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Modification of Peatlands Amendment with Dolomite and Fly Ash

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ABSTRACT

High acidity levels and low availability of alkaline elements such as Ca, Mg, and K inhibit plant growth and reduce land productivity. This study examined the effect of dolomite and fly ash doses on the chemical properties of peatland. This study used a 2 × 3 factorial randomized block design (RBD) with three replicates. The first factor was the type of soil conditioner, namely dolomite and fly ash. The second factor was the soil conditioner dose, namely 5, 10, and 15 t ha^{-1}. The type of soil ameliorant did not interact significantly with the dose of soil conditioner for pH, water content, organic C, total N, K, P, Fe, Cu, Zn, Mg, Ca, K-exch, and humate. Dolomite was superior in increasing base elements (Ca, Mg, and K) and the humification process of organic matter, while fly ash played an important role in increasing microelements (Fe, Cu, Zn) and carbon stabilization. Meanwhile, an ameliorant dose of 15 t ha^{-1} significantly increases pH, moisture content, organic carbon, and macronutrients (P and K). Dolomite and fly ash at an optimal dose of 15 t ha^{-1} are recommended as a sustainable amelioration strategy to increase pH, chemical fertility, and carbon stability in peat soils without causing negative environmental impacts.

Keywords: Amelioration, degradation, dolomite, fly ash, peatland

INTRODUCTION

Peatlands are ecosystems that play important ecological roles, particularly in carbon storage, hydrological regulation, and the support of tropical biodiversity. However, degradation from drainage, land conversion, and fires has caused major problems, including reduced fertility, increased greenhouse gas emissions, and increased vulnerability to fire (Yunus et al., 2025). Analysis of the chemical properties of peat in Padang Pariaman Regency, West Sumatra, Indonesia, shows that the pH of peat is between 3.68 and 4.81, Ash and organic C levels are around 16.27-39.13% and 35.30-48.18% C with macro nutrient composition N, P and K Total around 0.76-3.52% N; 5.58-11.79% P and 1.74-2.31% K. The micro-nutrient composition of Fe, Cu, and Zn is around 2.71–3.03 ppm Fe; 0.23–0.26 ppm Cu; and 0.21–0.31 ppm Zn (Zulkarnaini et al., 2024). These conditions require efforts to improve the physical and chemical properties of peat soil through the application of effective and environmentally friendly soil amendments. Agronomically, peat soils face significant constraints, including high acidity, low base saturation, and a lack of essential nutrients for plant growth (Asie et al., 2025). In addition, the physical properties of peat, such as low bearing capacity and susceptibility to subsidence, further reduce its productivity potential (Yuwati et al., 2021). Therefore, amelioration is a strategic step to increase agricultural productivity while reducing the rate of peatland degradation.

Dolomite [$CaMg(CO_3)_2$] has long been used as a liming agent to raise the pH of acidic soils and increase the availability of calcium and magnesium (Wu et al., 2021). The application of dolomite has been shown to increase the pH of peat soils, reduce aluminum solubility, and increase the availability of macronutrients (Parmar & Meenakshi, 2024). Dolomite plays an important role in improving the chemical properties of peat, which is generally very acidic. Meanwhile, fly ash, a byproduct of coal combustion, has significant potential as a soil conditioner. Fly ash contains minerals such as silica, alumina, calcium, and iron that can increase soil pH and improve physical properties such as porosity and density (Alterary and Marei, 2021). In addition, the use of fly ash helps reduce industrial waste, thereby providing added environmental value. Dolomite and fly ash can improve chemical conditions by raising pH and adding calcium and magnesium, while fly ash can improve physical properties and provide additional mineral reserves (Cohen et al., 2019). They can also reduce dependence on chemical fertilizers, thereby supporting sustainable agriculture on peatlands. However, the use of fly ash poses potential environmental risks, including varying heavy metal content (Chen et al., 2024). Therefore, research that integrates soil productivity evaluation, environmental quality, and potential risks is very important. It ensures that the use of a combination of dolomite and fly ash is not only effective but also safe in the long term.

