Utilization of Red Mud and Biofertilizer for Peat Quality Improvement and Its Effect on the Growth and Production of Hybrid Corn

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INFO ARTIKEL

Diterima: 13-11-2024
Direvisi: 29-12-2024
Dipublikasi: 31-12-2024

Keywords:
Bauksit, Lahan suboptimal, Mikroorganisme, Pertanian

Kata Kunci:
Agricultural, Bauxite, Microorganisms, Suboptimal land

ABSTRACT/ABSTRAK

Pemanfaatan lumpur merah dan pupuk hayati untuk perbaikan kualitas gambut dan pengaruhnya terhadap pertumbuhan dan produksi jagung hibrida

Lahan gambut adalah lahan suboptimal yang dapat ditingkatkan kualitasnya sehingga dapat digunakan untuk budidaya pertanian. Salah satu cara yang dapat dilakukan adalah dengan memanfaatkan lumpur merah dan pupuk hayati. Lumpur merah merupakan limbah dari pengolahan bauksit yang banyak tersedia di Kalimantan Barat. Lumpur merah memiliki pH tinggi, daya hantar listrik tinggi, natrium dapat ditukar yang tinggi, dan kejenuhan basa yang tinggi. Pupuk hayati adalah produk yang mengandung mikroorganisme terpilih yang dapat membantu meningkatkan pertumbuhan dan hasil tanaman. Penelitian ini bertujuan untuk mengetahui pengaruh lumpur merah dan pupuk hayati terhadap perbaikan kualitas gambut dan pengaruhnya terhadap pertumbuhan dan hasil jagung hibrida. Percobaan ini disusun dalam rancangan acak kelompok (RAK) dengan dua faktor. Faktor pertama adalah lumpur merah dengan tiga tingkat dosis: kontrol (l_0), 6 ton/ha (l_1), dan 12 ton/ha (l_2). Faktor ke dua adalah pupuk hayati dengan tiga jenis: kontrol (p_0), Mycofer sebanyak 10 g/tanaman (p_1), dan Provibio sebanyak 10 ml/l (p_2). Hasil penelitian menunjukkan bahwa lumpur merah pada dosis 12 ton/ha secara signifikan meningkatkan pH tanah, daya hantar listrik tanah, pertumbuhan tanaman, dan hasil jagung hibrida. Interaksi lumpur merah 12 ton/ha dan pupuk hayati Provibio secara signifikan meningkatkan kandungan natrium dan mencapai serapan fosfor, kalium, kalsium, dan magnesium tertinggi.

Peatlands are suboptimal lands that can be improved its quality to be used for agricultural cultivation. One of which is by using red mud and biofertilizer. Red mud, a by-product of bauxite processing, is widely available in West Kalimantan. Red mud has high pH, electrical conductivity, exchangeable sodium and base saturation. Biofertilizers are products containing selected microorganisms that can help enhance plant growth and yield. This study aims to examine the effects of red mud and biofertilizer applications on peat quality improvement and their impact on the growth and yield of hybrid corn. The experiment was arranged in a randomized block design (RBD) with two factors. The first factor was red mud with three dosage levels: control (l_0), 6 tons/ha (l_1), and 12 tons/ha (l_2). The second factor was biofertilizer with three types: control (p_0), Mycofer at 10 g/plant (p_0), and Provibio at 10 ml/l (p_2). The results showed that red mud at a dose of 12 tons/ha significantly affected soil pH, electrical conductivity, plant growth, and hybrid corn yield. The interaction of 12 tons/ha red mud and Provibio biofertilizer significantly increased sodium content and achieved the highest uptake of phosphorus, potassium, calcium, and magnesium.

INTRODUCTION

Peat is one type of soil with widespread distribution in West Kalimantan, covering around 1.74 million hectares across Mempawah, Ketapang, Sambas, Kubu Raya, and Pontianak City (Astiani *et al.*, 2020). In Kubu Raya Regency the peatland area reaches approximately 408,369 hectares, or 58% of the total area (Sanudin *et al.*, 2023). Peat is formed from the accumulation of organic materials derived from the remains of dead plants and animals. It is characterized by highly acidic pH, high organic acid content, low base saturation, a high C/N ratio, and low availability of macro and micronutrients (Krishnankutty *et al.*, 2024). The low nutrient availability in peat inhibits plant growth, nutrient uptake, and crop production (Salmon *et al.*, 2021; Lumbantoruan *et al.*, 2023). If properly managed, peat has the potential to become productive agricultural land that can increase farmers' income.

