSP. Fertilizers dose has three levels, namely 0% dose recommendation (0 kg/ha of Urea, ZA, KCl and TSP), 50% dose recommendation (100 kg/ha Urea, 150 kg/ha ZA, 75 kg/ha KCl, 50 kg/ha TSP), and 100% dose recommendation (200 kg/ha Urea, 300 kg/ha ZA, 150 kg/ha KCl, 100 kg/ha TSP). Fertilizers treatment labeled by P consists of P0 (0%), P2 (50%), and P3 (100%).

2.1.4 Land Preparation

Agriculture land made beds as many as 36 beds, where each bed is the treatment given in this study. Biochar application was carried out one week before planting to incubate biochar in the soil. Provision of biochar on agricultural cultivation is done by immersing it in the planting hole and covering it again with soil. The addition of TSP fertilizer was carried out 3 days before planting.

2.2 Planting Seeds of Edamame

Mycorrhizae application was carried out by coating method on edamame seeds, maximum 4 h before planting so that the added mycorrhizae do not expire. Planting of edamame seeds two inches deep in soil, about 20 x 20 cm space to another seeds. Urea, ZA, and KCL fertilizers were applied when the plants were 10 and 22 days after planting.

2.3 Soil and Plant Sampling

Soil sampling method was carried out during edamame harvesting. The auger was used in soil sampling. At every 20 cm of depth penetrated, the auger was taken out and the samples of the soils are collected separately. The sampling method of plant tissue, *i.e.,* shoots, roots, and edamame pods were carried out during generative period or ready to harvest.

2.4 Characterization of Soil and Plant

Measurement of the chemical properties of the soil in the form of soil moisture content, texture, soil bV, pH, CEC, C-organic, total N, available P, and available K. measurement of plant tissue in the form of N, P, and K total.

3 Result and Discussion

3.1 Characteristic of Soil Chemical and Physical Properties

The soil in the research area has a slightly acidic soil pH value with low CEC values, C-organic, organic matter, total N, and very low available K, and very high available P. Table 1 illustrated soil chemical properties in the research area. The research area is located in a tropical area which has higher rainfall so that it can cause the bases to leach from the soil adsorption complex and be lost through drainage. Soil acidity is influenced by H^+ ions originating from the leaching process of cations in the soil [20]. The soil in the research area is Inceptisol soil which is still young so it has not developed further. In these soil conditions, Inceptisol will have low organic matter. Soil with low organic matter will lose carbon faster so that the content of organic matter and organic C in the soil is low [10].

The Inceptisol soil has a low CEC which is influenced by the low clay content and low organic matter. The amount of clay, the type of clay minerals, and organic matter are factors that affect the KPK of the soil. Low soil CEC indicates the capacity of the soil in the absorption of cations is low so that it affects the K content available in the soil. Nutrient N (nitrogen) is also low due to the nature of N which is easy to move so that it is easily lost in the soil. In addition, nitrogen nutrients were absorbed by plants in the previous planting period so that the total N content of the soil was reduced.

Phosphorus in the soil in the research area is classified as high value. This high phosphorus content is influenced by the type of soil minerals that contain high phosphorus. In addition, the availability of high phosphorus can also be affected by the accumulation of phosphorus from fertilization in the previous planting period. Phosphorus is not

Table 1. Chemical and physical properties of the initial soil

No	Soil chemical and physical properties	Value	Unit	Dignity
1.	pH H_2O	6,42	–	Slightly acid*
2.	pH KCL	4,95	–	
3.	CEC	7,63	$Cmol{\cdot}kg^{-1}$	Low*
4.	C-Organic	0,90	%	Very low*
5.	Soil organic matter	1,71	%	Very low*
6.	Total N	0,019	%	Very low*
7.	Available P	63,19	$\mu g{\cdot}g^{-1}$	Very high*
8.	Available K	0,32	$Cmol{\cdot}kg^{-1}$	Very low*
9.	Texture			Sandy clay loam
	Sand	48	%	
	Loam	26	%	
	Clay	26	%	
10.	Volume weight	1,1	$g{\cdot}cm^{-3}$	

Note: *Dignity based on Soil Research Institute (2009)

easy to move compared to nitrogen nutrients so that its availability remains in the soil. Intensively cultivated agricultural lands can cause high phosphorus content in the soil [11].

Soil physical properties illustrated on Table 1. The soil has a sandy loam texture with a soil volume weight value of 1.1 $g{\cdot}cm^{-3}$ (Table 1). Soil texture on Inceptisol soil has a sand fraction of 48%, a dust fraction of 26%, and a clay fraction of 26%. Soil dominated by sand has large pores, resulting in high infiltration of the soil and smooth air circulation. Sand-dominated soil has a low clay content so that the soil surface has a low adsorption capacity, causing low cation exchange capacity and soil potassium. Sand-dominated soils with low BV values have more soil pore space so that the soil mass is lighter. Soil conditions like this will help the growth and acceleration of plant roots so that they are able to penetrate further in search of nutrients and water.