From a climate change mitigation perspective, the application of ameliorants in peatlands must consider their impact on greenhouse gas emissions. Changes in pH and organic mineralization can increase the rate of organic matter decomposition, potentially releasing significant amounts of CO_2 and CH_4 (Li et al., 2024). Therefore, research must include an evaluation of the carbon balance so that amelioration interventions do not cause environmental trade-offs. In addition to biophysical factors, the success of soil amendment applications in peatlands is largely determined by the socio-economic context. Smallholders who manage peatlands need affordable, easy-to-apply technologies that utilize locally available materials or industrial waste (Uda et al., 2020). The use of dolomite or fly ash is expected to improve the chemical properties of peat, but its impact on crop productivity and greenhouse gas emissions is still relatively limited (Priatmadi et al., 2024). This study has examined the effects of dolomite and fly ash doses on the chemical properties of peatlands, as an alternative to productive, environmentally friendly land management and to support restoration strategies that contribute to food security and climate change mitigation.

MATERIALS AND METHODS

This study was conducted from April to August 2024 at the Water Laboratory, Department of Environmental Engineering, Faculty of Engineering, Andalas University, Padang.

Experimental design

This study used a 2 × 3 factorial randomized block design (RBD) with three replicates. The first factor was the type of soil conditioner, namely dolomite and fly ash. The second factor was the soil conditioner dose, namely 5, 10, and 15 t ha^{-1}.

Soil Sample Preparation and Ameliorant Application

The peatland used for the experiment was peat soil from Padang Pariaman, West Sumatra, Indonesia. The soil was first tilled using a plow. After that, approximately 500g of soil was collected from 5 different points in the flooded rice fields for analysis of the soil's initial chemical properties. Next, the land was divided into 12 main plots measuring 10 m × 7.5 m, and within each main plot, 16 sub-plots measuring 2 m × 1.5 m were arranged with a 25 cm spacing. Next, dolomite and fly ash were homogenized with the soil in each treatment plot, then mixed evenly and incubated for 2 weeks. Soil samples were then taken for analysis in the laboratory. After that, the planting process was carried out.

Soil and Statistics Analysis

Soil analysis was performed using standardized laboratory procedures for each parameter. Soil water content was determined by the gravimetric method and expressed as a percentage. Soil pH was measured using a calibrated pH meter and reported in pH units. Organic carbon content was determined using the Loss-on-Ignition (LOI) method. Total nitrogen (%) was analyzed using the Kjeldahl digestion method. Total phosphorus and potassium were extracted using 25% HCl solution and measured accordingly. Micronutrients, including Fe, Cu, and Zn, were quantified in ppm following acid digestion with HNO_3 and $HClO_4$. Total Ca and Mg were determined using the Morgan–Wolf extraction method. Exchangeable K was measured with 1 M NH_4OAc at pH 4. Humate content was determined by gravimetric analysis following extraction with 0.1 M NaOH (Eviati et al., 2023).

The soil analysis was subjected to statistical analysis using software (Microsoft Excel 2016 and SPSS 23). The statistical analyses used were analysis of variance (ANOVA) and Duncan's multiple range test (DMRT). After detecting a significant effect in ANOVA, DMRT was used as a post hoc test to identify which group means differ. Significance levels were determined as follows: if F count > F table at the 5% level, the results are significant and marked with [*], and if F count > F table at the 1% level, the results are very significant and marked with [**]. The [*] and [**] annotations reflect the significance levels of these differences.

RESULTS AND DISCUSSION

Natural chemical properties of peatlands

The natural chemical properties of peatlands in Nagari Sunur, Nan Sabaris, Padang Pariaman, Indonesia, exhibit the distinctive characteristics of tropical peat ecosystems, which are dominated by organic matter and saturated with water. A water content of 38.48% indicates a high water retention capacity, a key feature of peat soils due to the macro-micro-pore structure of decomposed organic matter. High water content plays an important role in controlling oxygen diffusion and the rate of organic matter decomposition (Khan et al., 2025). A soil pH of 4.87 indicates an acidic soil reaction, which is commonly observed in peatlands due to the accumulation of organic acids, such as humic and fulvic acids, produced by the decomposition of vegetation. Soils with a pH below 5 usually have limited availability of certain macronutrients and increased solubility of certain metals, thereby affecting soil fertility and plant response. The organic C content of 14.50% indicates a strong dominance of organic matter in the soil matrix. Peat soils are generally characterized by high organic carbon content, resulting from humification under anaerobic conditions. Organic carbon plays a major role in cation exchange capacity and water retention, but it can also bind nutrients, so not all nutrients are immediately available to plants (Prekop et al., 2023).