People generally clear peatland by burning, as it is considered cost-effective and time efficient. However, besides causing ecological and biodiversity damage to peatlands, the fertility increase from the ash produced by burning is only temporary (Davies *et al.*, 2023). Corn production on peatlands burnt in Kubu Raya Regency only reaches 1-2 tons/ha (Suryadi & Kusrini, 2022). Therefore, to improve soil quality without damaging the peat ecosystem, other methods are needed, such as using location-specific ameliorants like red mud, a by-product of bauxite processing.

West Kalimantan is the province with the largest bauxite reserves in Indonesia (Aprillia *et al.*, 2024). For every 1 ton of aluminum produced from 2-3 tons of bauxite, 1-1.5 tons of red mud waste is generated (Svobodova-Sedlackova *et al.*, 2024). Bauxite processing in West Kalimantan can produce over 3 million tons of red mud annually (Anugrah & Mamby, 2020). The red mud studied by Aini *et al.* (2017) has characteristics of pH 11.9, EC 28.70 dS/m, CEC 25.65 cmol(+)/kg, exchangeable K 0.70 cmol(+)/kg, exchangeable Na 149.39 cmol(+)/kg, exchangeable Mg 0.26 cmol(+)/kg, and exchangeable Ca 16.98 cmol(+)/kg. Red mud contains low levels of heavy metals, making it safe to use as an ameliorant (Surachman *et al.*, 2024). According to Ujaczki *et al.* (2016), applying red mud at 5% of soil weight can improve soil pH, increase water-holding capacity, and has no significant adverse effects on soil organisms.

In addition to red mud, soil quality improvement can also be achieved by applying biofertilizers-biologically active products containing selected microbes that can act as decomposers of soil organic matter, nitrogen fixers, phosphorus solubilizers, growth hormone producers, and antagonistic agents against plant pests (Rahhutami *et al.*, 2021). According to Ghimirey *et al.* (2024), the application of biofertilizers can improve the quality of peat soil, thereby supporting plant growth. The abundant availability of red mud in West Kalimantan can be utilized as an ameliorant material, particularly for peat soil. The application of red mud and biofertilizers is expected to enhance soil quality, supporting plant growth and production without compromising the ecological and hydrological functions of peatlands. This study aims to determine and explain the effects of using red mud and biofertilizers on peat quality improvement and their effect on the growth and production of hybrid corn.

MATERIALS AND METHODS

Materials and Methods

This study was conducted from January to October 2024 on peatlands in Arang Limbung Village, Sungai Raya District, Kubu Raya Regency, West Kalimantan Province. Red mud, used as an ameliorant, was sourced from PT. ICA in Sanggau Regency. The biofertilizers used consisted of two typeof biofertilizer: Provibio and Mycofer. Provibio biofertilizer contains microorganisms such as *Azotobacter* sp., *Rhizobium* sp., *Lactobacillus* sp., *Azospirillum* sp., *Saccharomyces* sp., phosphate-solubilizing microbes, cellulolytic microbes, *Escherichia coli*, and *Salmonella* sp. (Hazra & Santosa, 2022).

Mycofer biofertilizer contains spore genera such as *Gigaspora* sp., *Glomus manihotis*, *Glomus etunicatum*, and *Acaulospora tuberculata* with a density of 500 spores/10 g. All experimental plots on the peatland were first provided with a base fertilizer at doses of 230 kg/ha N, 144 kg/ha P_2O_5, and 180 kg/ha K_2O (Kristino *et al.*, 2022), as well as 123 kg/ha CaO and 52 kg/ha MgO (Tabri *et al.*, 2020), along with compost at a dose of 5 tons/ha. Hybrid corn of the Pioneer 32 variety was used as the test crop. The conditions of the research site were shown in Figure 1.

