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Research Article

Improving edamame yield on peat soil via *Rhizobium* and soil amendment applications

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ABSTRACT

Soil amendment is a key factor in improving peat soil suitability for agriculture from the perspective of its fertility and quality. Red mud is potentially used as a peat soil ameliorant. The study aimed to evaluate red mud application as an ameliorant and application of *Rhizobium* on peat soil for growing edamame. The research was conducted at Tanjungpura University, Pontianak, from February to October 2024. A completely randomized design factorial was used to compile field experiments. The ameliorant factor consisted of 4 levels: control (dolomite 8 tons ha^{-1}) and Red Mud of 10 tons ha^{-1}, 15 tons ha^{-1}, and 20 tons ha^{-1}. The second factor was without and with *Rhizobium*. The application of Red Mud as an ameliorant increased pH, Na, and P_2O_5 levels and increased base saturation in peat soil. The Red Mud increased Na absorption in edamame tissues and increased pod yield. The highest edamame yield was reached with 20 tons ha^{-1} of red mud which was similar to with 8 tons ha^{-1} dolomite. *Rhizobium* has a role in supporting the formation of better root nodules.

Keywords: crop yield; microorganisms; red mud; soil chemistry; soybean

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INTRODUCTION

Peat land is believed as a new agriculture field in West Kalimantan. The peat land covers about 1.5 million hectares in West Kalimantan (Pantau Gambut, 2024), with the area of peat soil used as an agricultural field reaching 550,340 ha (Miettinen et al., 2016). The peat soil is characterized by very low fertility, such as highly acidic soil reactions that are toxic to many plants, and very low availability of nutrients such as phosphorus and potassium (Khotimah et al., 2020; Sardiana et al., 2017; Suherman et al., 2019).

In such a case, cultivation technology through soil amendment is essential in peat soil as a planting media, one of the potential ameliorants is Red Mud. Red Mud is a bauxite mine waste with very high alkaline properties and a pH value ranging from 10-14 (Susana et al., 2024). The strong alkaline nature of Red Mud is expected to be an alternative to liming to increase pH and fertility in peat soils.

Edamame (*Glycine max* L. Merr.) is a soybean variant, a legume commodity, that has the potential to be developed on peat lands. This is related to the increasing demand for soybeans for industrial purposes (Ministry of Agriculture, 2020). The global edamame market is still quite high, and Indonesia can only meet 13.58% of the total export demand to Japan (Ministry of Agriculture, 2020). The strategies to improve the quality of peat soil fertility, such as lime application, organic matter application, and balanced fertilizer application, are important factors in achieving success in increasing edamame productivity on peat soils (Sofyan et al., 2022; Vebiola et al., 2022; Asie et al., 2024). According to Sari et al. (2021), fertile land is needed and supported by using *Rhizobium* as a biofertilizer to achieve optimal growth and yield of edamame.

Rhizobium is a type of soil bacteria that is endosymbiotically associated with the roots of leguminous commodities and has a role in helping the process of N fixation and forming colonization in the root nodules (D'Souza et al., 2023). *Rhizobium* supports plant growth by converting nitrogen (N_2) into ammonia (NH_3), which can contribute 65% of nitrogen requirements for plants (Simon et al., 2014). The introduction of *Rhizobium* can increase the number of effective root nodules of legume plants compared to the absence of *Rhizobium* (Saptiningsih, 2016). The study aimed to evaluate red mud application as an ameliorant and application of *Rhizobium* on peat soil for growing edamame.

MATERIALS AND METHODS

The research was conducted at the Laboratory of Soil Chemistry and Fertility and Experimental Garden of the Faculty of Agriculture, Tanjungpura University, Pontianak, West Kalimantan, from February to October 2024. Field experiments were arranged using a randomized, complete factorial design. The first factor consisted of 4 levels of ameliorant treatment, namely control (dolomite 8 tons ha^{-1}), Red Mud with doses of 10 tons ha^{-1}, 15 tons ha^{-1}, and 20 tons ha^{-1}. The second factor was treatment without and with the use of *Rhizobium*. There were eight treatment combinations, and 3 replications were set with 4 sample plants so that the total experimental units were 96 plants.