The total N of 3.25% is very high compared to that of ordinary mineral soils. However, in peat soils, most of the nitrogen is present as complex organic compounds, so it must first undergo mineralization to become available to plants. The rate of mineralization is greatly influenced by aeration, temperature, and soil pH (Chen et al., 2021). The total P of 0.04% indicates low P status, which is one of the main constraints in peat soils. Phosphorus is often bound in organic complexes or associated with Fe and Al in acidic conditions, thus limiting its availability. Therefore, peat soils often require the addition of P fertilizers or mineral ameliorants (Maftu'ah et al., 2019). The total K of 0.03% is also relatively low. In peat soils, potassium is relatively easily leached due to the low clay mineral fraction and the dominance of organic colloids. High rainfall in tropical regions accelerates this leaching process, often resulting in K deficiency in cultivation systems on peatlands (Agus et al., 2025).

An iron (Fe) level of 12.30 ppm indicates moderate Fe content. In acidic soil, Fe is more soluble and available. However, under reductive conditions caused by water saturation, Fe can change valence state and increase dissolved Fe concentration, which, in some cases, can cause toxicity to certain plants (Nandakumar et al., 2024). The microelement content of Cu at 0.93 ppm and Zn at 0.85 ppm indicates a relatively low to moderate status. Peat soils often exhibit deficiencies in microelements because these elements are strongly bound by organic matter and are supplied in low amounts. The Cu and Zn deficiencies have been widely reported as limiting factors for crop production in tropical peatlands (Pulunggono et al., 2022). The classic pattern of peatland fertility is rich in organic matter but poor in available nutrients. These conditions result in low natural productivity, requiring management interventions such as liming, mineral amelioration, and balanced fertilization. Thus, the natural chemical properties of peat indicate that the main constraints on peatlands are acidity, nutrient imbalance, and the dominance of slow-release organic nutrients.

Modification of peatland amendment with dolomite and fly ash

The effect of the type of ameliorant does not significantly interact with the dose of ameliorant (dolomite and fly ash) on the chemical properties of peatland (Figure 1, 2, 3, 4, 5, and 6). However, the main effect of the type of ameliorant is not significant on pH and water content of peatland (Figure 1A). The use of fly ash as an ameliorant resulted in a slightly higher pH (5.96) and water content (44.73%) compared to dolomite, which had a pH of 5.86 and a water content of 44.3%. This shows that fly ash is more effective in increasing the pH of peat soil. The effectiveness of fly ash is due to its content of basic metal oxides such as CaO, MgO, and K, O, which can neutralize Hz ions in acidic soils (Bennehalli et al., 2025). These base contents help neutralize the high levels of humic and fulvic acids in peat soil, thereby increasing soil pH and water stability (Wang et al., 2025).

Meanwhile, the main effect of the ameliorant dose is significant on pH and water content of peatland (Figure 1B). In terms of dosage, increasing the ameliorant dosage from 5 tons/ha to 15 tons/ha resulted in a gradual increase in pH from 5.53 to 6.42 and moisture content from 42.2 to 47.01%. It indicates that the greater the amount of ameliorant applied, the stronger the soil's ability to retain water and neutralize acidity. The increase in pH with the addition of dolomite and fly ash doses was due to an increase in the concentration of base cations (Ca^{2+}, Mg^{2+} and K^{+}), which replaced Hz and Al^{3}z ions in the adsorption complex (Bennehalli et al.,