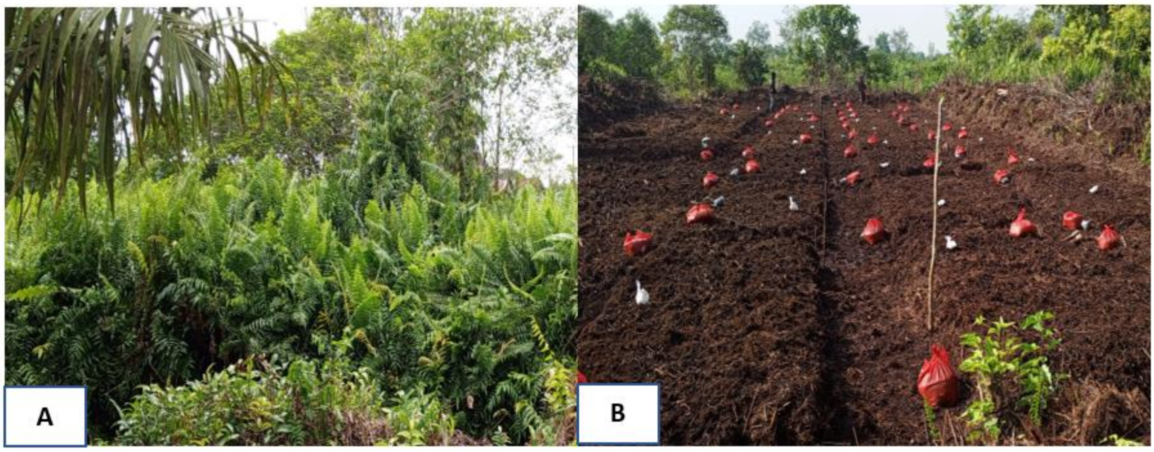

Figure 1. Research site before treatment (A) and after treatment (B)

Research Design

The study was arranged in a randomized block design (RBD) with two factors. The first factor was red mud with three dosage levels: control (l_0), 6 tons/ha (l_1), and 12 tons/ha (l_2). The second factor was the type of biofertilizer: control (p_0), mycorrhizal biofertilizer (Mycofer) at 10 g/plant (p_1), and liquid biofertilizer (Provibio) at a concentration of 10 ml/l (p_2). The first and second factors were combined, resulting in 9 treatments, each repeated 3 times, for a total of 27 experimental plots. Each experimental unit was a plot measuring 350 cm in length and 150 cm in width, with a planting distance of 25 cm x 75 cm. Each planting hole was sown with 2 seeds, resulting in 50 hybrid corn plants per plot. Detailed treatment combinations presented in Table 1.

Table 1. Details of experimental treatment combinations

Treatment	Description
l_0p_0	Control
l_0p_1	Mycofer 10 g/plant
l_0p_2	Provibio at a concentration of 10 ml/l
l_1p_0	6 tons/ha red mud
l_1p_1	6 tons/ha red mud + Mycofer 10 g/plant
l_1p_2	6 tons/ha red mud + Provibio at a concentration of 10 ml/l
l_2p_0	12 tons/ha red mud
l_2p_1	12 tons/ha red mud + Mycofer 10 g/plant
l_2p_2	12 tons/ha red mud + Provibio at a concentration of 10 ml/l

Experimental Procedures

The peatland was cleared from pant debris such as roots and plant litter, tilled until loose, then divided into plots according to the specified dimensions, and treated with red mud according to the dosage for each treatment. A base fertilizer and compost were applied to all experimental plots, followed by a one-week incubation period. The biofertilizer Provibio at concentration of 10 ml/l was sprayed on both the soil and plants in the experimental plots at intervals: 0 days after planting (at dosage of 1 l/ha), 14 days after planting (at dosage of 1 l/ha), 45 days after planting (at dosage of 2 l/ha), and 60 days after planting (at dosage of 4 l/ha). The Mycofer biofertilizer was applied through spot placement at a dose of 10 g/plant by placing it in the planting hole with the seed at planting time.

The observed variables in this study included soil quality, plant growth, nutrient uptake, and hybrid corn yield. Soil and plant analysis methods followed the guidelines by Eviati *et al.* (2023). The observed variables were as follows:

1. Soil Quality: Soil reaction (pH) and electrical conductivity measured at 0, 50, and 100 days

after planting (DAP); organic C, total N, available P, exchangeable bases (K, Ca, Mg, Na), base saturation, and cation exchange capacity (CEC) measured post-harvest at 100 DAP.
2. Plant Growth: Plant height, stem diameter, and leaf count measured at 56 DAP.
3. Nutrient Uptake: Nutrient content (N, P, K, Ca, and Mg), dry weight of the plant, and nutrient uptake (N, P, K, Ca, and Mg) measured at the maximum vegetative phase.
4. Hybrid Corn Yield: Kernel weight per ear, kernel weight per plot, and kernel weight per hectare (calculated based on plot yields).

The observational data were statistically analyzed using Analysis of Variance (ANOVA) at a significance level of α = 0.05. For treatments with significant differences, further analysis was conducted using Duncan's Multiple Range Test (DMRT) at the 5% level, utilizing the R Studio software.