Ameliorant from Red Mud was prepared by air-drying and sieving it to a fine texture. Planting media was prepared by cleaning peat soil from debris, and root remains into polybags as much as 8 kg per polybag. Red Mud was applied by mixing evenly with peat soil in each polybag. The dose of Red Mud was in accordance with the treatment (78.1, 117.1, and 156.2 g per polybag); for the control treatment, dolomite was applied as much as 32.2 g per polybag, and then the incubation was proceeded for 3 weeks.

Edamame seeds of the Ryoko variety were planted directly into polybags with two seeds per planting hole. Seeds were first coated with *Rhizobium* (Rhizoka legumin®) before planting at a ratio of 5 g per 1 kg of edamame seeds. The best seedlings were selected at 7 days after planting (DAP). NPK fertilizer 9:25:25+TE (trace element: B_2O_3 0.015%; Zn 0.020%; and Mn 0.020%) was applied at the age of 20 DAP as much as 2.34 g $plant^{-1}$ and 40 DAP as much as 1.17 g per plant.

The observations on the chemical quality of peat soils were conducted before the application of Red Mud and dolomite (control) and after 2 weeks of incubation (given Red Mud and dolomite) at the Laboratory of Chemistry and Soil Fertility, Faculty of Agriculture, Tanjungpura University. Soil pH was observed using the electrometric method. Available P levels were monitored using the Bray II method. Sodium levels were measured using the photometric method. Mg levels were observed using the atomic absorption spectrophotometer method. CEC value was measured using the leaching method with ammonium acetate.

Alkaline saturation (AS) was observed using the 1N NH_4OAc pH 7 extraction method on peat soil before and after incubation with Red Mud and dolomite (control). Sodium concentration in edamame tissues was measured during the maximum vegetative phase at the Soil Chemistry and Fertility Laboratory. The number of root nodules was counted at harvest on all sample plants. The number of edamame pods was counted after harvest on all sample plants. The weight of edamame fresh pods was weighed using a digital scale.

The average data were statistically analyzed using analysis of variance (ANOVA). Furthermore, results with a significant effect were tested using the Honest Significant Difference (HSD) test at the 0.05 level (Gaspersz, 1991).

RESULTS AND DISCUSSION

Chemical characteristics of peat soils

The laboratory analysis conducted on the chemical characteristics of peat soil showed that the greater the dose of Red Mud given to the soil, the better the pH value of the peat soil. The administration of 20 tons ha^{-1} changed the soil pH from very acidic to slightly acidic. In comparison, the administration of 8 tons ha^{-1} of dolomite lime caused the soil pH to be very acidic, and the administration of 8, 10, and 15 tons ha^{-1} of Red Mud caused the soil pH to change to acidic (LPT, 1983) (Table 1). This is due to the highly alkaline nature of red mud and its excellent calcium oxide (CaO) content, which accelerates the process of increasing soil pH (Sun et al., 2019; Li et al., 2024).

Increasing the pH value of peat soil has a very beneficial impact on the suitability of plant growth media because, in better soil pH conditions (neutral), the nutrients needed by plants can be optimally available and dissolved in water (Fajeriana & Wijaya, 2020). Soil reaction with neutral pH levels following plant needs is one of the critical factors needed to support plant growth and increase plant productivity (Jiang et al., 2017; Samson & Mahmudi, 2024).

Table 1. Peat soil characteristics from different Red Mud dosages.

Ameliorant (tons ha^{-1})	pH	Na ($cmol^{(+)}kg^{-1}$)	P_2O_5 (ppm)	Mg ($cmol^{(+)}kg^{-1}$)	CEC ($cmol^{(+)}kg^{-1}$)	AS (%)
Before treatment	4.36	0.46	62.32	3.83	93.06	24.53
Dolomite (8)	4.80	2.49	63.25	8.51	87.40	33.59
Red Mud (10)	4.84	18.12	75.88	3.95	90.98	38.62
Red Mud (15)	5.24	21.70	109.53	3.99	90.21	42.31
Red Mud (20)	5.74	26.22	149.05	3.75	90.54	50.61

Note: Data from analysis in Laboratory of Chemistry and Soil Fertility, Faculty of Agriculture, Tanjungpura University; CEC-cation exchange capacity, AS-alkaline saturation