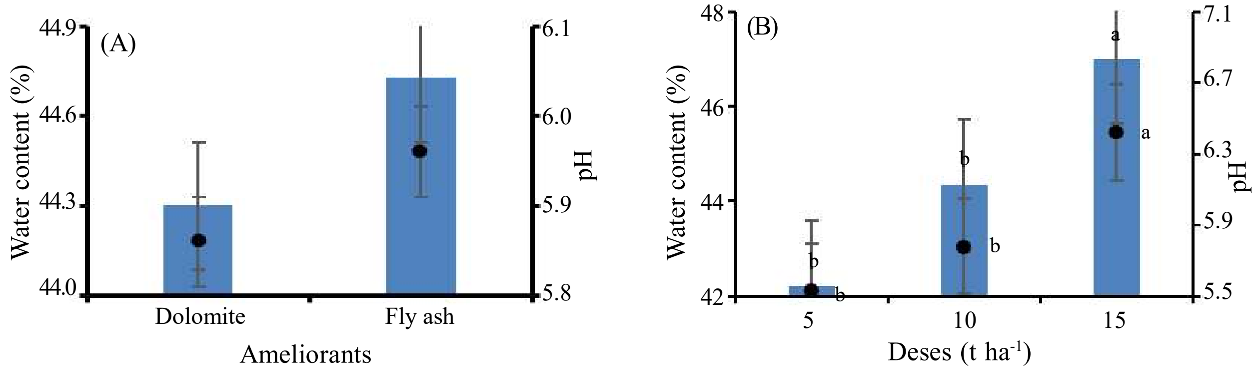

Figure 1. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on water content and pH of peatland. ■: WC, ●: pH.

2025). High ameliorant doses increased base saturation and improved the chemical conditions of peat soil.

The increase in peat soil moisture content after the application of soil amendments is also an indirect effect of increased pH and soil aggregate stability. Basic amendments such as fly ash and dolomite strengthen the bonds between soil particles, increasing aggregation and microporosity, and enhancing soil water retention capacity (Utkarsh and Jain, 2024). In addition, fly ash has a fine texture and acts as a soil structure-forming agent, more reactive with organic matter in peat soil (Alterary and Marei, 2021). Therefore, the increase in water content at high doses can be attributed to improvements in soil physical properties due to chemical interactions between the soil conditioner and organic matter in peat. Fly ash at high doses produces a greater increase in pH than dolomite. Fly ash can increase the pH of peat soil more quickly than dolomite, due to its higher reactive base-metal and silicate content. However, the relative effectiveness of soil conditioners also depends on the initial characteristics of the peat soil, including decomposition level, ash content, and organic acidity (Säurich et al., 2019). Fly ash yields slightly higher results than dolomite, and a dose of 15 tons ha^{-1} is the most effective application rate for improving soil physical and chemical properties. The application of base-based soil amendments can improve the fertility of peat soils and support plant growth (Garbowski et al., 2023). However, the use of fly ash must be balanced with monitoring of potential heavy metal content to avoid long-term environmental impacts (Chen et al., 2024).

The main effect of the type of ameliorant is significant on organic C of peatland and not significant on total N of peatland (Figure 2A). The use of fly ash produces a higher organic C content (29.71%) compared to dolomite (27.64%). In comparison, the total N content is relatively similar (0.56%-0.57%). The increase in organic C in fly