RESULTS AND DISCUSSION

Chemical Characteristics of Peat and Red Mud

The initial characteristics of peat soil and red mud are presented in Table 2. The peat soil reaction was highly acidic, with a pH of 3.93. The acidity in peat soil is due to organic acids such as humic and fulvic acids, as the peat soil used was coming from 1-2 m depth with 50 cm groundwater table (Kale *et al.*, 2022). Additionally, peat soil has a very low electrical conductivity. The total N content in peat soil was 3.49%, classified as high. However, most of this total nitrogen in peat is in the form of organic nitrogen, which is generally not readily available to plants (Moore & Bubier, 2020). The available P content in the initial peat sample was 36.48 ppm, which is considered moderate. The amount of exchangeable base cations such as K, Ca, Mg, and Na was low, primarily due to the peat soil's composition, which is largely organic plant material (Arabia and Basri, 2020) and its low pH (Vanguelova *et al.*, 2022). The base saturation of peat soil was also low, a result of its highly acidic reaction (Purnamasari *et al.*, 2024).

The characteristics of red mud are shown in Table 2. Red mud had a relatively high pH. Its electrical conductivity (EC) was extremely high, reaching 7,000 µmhos/cm, due to the high concentration of soluble base cations, particularly sodium (Shoppert *et al.*, 2022). The organic carbon and total nitrogen content in red mud were both very low. Available P, exchangeable K, and Mg were also low to very low, while exchangeable Ca and Na range from moderate to very high. The high sodium content in red mud is a result of sodium hydroxide (NaOH) used in the extraction of aluminium from bauxite. The cation exchange capacity (CEC) and base saturation in red mud were high to very high. The high CEC value in red mud originates from its clay fraction, which has a large specific surface area (Nie *et al.*, 2020). The very high base saturation in red mud is due to the high concentration of soluble base cations, particularly sodium (Kapri &Jain, 2023).

Table 2. Chemical characteristics of peat and red mud

Parameter	Peat		Red mud	
	Value	Criteria*	Value	Criteria**
pH H_2O	3.93	Very acidic	10.78	Alkaline
Electrical Conductivity (µmhoscm^{-1})	47.87	Very low	7,000	High
Organic Carbon (%)	57.14	Very high	0.68	Very low
Total N (%)	3.49	High	0.11	Low
Available P (ppm)	36.48	Moderate	12.46	Low
Exch. K (cmol(+)kg^{-1})	0.50	Low	0.08	Very low
Exch. Ca (cmol(+)kg^{-1})	6.60	Low	8.10	Moderate
Exch. Mg (cmol(+)kg^{-1})	1.00	Low	0.04	Very low
Exch. Na (cmol(+)kg^{-1})	1.39	Low	84.58	Very high
CEC (cmol(+)kg^{-1})	83.42	Low	26.74	High
Base Saturation (%)	11.38	Low	346.98	Very high

Note : *Criteria based on the chemical properties of peat soil (Jones, 2001)
** Criteria based on Eviati *et al.* (2023)

Effects of Treatments on Soil Quality

Soil pH and Electrical Conductivity Dynamics Due to Treatments

The dynamics of soil pH and electrical conductivity (EC) due to the treatments are presented in Table 3. The application of red mud alone had a significant effect on the pH and EC of peat soil at 0, 50, and 100 days after planting (DAP), whereas its combination with biofertilizers had no significant effect. Red mud application significantly increased the pH of peat soil, with the 12 tons/ha red mud treatment (l_2) yielding the highest peat pH compared to other treatments. Red mud raised the pH of peat soil because it had a high initial pH of 10.78 (Table 2). Red mud contains high levels of sodium hydroxide (NaOH), which helps to neutralize the very acidic pH of peat soil (Zhang *et al.*, 2021; Rai *et al.*, 2023).

Table 3. Dynamics of soil pH and electrical conductivity due to treatments

Treatments	pH			Electrical conductivity (μmhos/cm)		
	0 DAP	50 DAP	100 DAP	0 DAP	50 DAP	100 DAP
Control (l_0)	5.50c	5.15c	4.38c	247.7b	202.9b	138.9a
Red mud 6 tons/ha (l_1)	6.32b	5.97b	5.07b	323.4a	255.3ab	158.0a
Red mud 12 tons/ha (l_2)	6.92a	6.55a	5.68a	376.3a	288.2a	162.4a

Note: Numbers in the table followed by the same letter are not significantly different at the 5% level according to the Duncan Multiple Range Test (DMRT). DAP = Days after planting.