The Na content of the peat soil before treatment was 0.46 $cmol^{(+)}kg^{-1}$ with media criteria (LPT, 1983). After incubation with dolomite, there was an increase in Na content in the peat soil by 2.03 $cmol^{(+)}kg^{-1}$. Peat soil incubated with Red Mud showed a higher Na content increase than dolomite, reaching 17.66 to 25.76 $cmol^{(+)}kg^{-1}$. The Na content in the peat soil increased as the dose of Red Mud applied increased (Table 1). Higher levels of exchangeable Na can result in increased physical soil density, alkalization, and reduced porosity (Hualpa-Ramirez et al., 2024; Laker & Nortjé, 2019). This can benefit the improvement of the physical properties of peat soil used as a growing media to make it denser. In addition, the high Na content in peat soil can help neutralize organic acids such as carboxylic acids and phenolic acids (Prasetyo, 1996).

The laboratory analysis results showed that the available phosphorus content in peat soil before incubation was 62.32 ppm. After incubation with dolomite, the available phosphorus content increased to 63.25 ppm with very high status (LPT, 1983). The content of available phosphorus in peat soil after incubation with Red Mud showed a much higher value than in the dolomite treatment (control) of 75.88 to 149.05 ppm. The increase occurred along with the higher dose of Red Mud applied (Table 1). The increase in available phosphorus content in peat soil is due to the soil reaction, which was initially very acidic, becoming better and increasing towards neutral, thus preventing the fixation of phosphate ions by basic cations in the soil solution (Ashrafi et al., 2023; Golia & Diakoloukas, 2022; Jawang, 2021). Phosphorus is required by plants in large quantities for the formation and development of a strong root system, thereby increasing plant productivity (Béné et al., 2015; Sun et al., 2016).

The Mg content in peat soil after incubation with Red Mud 20 tons ha^{-1} showed a decrease of 0.08 $cmol^{(+)}kg^{-1}$, while the application of Red Mud 10 and 15 tons ha^{-1} increased Mg by 0.12 and 0.16 $cmol^{(+)}kg^{-1}$, and the use of dolomite increased the Mg content in peat soil much higher than the use of Red Mud, reaching 4.68 $cmol^{(+)}kg^{-1}$ (Table 1). This can be caused by the high Na^{+} ions, which act as an antagonistic factor to the elements Mg, K, and Ca (Wahyuningsih et al., 2017). The cation exchange capacity (CEC) of peat soil incubated with dolomite and Red Mud decreased compared to the initial condition of the peat (Table 1). Peat base saturation increased with the higher dose of Red Mud applied (Table 1). The increase in base concentration caused an increase in alkaline saturation and a decrease in the CEC of peat soil.

Sodium concentrations in plant tissues

The ANOVA results showed that Red Mud treatment had a significant effect on the value of Na concentration in edamame tissues. Sodium concentration in edamame tissues with 20 tons ha^{-1} Red Mud treatment was significantly higher by 0.175% compared to dolomite treatment and higher by 0.107% compared to 10 tons ha^{-1} Red Mud treatment, but not different compared to 15 tons ha^{-1} Red Mud treatment (Table 2). This is closely related to the Na content in the peat soil (Table 1), as the correlation value was 0.95, or 95% of Na uptake was influenced by the Na content in the peat soil.

Table 2. Average Na concentration in plant tissue, number of pods, and pods weight of edamame from different Red Mud dosages.

Ameliorant (tons ha^{-1})	Na concentration (%) HCl extraction 1:2	Number of pods per plant	Pods weight per plant (g)	Pods yield (tons ha^{-1})^x
Dolomite (8)	0.678c	41.44a	114.01a	15.20a
Red Mud (10)	0.746bc	34.83b	95.91b	12.79b
Red Mud (15)	0.816ab	35.55ab	97.79b	13.04b
Red Mud (20)	0.853a	39.66ab	110.30ab	14.71ab
HSD 0.05	0.055	3.42	16.21	2.16

Note: The numbers followed by the same letter in a column indicate non-significant differences based on the HSD test (0.05); ^{x} conversion using population per ha 133,333 plant

Na is a facultative nutrient that stimulates plant growth, it is an essential nutrient in certain types of plants that can increase a plant's production (Novi, 2016). Na is absorbed by plants in the form of Na^+ ions. The sound effect of Na on plant growth is detected if the potassium levels in the soil are relatively low (Gresinta, 2015). According to Khair et al. (2018), Na often affects the production quality in both positive and negative ways.