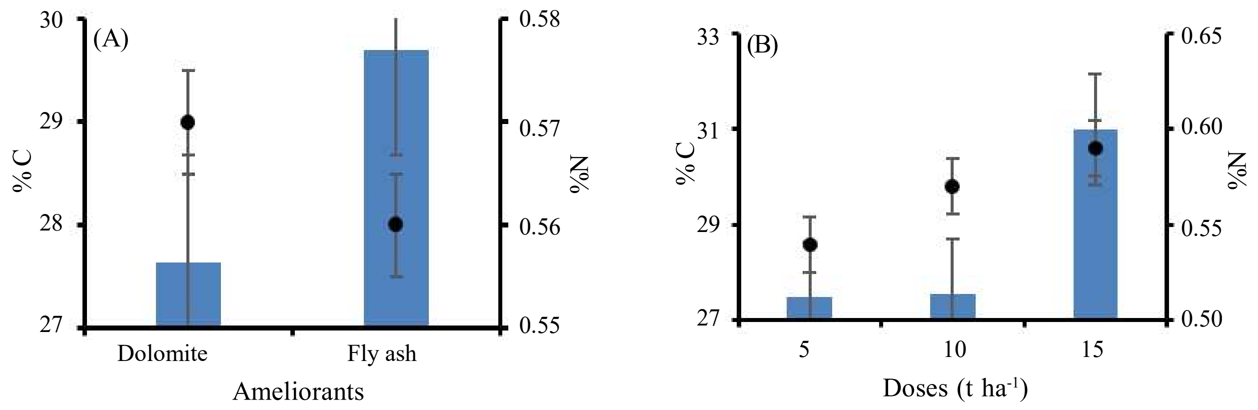

Figure 2. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on organic C and total N of peatland. ■ : C, ● : N.

ash is due to its ability to improve the soil microenvironment, thereby reducing the rate of organic matter decomposition and preserving carbon reserves in peat soils (Asadu et al., 2024). Fly ash contains silicate minerals and metal oxides that can accelerate the formation of organo-mineral complexes, increasing carbon stability in the soil (Palansooriya et al., 2020). Fly ash has the potential to play a dual role in neutralizing acidity and strengthening peat soil carbon retention.

In contrast, dolomite primarily serves as a source of base cations (Ca^{2+} and Mg^{2+}), which raise pH and reduce the activity of microorganisms that decompose organic matter excessively. Although the increase in C is not as significant as with fly ash, dolomite still contributes to the stability of organic matter by controlling acidity and increasing nutrient availability (Horvatinec et al., 2025). More neutral pH conditions can slow carbon oxidation and suppress C loss through microbial respiration (Atasoy et al., 2024). Therefore, the two types of soil amendments have different roles. Fly ash enriches stable carbon, while dolomite maintains chemical balance, preserving soil organic matter.

The main effect of the ameliorant dose is significant on organic C of peatland and not significant on total N of peatland (Figure 2B). In terms of dosage, increasing the ameliorant from 5 t ha^{-1} to 15 tons/ha resulted in a clear increase in organic C from 27.48% to 30.99% and total N from 0.54% to 0.59%. It indicates that amelioration at high doses improves soil biogeochemical conditions, thereby supporting the accumulation of organic matter. Higher doses accelerate the formation of organic-mineral complexes and reduce the activity of decomposer microbes, which are severely affected by high acidity (Atasoy et al., 2024). This process supports carbon and nitrogen retention by reducing the mineralization of peat organic matter. The increase in C and N at high doses indicates an improvement in the soil nitrogen cycle, driven by better redox conditions and pH. Basic amendments such as fly ash and dolomite increase the activity of nitrogen-solubilizing microbes without accelerating excessive decomposition (Chiodi et al., 2025).

Additionally, the increase in N levels at high doses indicates that some nitrogen can be absorbed and retained as stable ammonium, due to decreased soil acidity (Rivero-Marcos et al., 2024). Thus, the combination of increased pH and organic complex formation can maintain a balance between carbon storage and nitrogen availability. Fly ash has been proven to be more effective in increasing organic carbon, while dolomite provides a balancing effect on nitrogen availability. A dose of 15 t ha^{-1} is optimal for enriching C and N without causing excessive oxidation or loss of organic matter. Inorganic base amendments can improve peat soil fertility through physical and chemical mechanisms that stabilize nutrients (Basak et al., 2024).