The application of red mud alone had a significant effect on the electrical conductivity (EC) of peat soil, with EC values increasing in tandem with higher doses of red mud. The 12 tons/ha treatment (l_2) produced the highest soil EC among the treatments. Initial analysis of the red mud showed an EC value of 7,000 μmhos/cm (Table 2), contributing to an increase in the otherwise low EC of peat soil. According to Smith *et al.* (2024), red mud readily releases sodium ions when applied to soil, thereby raising EC values. Additionally, an increase in soil pH also enhances EC values (Hayes *et al.*, 2022). Over time, the EC of peat soil tended to decrease at 50 and 100 DAP (Table 3). This decline in EC is likely due to a drop in soil pH as the base cations diminish (Sadeghian *et al.*, 2022). Cherie (2022) notes that soil pH reduction correlates positively with decreases in EC values.

Effect of Treatments on Peat Soil Quality

The red mud and biofertilizer applications had a significant effect only on the sodium parameter. The influence of red mud and biofertilizers on peat soil quality is shown in Table 4. The application of red mud can increase the pH of peat soil. Suswati (2023) suggests that red mud can raise pH in acidic soils. Additionally, the Provibio biofertilizer aids in the decomposition of peat soil, producing phenolate and carboxylate groups that carry negative charges (Kassim *et al.*, 2024). The application of red mud can reduce the organic carbon content of peat soil. Research by Susana *et al.* (2024) showed that applying red mud to peat soil can reduce organic carbon levels. According to Zhang *et al.* (2021), red mud raises soil pH, accelerating organic matter decomposition and reducing soil organic carbon. Furthermore, the decrease in organic carbon in the l_2p_2 plot may also be due to the dissolution of humic and fulvic acids caused by the high NaOH content in red mud. Notably, NaOH solutions are used to extract humic and fulvic acids from organic materials (Nieweś *et al.*, 2022).

The decrease in nutrient levels in the l_2p_2 treatment is believed to be a result of the application of red mud, which can dissolve humic and fulvic acids in peat soil. According to Yang *et al.* (2024), when dissolved, humic and fulvic acids no longer function as nutrient binders, causing elements like phosphorus, potassium, calcium, and magnesium to lose their ability to bind with the soil's organic colloids and become easily leached. The low levels of available-P, exchangeable Ca, and exchangeable Mg may also be caused by the increased soil pH, which results in the formation of phosphorus bonds with calcium or magnesium that are unavailable to plants (Fan *et al.*, 2022). The results of the correlation test between soil pH and nitrogen, phosphorus, potassium, calcium, and magnesium levels showed negative values (Table 5). This indicates that as the pH value increases, the levels of nitrogen, phosphorus, potassium, calcium, and magnesium decrease.

Table 4. Influence of treatments on nutrient availability

Treatments	pH	Organic C	Total N	Available P	Exch.K	Exch.Ca	Exch.Mg	Exch.Na	CEC	BS
		----------%------		ppm	--------------------cmol (+)/kg	-------------------				%
l_0p_0	4.29	53.88	1.79	80.45	2.34	18.25	11.15	1.27d	118.54	27.85
l_0p_1	4.43	54.79	1.65	77.43	1.86	21.58	11.46	0.95d	123.16	29.11
l_0p_2	4.42	54.83	1.63	95.21	1.50	27.86	11.55	1.35d	124.46	33.95
l_1p_0	4.93	51.65	1.68	88.90	1.60	19.31	10.79	9.33c	121.05	33.90
l_1p_1	4.92	51.93	1.60	81.80	1.56	16.69	9.17	12.35bc	127.18	23.41
l_1p_2	5.36	49.59	1.54	63.87	1.62	21.69	9.58	14.50bc	126.52	37.46
l_2p_0	5.26	50.47	1.52	65.49	1.27	15.44	8.61	17.66ab	127.68	33.66
l_2p_1	5.85	44.79	1.54	72.99	1.17	15.03	9.05	19.84ab	125.04	38.53
l_2p_2	5.91	42.30	1.51	61.65	0.89	14.31	7.60	20.84a	134.85	33.10

Note: Values in the table followed by the same letter are not significantly different at the 5% level according to the Duncan Multiple Range Test (DMRT). l_0p_0 = control, l_0p_1 = Mycofer, l_0p_2 = Provibio, l_1p_0 = 6 tons/ha red mud, l_1p_1 = 6 tons/ha red mud + Mycofer, l_1p_2 = 6 tons/ha red mud + Provibio, l_2p_0 = 12 tons/ha red mud, l_2p_1 = 12 tons/ha red mud + Mycofer, l_2p_2 = 12 tons/ha red mud + Provibio, CEC = cation exchange capacity, BS = base saturation.