3.2 Effect of Treatments on Soil Chemical Properties

The addition of rice husk biochar and mycorrhizae gave significant results on the CEC (Cation Exchange Capacity), available P, and available soil K. Table 2 illustrated the soil chemical properties after treatments addition. The increase in the KPK occurred due to the increase in the adsorption complex on the soil. Rice husk biochar has a KPK value which is able to add adsorption complexes to the soil. Biochar has a high surface area, negative charge, and has a charge density so that it can significantly increase soil CEC [12]. Biochar has a carboxyl group of organic matter so it has a negative charge [9]. Potassium cations (K^+) are cations in the soil adsorption complex. The increase in the adsorption process in the soil can increase K^+ activity so that in soils that have soil CEC

Table 2. Effect of treatments on soil chemical properties

Treatments	pH H20 **	pH KCL	CEC *** (Cmol·kg^{1})	Organic matter **** (%)	Total N **** (%)	Avail-P ***** (μg·g^{-1})	Avail-K **** (Cmol·kg^{-1})
Biochar							
0 ton/ha	5,70a	4,39a	8,47b	2,49a	0,02a	74,27b	0,27b
2 ton/ha	5,82a	4,43a	9,49a	2,65a	0,03a	98,56a	0,31a
Mycorrhizae							
Without Mycorrhizae	5,73a	4,40a	9,10a	2,55a	0,02a	86,03	0,28a
Plus Mycorrhizae	5,80a	4,41a	9,14a	2,59a	0,03a	86,79a	0,30a
N, P, K doses*							
0%	5,71a	4,36a	8,89a	2,50a	0,02a	76,69a	0,26b
50%	5,75a	4,38a	9,08a	2,57a	0,02a	87,19a	0,29ab
100%	5,83a	4,49a	9,38a	2,64a	0,03a	95,36a	0,31a
Biochar x NPK Doses	(−)	(−)	(−)	(−)	(−)	(−)	(−)
Biochar x Mycorrhizae	(−)	(−)	(−)	(−)	(−)	(+)	(−)
Biochar x NPK Doses x Mycorrhizae	(−)	(+)	(−)	(−)	(−)	(−)	(−)

Note: Numbers in the same column followed by the same letter indicate that the result are not significantly different from the 5% DMRT. The sign (−) indicate there is no interaction, and the sign (+) indicates the interaction.
*: TSP, Urea, ZA, and KCl
**: Slightly acid
***: Low
****: Very Low

it can increase the K^+ content of the soil. The cations in the soil adsorption complex are easily decomposed and available in the soil so that the availability of these nutrients can be utilized by plants.

Soil available P increased with increasing $(PO4)^{3-}$ or orthophosphate ions in the soil. Biochar added to the soil has pores which can be filled with orthophosphate ions. Phosphorus loss due to the addition of biochar is reduced due to the ability of biochar to adsorb P. P adsorption by the biochar pores becomes less susceptible to loss through surface runoff and leaching. This absorbed phosphorus can still be accessed by plant roots so that it can be absorbed by plants [13].

The addition of rice husk biochar and mycorrhizae results in a decrease in soil pH. The decrease in soil pH can be caused by an increase in H^+ ions in the soil so that it can reduce soil pH. Inorganic fertilizers in the form of the addition of ZA fertilizers in the soil containing $SO4^{-}$ compounds can push H + ions in the soil and increase the availability of H^{+} ions. ZA fertilizer is a type of inorganic fertilizer that contains elements of Nitrogen (N) and Sulfur (S) derived from $SO4^{-}$ compounds [10].

The addition of 2 tons/ha of biochar into the soil did not significantly affect the chemical properties of the soil such as soil pH, soil organic matter, and total nitrogen. This happened because the first addition of biochar to the soil did not give significant results on the chemical properties of the soil. The addition of biochar that gave significant results to the soil occurred due to the addition of more than one and continuous biochar. The addition of biochar into the soil with a biochar pH of 7.9 can increase soil pH [14]. Biochar added to soil with a loamy texture of sandy loam can increase organic matter in the soil [15].