The main effect of the type of ameliorant is significant on total P and K of peatland (Figure 3A). Fly ash amendments provide a slightly higher total P content (0.061%) than dolomite (0.058%). In comparison, the total K content is higher in dolomite (0.43%) than in fly ash (0.32%). This difference reflects the chemical composition of the two materials. Fly ash contains phosphate in the form of calcium phosphate [$Ca_3(PO_4)_2$]. At the same time, dolomite is richer in base cations (Ca^{2+} and Mg^{2+}), which can increase the availability of K in the soil through ion exchange (Palansooriya et al., 2020). Phosphorus in fly ash tends to be more soluble in acidic peat soil conditions, thereby slightly increasing its availability to plants (Schönegger et al., 2018). The increase in phosphorus availability due to fly ash can also be explained by the higher pH, which improves the solubility of organic P compounds in peat soil. Acidic peat soils generally have P bound to Fe and Al, but the increase in pH from ameliorants reduces this binding, increasing P availability (Ronkanen et al., 2025). Conversely, potassium is more responsive to the presence of base cations from dolomite, because Ca and Mg from dolomite can exchange Hz ions in soil adsorption complexes and stimulate the release of K from organic matter (Yang et al., 2024). Therefore, dolomite plays a dominant role in improving K status, while fly ash increases P availability.

The main effect of the ameliorant dose is significant on total P and K of peatland (Figure 3B). In terms of ameliorant dosage, an increase from 5 tons/ha to 15 tons/ha showed a gradual increase in both total P from 0.058% to 0.061% and total K from 0.36% to 0.38%. It indicates that higher doses of ameliorants can improve the chemical conditions of peat soil by increasing base saturation and reducing acidity, both of which support the release of bound nutrients. The application of base ameliorants increases base saturation by 20–30%, making elements such as P and K more readily available (Ethika et al., 2021). This increase can also be attributed to the decomposition of organic matter due to improved soil oxidation conditions, which accelerates the mineralization of macronutrients. The relatively small but consistent increase in P and K indicates that the amelioration process not only changes the pH but also modifies the ion balance in peat soil. Amelioration with fly ash and dolomite accelerates the transformation of

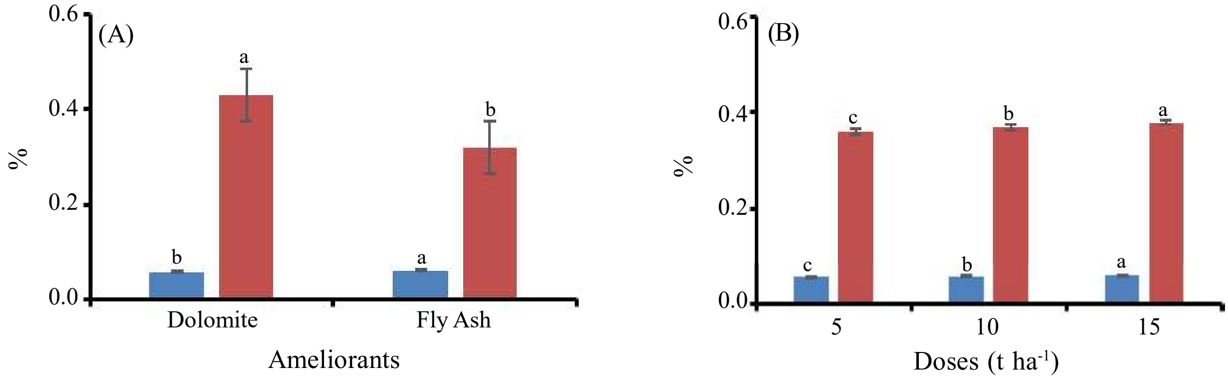

Figure 3. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on total P and K of peatland. ■ : P, ■ : K.

nutrients from unavailable to soluble forms, mainly by increasing pH and CEC (Pramudya et al., 2025). However, its effectiveness is influenced by the characteristics of fly ash (e.g., particle size and Si/Al ratio) and the active mineral content in dolomite. In the long term, repeated applications are necessary to maintain consistent P and K availability, as peat soils exhibit high leaching. Fly ash is more effective in increasing total P, while dolomite is superior in improving total K in peat soils. Both amendments showed positive effects on macronutrient levels at the highest dose (15 t ha^{-1}), indicating that sufficient amounts of amendments are needed to improve peat soil fertility sustainably. A combination of base amendments can increase the availability of major nutrients (P, K, Ca, and Mg) through acid neutralization and increased soil biogeochemical activity (William et al., 2020).