Furthermore, high nutrient uptake by plants can also lead to a decrease in total N, available phosphorus, exchangeable potassium, exchangeable calcium, and exchangeable magnesium levels in the soil after harvest. The results of the correlation test between total N, available phosphorus, exchangeable potassium, exchangeable calcium, and exchangeable magnesium with the uptake of nitrogen, phosphorus, potassium, calcium, and magnesium nutrients showed negative values in each parameter comparison (Table 5). This indicates that the lower the levels of total nitrogen, available phosphorus, exchangeable potassium, exchangeable calcium, and exchangeable magnesium in the soil after harvest, the higher the uptake of nitrogen, phosphorus, potassium, calcium, and magnesium nutrients by the plants. High nutrient uptake by plants reduces the residual nutrients in the soil because plants absorb nutrients for vegetative and generative growth processes (Coonan *et al.*, 2020). Kumar *et al.* (2014) found that high potassium uptake by plants results in lower potassium residue in the soil.

Table 5. Correlation between research observation variables

Variable	pH	Total-N	Available P	Exch. Ps	Exch. Ca	Exch. Mg	CEC	NU	PU	PsU	CaU	MgU
pH	1											
Total-N	-0,45**	1										
Available P	-0,27^{tn}	-0,06^{tn}	1									
Exch. Ps	-0,70**	0,34^{tn}	0,18^{tn}	1								
Exch. Ca	-0,17^{tn}	0,06^{tn}	0,24^{tn}	0,17^{tn}	1							
Exch. Mg	-0,52**	0,03^{tn}	0,41**	0,50**	0,46*	1						
CEC	**0,52****	0,23^{tn}	-0,43**	-0,32^{tn}	-0,06^{tn}	-0,46*	1					
NU	0,51**	**-0,07**^{tn}	-0,17^{tn}	-0,62**	-0,40*	-0,26^{tn}	0,31^{tn}	1				
PU	0,45**	0,03^{tn}	**-0,37**^{tn}	-0,54**	-0,54**	-0,52**	0,50**	0,83**	1			
PsU	0,51**	-0,12^{tn}	-0,36^{tn}	**-0,60****	-0,54**	-0,20**	0,43*	0,84**	0,93**	1		
CaU	0,41**	-0,18^{tn}	-0,44**	-0,44*	**-0,56****	-0,40**	0,27^{tn}	0,74**	0.85**	0,86**	1	
MgU	0,49**	-0,17^{tn}	-0,13^{tn}	-0,55**	-0,37^{tn}	**-0,33**^{tn}	0,21^{tn}	0,86**	0,81**	0,84**	0,68**	1

Note : tn = not significant correlation at the 5% level; * significant correlation at the 1% level, ** highly significant correlation at the 1% level. NU =nitrogen uptake, PU = phosphorus uptake, PsU = potassium uptake, Calcium uptake, MgU = magnesium uptake.

The l_2p_2 treatment increased exchangeable Na in the peat soil. The initial analysis showed that red mud contains very high exchangeable Na levels, up to 84.58 cmol(+)/kg (Table 2). According to Zinoveev *et al.*, 2021), red mud contains sodium that is easily dissolved, thus increasing sodium levels in the soil. The high sodium content in red mud can cause competition among sodium, potassium, and magnesium ions at cation exchange sites in the soil (Huang *et al.*, 2022). This competition often causes potassium and magnesium to be more easily leached as sodium ions can replace them on the organic colloid surface of the soil. In addition, the application of Provibio containing microbes also helps release Na from red mud, leading to an increase in its levels. Research by Ding et al. (2024) demonstrated that the use of biofertilizers containing microbes can release Na in saline soils. This results in a decrease in K and Mg levels, particularly in peat soil with high CEC. The application of red mud can increase the pH of peat soil, which in turn enhances the soil's cation exchange capacity (CEC). The correlation test results between soil pH and CEC showed a positive correlation of 0.52 (Table 5). This indicates that as soil pH increases, the CEC value also increases. According to Manurung *et al.* (2021), the higher the pH of peat soil, the higher the CEC will be. The application of red mud, which contains NaOH, can increase the negative charge of the soil through the deprotonation of H^+ ions on carboxyl and phenolic groups, thereby increasing the CEC of the soil.