Root nodules

The number of root nodule was affected by Red Mud and Rhizobium, but not by the interaction of the two treatment factors. The numbers of root nodules were similar with the application of dolomite (8 tons ha^{-1}) or Red mud at 15 and 20 tons ha^{-1} and they were higher than with red mud of 10 tons ha^{-1} (Table 3).

Table 3. Average number of edamame root nodules from different Red Mud dosages treatment.

Ameliorant (tons ha^{-1})	Root nodules number per plant	
	Research result (x)	Data transformation (log x)
Dolomite (8)	113.25	4.58a
Red Mud (10)	46.03	3.77b
Red Mud (15)	155.42	4.73a
Red Mud (20)	132.20	4.84a
HSD 0.05	-	0.64

Note: The numbers followed by the same letter in a column indicate non-significant differences based on the HSD test (0.05); (x) - research result of root nodules number per plant

Root nodules of edamame treated with *Rhizobium* were significantly higher at 59.73 nodules compared to those without *Rhizobium* (Table 4). Leguminous plants form a symbiotic relationship with *Rhizobium* and fix nitrogen from the atmosphere in specialized root organs known as root nodules (Singh & Valdés-López, 2023). *Rhizobium* in the root nodule utilizes the catalytic activity of nitrogenase to convert atmospheric dinitrogen into ammonium, which serves as a nitrogen source for its host plant. In return, the host plant provides a carbon source to the *Rhizobium* (Stambulska & Bayliak, 2020). This describes that edamame with more root nodules had better growth and development. When root nodules provides more nitrogen, plant photosynthesis is expected to increase.

Table 4. Average number of edamame root nodules from different *Rhizobium* treatment.

Rhizobium	Root nodules number per plant	
	Research result (x)	Data transformation (log x)
Without *Rhizobium*	102.33	4.60b
With Rhizobium	162.06	5.08a
HSD 0.05	-	0.46

Note: The numbers followed by the same letter in a column indicate non-significant differences based on the HSD test (0.05); (x) - research result of root nodules number per plant

Pod numbers and weight

The numbers and weight of edamame were significantly affected by the ameliorant (red mud) treatment. However, the *Rhizobium* treatment and the interaction of the two factors did not significantly affect the number and weight of edamame pods. The HSD test showed that the average number of pods in the control treatment (dolomite) resulted higher number and weight of pod than with 10 tons ha^{-1} Red Mud treatment, but they were not significantly different with red mud 20 tons ha^{-1} (Table 2).

Pods weight of edamame obtained in the study ranged from 95.91-114.01 g per plant, with a conversion of 12.79-15.20 tons ha^{-1}. The pod yield obtained from the application of Red Mud to peat soil was higher compared to the results of the study by Asie et al. (2024), where the dolomite lime and biofertilizer applied produced the highest pod weight of 10.62 g per plant (1.42 tons ha^{-1}). Sofyan et al. (2022) showed that treating petrhikafos and chicken manure produced the highest pod weight of 52.48 g (7.00 tons ha^{-1}).

The increase in the number of edamame pods obtained in this study can be caused by plants' ability to optimally absorb nutrients such as phosphorus and magnesium. The formation of pods on a plant is influenced by the ability of plants to assimilate photosynthesis, as well as the role of nutrients as plant raw materials for the photosynthesis process (Kurniawan et al., 2017; Lubis et al., 2013). The availability of nutrients such as phosphorus and magnesium for plants will optimize the photosynthesis process so that the carbohydrates produced are sufficient for plant growth until the production stage (Sumbayak & Gultom, 2020).

CONCLUSIONS

Red Mud applied as an ameliorant to peat soil increases pH value, Na and P_2O_5 levels, and alkaline saturation. Red Mud increased Na uptake in plant tissues and increased edamame productivity the highest edamame yield was reached with 20 tons ha^{-1} of red mud which was similar to with 8 tons ha^{-1} dolomite. The use of *Rhizobium* on edamame growing in peat soil amended with Red Mud can improve the formation of root nodules.

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