The main effect of the type of ameliorant is significant on Fe, Cu, and Zn in peatlands (Figure 4A). Fly ash has higher Fe (0.45 ppm), Cu (0.46 ppm), and Zn (0.64 ppm) contents than dolomite, which only contains Fe (0.23 ppm), Cu (0.22 ppm), and Zn (0.37 ppm). Fly ash is more effective in increasing the availability of microelements because it contains metal residues from the coal combustion process (Lanzerstorfer, 2018). This higher microelement content can enrich microelements in peat soil, which is generally poor in these elements (Parzych and Jonczak, 2025). The main effect of the ameliorant dose is not significant on Fe in peatland, and significant on Cu and Zn in peatland (Figure 4B). An increase in the ameliorant dose from 5% to 15% also showed an upward trend in Fe, Cu, and Zn levels in peat soil. Fe increased from 0.30 ppm to 0.38 ppm, Cu from 0.33 ppm to 0.35 ppm, and Zn from 0.50 ppm to 0.51 ppm. This increase indicates that higher doses of soil conditioner can improve micronutrient availability by increasing soil pH and enhancing cation exchange reactions (Razzaghi et al., 2021). With increased pH due to amelioration, metal elements that were previously bound in unavailable forms become more readily absorbed by plants (Efficiency et al., 2022).

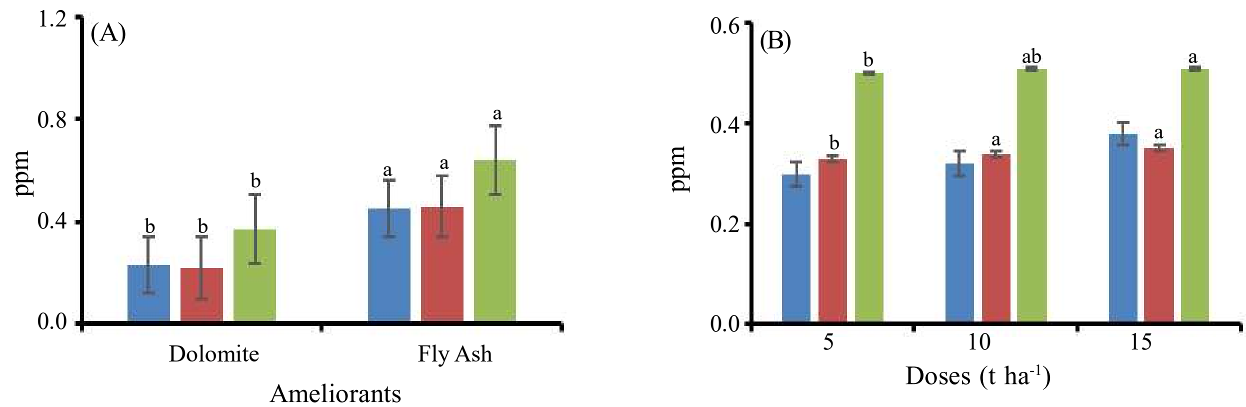

Figure 4. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on Fe, Cu, and Zn in peatlands. ■ : Fe, ■ : Cu, ■ : Zn.

Fly ash contributes more to the increase in micronutrients than dolomite because it contains metal oxides such as Fe_2O_3 , CuO, and ZnO that can be dissolved in acidic soil conditions. In addition, the silicate and aluminate components in fly ash increase cation exchange capacity (CEC), making micronutrients more stable and available to plants (Horvatinec et al., 2025). Meanwhile, dolomite functions more as an acidity neutralizer and a source of Ca and Mg, rather than a source of microelements (Wu et al., 2021). The increase in Fe, Cu, and Zn content resulting from the application of ameliorants positively affects peatland productivity, especially for crops that require sufficient levels of these microelements, such as oil palm and swamp rice. Fe, Cu, and Zn play an important role in photosynthesis, respiration, and enzymatic activity. However, fly ash application needs to be controlled to prevent heavy metal accumulation beyond thresholds that could be toxic to plants and the environment. The application of soil amendments, particularly fly ash at optimal doses (10 and 15 tons ha^{-1}), effectively increases the microelement content of peat soil without causing negative effects on soil quality. The use of a combination of dolomite and fly ash can also be a more sustainable strategy because dolomite neutralizes acidity while fly ash enriches microelements (Horvatinec et al., 2025).