Effect of Treatments on Plant Growth

The application of red mud alone had a significant effect on plant growth, while its combination with biofertilizers showed no significant effect. The impact of red mud on plant growth can be seen in Table 6. The treatment of 12 tons/ha of red mud (l_2) resulted in the highest plant height, stem diameter, and number of leaves compared to other treatments. The application of red mud can increase the plant height, stem diameter, and number of leaves of hybrid corn in peat soil. This finding is consistent with the research of Pratama *et al.* (2021) and Kristino *et al.* (2022), which stated that the application of red mud on peat soil can enhance the height and stem diameter of corn plants. Furthermore, the study by Demero *et al.* (2024) indicated that the application of red mud can increase the number of leaves in lettuce plants. The availability of macro-nutrients is essential to support plant growth (Kiani *et al.*, 2021). According to Speetjens & Jacobs (2023) high nutrient availability in the soil promotes plant growth. The effect of red mud on plant height can be observed in Figure 2.

Table 6. Effect of treatments on hybrid corn growth

Treatments	Plant height (cm)	Stem diameter (mm)	Number of leaves (pieces)
Control (l_0)	209.7b	14.31b	13.5b
Red mud 6 tons/ha (l_1)	227.2a	15.82a	14.2a
Red mud 12 tons/ha (l_2)	231.5a	16.16a	14.2a

Note: Numbers in the table followed by the same letter are not significantly different at the 5% level according to the Duncan Multiple Range Test (DMRT).

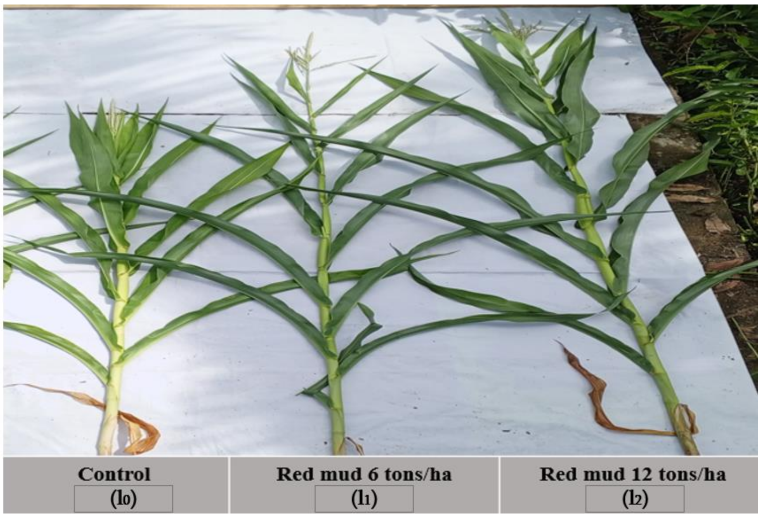

Figure 2. The effect of red mud on plant height at 56 DAP

Effect of Treatments on Plant Nutrient Uptake

The combination of red mud and biofertilizers significantly affected the uptake of P, K, Ca, and Mg. The nutrient uptake values are shown in Table 6. The application of red mud can increase the highest dry weight of plants. According to Wulandari et al. (2024), the application of red mud can increase the dry weight of corn plants. In addition, the application of red mud can also enhance nitrogen nutrient uptake in corn plants. Perkasa et al. (2023) found in their research that the application of red mud in peat soil resulted in high nitrogen uptake by corn plants. The biofertilizer Provibio, which contains Azotobacter bacteria, is believed to help plants improve nitrogen uptake.

The treatment l_2p_2 (12 tons/ha of red mud + Provibio) resulted in the highest uptake of phosphorus, potassium, calcium, and magnesium compared to other treatments. This result is consistent with the findings of Perkasa et al. (2023) and Wulandari et al. (2024) , which showed that red mud can increase phosphorus and potassium uptake in corn plants. Additionally, Jamli (2024) showed that red mud can enhance calcium and magnesium uptake in corn plants grown in peat soil. The biofertilizer Provibio contains phosphate-solubilizing microbes, which could convert phosphorus into a more available form (Setyawan & Santoso, 2021). The diversity of microbes in the soil can form symbiotic relationships with plants, thereby increasing nutrient uptake (Prisa et al., 2023). Microorganisms in the biofertilizer can also produce plant hormones such as auxins, cytokinins, and gibberellins, which play a role in enhancing nutrient absorption (Kour et al., 2020). The auxin hormone can improve root development, making nutrient absorption of macronutrients such as potassium, calcium, and magnesium more optimal (Mazzoni-Putman et al., 2021).