Mycorrhizae are added to edamame seeds by coating the seeds to absorb nutrients in the soil. The uptake of nutrients from the soil by plants did not provide a significant amount of adsorption complexes. Mycorrhizae added to the soil have not been able to increase the activity of soil microorganisms so that they are less able to add hyphae to plant roots. Mycorrhizae get energy from photosynthesis, so mycorrhizae must inoculate with plant roots to help plants absorb more nutrients so as to increase photosynthesis. However, in soils containing high available phosphorus, plant roots tend to accumulate and absorb phosphorus in the soil. This causes mycorrhizae to tend not to be in symbiosis with plants because the nutrients needed by plants are ready to be absorbed by plant roots [16].

3.3 Effect of Treatments on Edamame Plant Height

Edamame plant growth was maximized when treated in the form of rice husk biochar, mycorrhizae, and inorganic fertilizers. Figure 2 illustrated the effect of treatments on edamame plant height. Plant height is influenced by temperature and the environment around the plant cultivation area. In plants that are not optimal nutrient uptake can affect plant growth, one of which is edamame plant height. Nitrogen is one of the limiting factors for plant growth due to N deficiency which causes plants to become stunted [17]. The low total N in the soil is one of the inhibiting factors for plant growth. In edamame plants, excess potassium nutrients can prevent the growth of new roots and stop the extension of plant roots so that plants do not optimally absorb nutrients [18].

3.4 Effect of Treatments on Nutrient Uptake of Edamame Plants

The effect of treatments on nutrient uptake of edamame plants illustrated by Table 3. The low content of total nitrogen in plant tissues can be caused by the lack of ability of plant roots to absorb this nutrient. The added nitrogen inorganic fertilizer can be lost due to the leaching process so that the availability of nitrogen is reduced. The mobile nitrogen in the soil also affects the ability of roots to absorb N [3].The addition of ZA and Urea fertilizers can increase the availability of nitrogen in the soil but only significantly in the canopy. This happens because the canopy needs nitrogen to help the photosynthesis process so that there is an accumulation of nitrogen in the plant canopy.

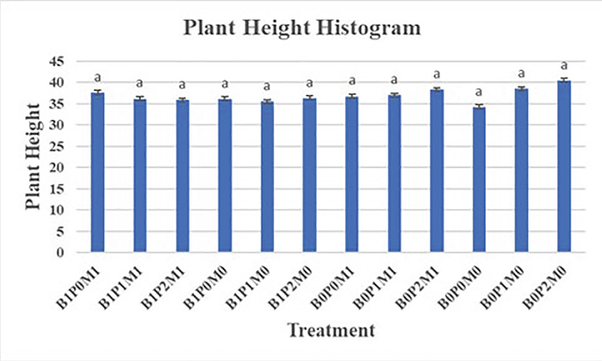

Fig. 2. Effect of treatments on edamame plant height

Table 3. Effect of treatments on nutrient uptake of edamame plants

Treatments	Total N (%)			Total P (%)			Total K (%)		
	Root	Shoot	Pod	Root	Shoot	Pod	Root	Shoot	Pod
Biochar									
0 ton/ha	0.16a	0.33a	0.74a	0.13a	0.19a	0.77a	0.46b	0.65b	0.86a
2 ton/ha	0.18a	0.37a	0.78a	0.15a	0.20a	0.87a	0.56a	0.74a	0.89a
Mycorrhizae									
Without Mycorrhizae	0.17a	0.35a	0.75a	0.14a	0.17a	0.79a	0.51a	0.66a	0.85a
Plus Mycorrhizae	0.17a	0.36a	0.77a	0.14a	0.22a	0.84a	0.51a	0.72a	0.90a
N, P, K doses*									
0%	0.17a	0.32b	0.75a	0.14a	0.18a	0.78a	0.52a	0.64a	0.82a
50%	0.19a	0.38a	0.77a	0.14a	0.20a	0.89a	0.52a	0.72a	0.89a
100%	0.16a	0.37a	0.77a	0.13a	0.20a	0.79a	0.49a	0.72a	0.92a
Biochar x NPK Doses	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)
Biochar x Mycorrhizae	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)
Biochar x NPK Doses x Mycorrhizae	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)	(−)

Note: Numbers in the same column followed by the same letter indicate that the result are not significantly different from the 5% DMRT. The sign (−) indicate there is no interaction, and the sign (+) indicates the interaction.
*: TSP, Urea, ZA, and KCl
**: Slightly acid
***: Low
****: Very Low

Phosphorus uptake in edamame plants treated with mycorrhizae had a higher value than plants without mycorrhizal treatment. Mycorrhizae will symbiotic with plant roots to form external hyphae that help absorb water and nutrients, especially phosphorus. The phosphorus in the edamame plant helps in the pod filling process. Rice husk biochar added to the soil can increase the CEC and K available soil so that the K content available in the soil can increase. This increase is in line with the absorption of potassium by plants which can be seen from the accumulation of potassium in the shoots and roots of plants.