Table 6. Effect of treatments on hybrid corn nutrient uptake

Treatments	Content					Dry weight	Uptake				
	N	P	Ps	Ca	Mg		N	P	Ps	Ca	Mg
	---------------------%--------------------					---------------------------g/plant --------------------------					
l_op_o	1,80	0,47	1,82	0,08	0,09	39,66	0,70	0,18d	0,72c	0,035cd	0,038d
l_op_1	1,79	0,52	1,91	0,09	0,08	41,24	0,74	0,21cd	0,79c	0,038cd	0,032d
l_op_2	2,02	0,49	1,86	0,07	0,10	41,91	0,85	0,21cd	0,78c	0,028d	0,044cd
l_1p_o	2,01	0,51	1,90	0,10	0,11	48,01	0,97	0,24bcd	0,91bc	0,049bcd	0,051bcd
l_1p_1	1,79	0,60	2,18	0,11	0,12	53,52	0,95	0,32bc	1,17b	0,060bc	0,066bc
l_1p_2	1,94	0,53	1,99	0,10	0,11	49,45	0,96	0,26b	0,98bc	0,050bcd	0,053bcd
l_2p_o	1,79	0,56	2,13	0,12	0,13	55,30	0,99	0,31bc	1,18b	0,064b	0,070ab
l_2p_1	1,79	0,47	2,03	0,08	0,10	46,88	0,84	0,22cd	0,95bc	0,040bcd	0,049bcd
l_2p_2	1,91	0,67	2,24	0,14	0,14	64,17	1,22	0,43a	1,44a	0,089a	0,090a

Note: Values in the table followed by the same letter are not significantly different at the 5% level according to the Duncan Multiple Range Test (DMRT). l_op_o = control, l_op_1 = Mycofer, l_op_2 = Provibio, l_1p_o = 6 tons/ha red mud, l_1p_1 = 6 tons/ha red mud + Mycofer, l_1p_2 = 6 tons/ha red mud + Provibio, l_2p_o = 12 tons/ha red mud, l_2p_1 = 12 tons/ha red mud + Mycofer, l_2p_2 = 12 tons/ha red mud + Provibio. N =nitrogen, P = phosphorus, Ps = potassium, Ca = calsium, and Mg = magnesium.

Effect of Treatments on Hybrid Corn Production

The application of red mud alone had a significant effect on plant growth, while its combination with biofertilizers did not. The effect of red mud on plant growth is shown in Table 7. The treatment with 12 tons/ha of red mud (l_2) resulted in the highest hybrid corn production compared to the other treatments. The treatment with 12 tons/ha of red mud produced the highest cob weight per ear (CWPE), cob weight per plant (CWPP), and cob weight per hectare (CWPH) compared to the other treatments. The application of red mud improved corn plant growth as well as nutrient uptake. Optimal nutrient uptake can enhance corn production (Budiastuti *et al.*, 2023). Sekali *et al.* (2021) reported that red mud can increase the cob weight of hybrid corn. Furthermore, Perkasa *et al.* (2023) indicated that red mud can lead to high hybrid corn production in peat soils. The effect of red mud on hybrid corn production can be seen in Figure 3.

Table 7. Effect of treatments on hybrid corn production

Treatments	CWPE	CWPP	CWPH
	---------------g------------		ton/ha
Control (l_o)	54.58c	2177.56c	3.82c
Red mud 6 tons/ha (l_1)	84.11b	3642.22b	6.35b
Red mud 12 tons/ha (l_2)	97.88a	4463.89a	6.85a

Note: Values followed by the same letter in each column are not significantly different at the 5% level according to the DMRT test. CWPE = cob weight per ear, CWPP = cob weight per plant, CWPH = cob weight per hectare.

Figure 3. Comparison of red mud application on hybrid corn production

CONCLUSION

Red mud can be used as an ameliorant for low-quality soils, such as peat. The application of red mud at a dose of 12 tons/ha resulted in the best growth and yield of hybrid corn compared to other treatments. A 12 ton/ha dose of red mud was able to increase the pH and electrical conductivity of peat soil. The combination of 12 tons/ha of red mud with the biofertilizer Provibio improved phosphorus, potassium, calcium, and magnesium uptake in hybrid corn plants. However, this combination also led to an increase in sodium content. The combination of red mud and biofertilizers had no significant effect on the growth and yield of hybrid corn. Additionally, the combination of red mud and biofertilizers also had no significant effect on the parameters of pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, exchangeable calcium, exchangeable magnesium, cation exchange capacity, and base saturation in post-harvest peat soil.

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