3.5 Effect of Treatments on Sweetness of Edamame Pods

Rice husk biochar, mycorrhizae, and doses of inorganic fertilizers can increase the sweetness of the pods. Table 3 illustrated the effect of treatments on sweetness of edamame pods. Rice husk biochar has a high carbon content that lasts a long time in the soil. The carbon content in biochar will be absorbed by the edamame plant. The edamame pods produced will have different qualities which are influenced by the sweetness of the pods. The sweetness of the edamame pods is influenced by the sucrose, glucose, and fructose content in each edamame pod. The C (carbon) bond in biochar can extend the sucrose bond by binding to C glucose and fructose. Sucrose consists of glucose and fructose. The content of C, H, and O in sucrose can increase the sucrose bond so that the level of sweetness of the pods can increase. Glucose is a ring group 6 and fructose has a ring group 5 which is bound through an O (oxygen) bond at C1 glucose and C2 fructose [19].

The highest sweetness of edamame pods in the addition of rice husk biochar treatment. The sweetness value of pods in edamame plants that were given biochar was higher than in plants that were not given the addition of biochar. The highest sweetness value of pods was 12.2 g/100 g pods and the lowest sweetness value was 8.8 g/100 g pods. This value is higher than the sweetness value of other edamame pods. Edamame varieties such as Jiaoda 133 have a sucrose content of 2.39 g/100 g pods and a Williams 82 variety 1.52 g/100 g [1].

Table 4. Effect of treatments on sweetness of edamame pods

Treatments		Biochar		
		0 ton/ha	2 ton/ha	
Without Mycorrhizae (M0)	0% recommendation doses (P0)	8.8i	11.2b	10.0
	50% recommendation (P50)	10.4e	8.8i	9.6
	100% recommendation doses (P100)	11.0c	12.2a	11.6
Plus Mycorrhizae (M1)	0% recommendation doses (P0)	11.0c	9.2h	10.1
	50% recommendation doses (P50)	9.6g	10.6d	10.2
	100% recommendation doses (P100)	10.2f	10.8e	9.0
	Average	10.1	10.4	

Note: Numbers in the same column followed by the same letter indicate that the result are not significantly different from the 5% DMRT

Table 5. Effect of treatments on productivity of edamame

Treatments	Wet pod productivity (ton/ha)
Biochar	
0 ton/ha	2,57a
2 ton/ha	2,46a
Mycorrhizae	
Without Mycorrhizae	2,60a
Plus Mycorrhizae	2,53a
N, P, K doses*	
0%	2,24b
50%	2,44b
100%	3,02a
Biochar × NPK Doses	(−)
Biochar × Mycorrhizae	(−)
Biochar × NPK Doses x Mycorrhizae	(+)

Note: Numbers in the same column followed by the same letter indicate that the result are not significantly different from the 5% DMRT. The sign (−) indicate there is no interaction, and the sign (+) indicates the interaction.
*: TSP, Urea, ZA, KCl

3.6 Effect of Treatments on Productivity of Edamame

The productivity of edamame pods increased significantly with the use of 100% dose of inorganic fertilizer compared to the use of 0% and 50% dose of inorganic fertilizer illustrated by Table 5. Inorganic fertilizer added at a dose of 100% can provide optimal nutrients for edamame plant growth so that the result in the form of pod productivity can increase. The addition of rice husk and mycorrhizal biochar did not result in significantly increased productivity of edamame pods. This can occur due to the addition of biochar and mycorrhizae that have not been able to increase and improve the overall chemical properties of the soil and increase plant nutrient uptake of N, P, and K.

Its addition can increase pod productivity. The addition of inorganic fertilizers and biochar in edamame cultivation can increase the efficiency of phosphorus nutrient uptake. This increase in efficiency can be demonstrated by the accumulation of phosphorus in the edamame pods. The pods having high P accumulation can increase the productivity of edamame pods indirectly [1]. The added mycorrhizae interact with the roots and form hyphae on the roots. These hyphae will penetrate and infect the root zone so that the roots can absorb more nutrients. Nutrients that can be absorbed in greater quantities are N and P nutrients [4].

4 Conclusion

The addition of rice husk biochar and mycorrhizae could improve and increase soil chemical properties and increase sweetness of pods edamame. The conclusion of this study is based on the results of the study as follows:

1. The addition of treatments increases Cation Exchange Capacity (CEC) soil from 7,63 to 9,49 $Cmol \cdot kg^{-1}$, available P from 63,39 to 98,56 $\mu g \cdot g^{-1}$, and available K to 0,31 $Cmol \cdot kg^{-1}$.
2. The highest sweetness of edamame was 12,2 g/100 g pods and could increases the sweetness from 8,8 g/100g pods.

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