The main effect of the type of ameliorant is significant on Ca and Mg in peatlands (Figure 5A). Ameliorants from dolomite and fly ash serve to improve the chemical properties of peat soil, which is generally acidic and poor in basic nutrients, especially calcium (Ca) and magnesium (Mg). The Ca and Mg content in dolomite is 0.25% and 0.27%, respectively, whereas in fly ash it is 0.09% and 0.21%, respectively. These values indicate that dolomite has a relatively higher Ca and Mg content than fly ash. Dolomite is an effective primary source of Ca and Mg for increasing base saturation in peatland (Asie et al., 2025). The type of soil conditioner directly affects increases in soil Ca and Mg levels. The data show that dolomite contributes more to increasing soil Ca than fly ash does. Conversely, fly ash also increases Mg levels, albeit at slightly lower levels than dolomite. Fly ash contains several metal oxides, such as CaO and MgO, but with lower solubility than dolomite (Jadaa, 2024).

The main effect of the ameliorant dose is not significant on Ca and Mg of peatland (Figure 5B). Increasing the ameliorant dose from 5, 10, and 15 tons/ha showed an upward trend in Ca content from 0.169% to 0.174% and Mg from 0.24% to 0.25%. Although the increase was relatively small, it indicated that higher ameliorant doses tended to increase the base cation content in peat soil. Increasing the ameliorant dose increases the amount of base cations available in the soil due to cation exchange and organic acid neutralization reactions. High doses of dolomite can increase soil pH and Ca-Mg availability more quickly, while fly ash with a silicate content can improve soil structure and reduce Al toxicity in the long term (Ondrasek et al., 2021). Dolomite is more effective in increasing the Ca and Mg content of peat soil than fly ash, especially at higher application doses. However, fly ash still provides a positive contribution because, in addition to containing basic elements, it also has a residual effect that can gradually improve soil physical and chemical properties. The use of soil conditioners must be tailored to the specific needs of the soil and plants, while also considering

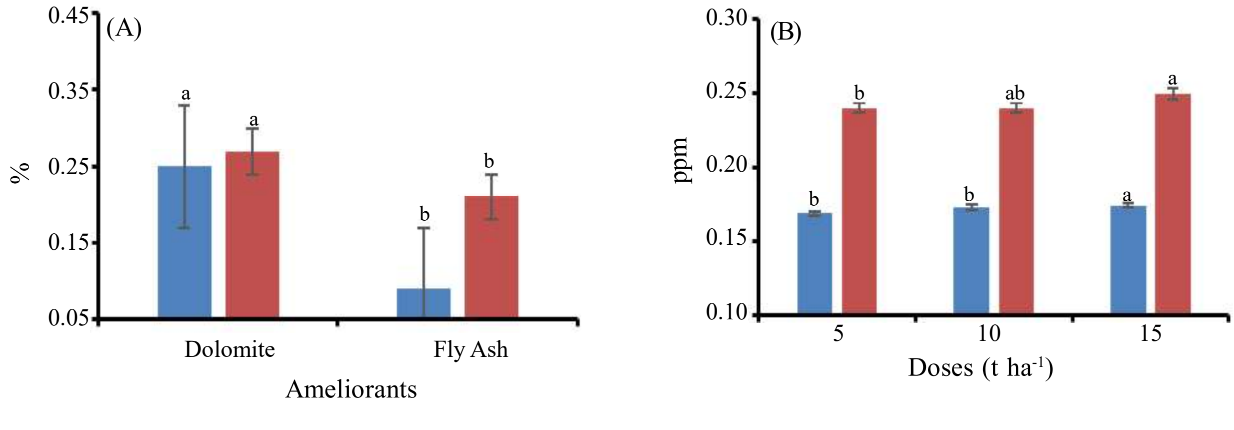

Figure 5. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on Ca and Mg of peatland. ■ : Ca, ■ : Mg.

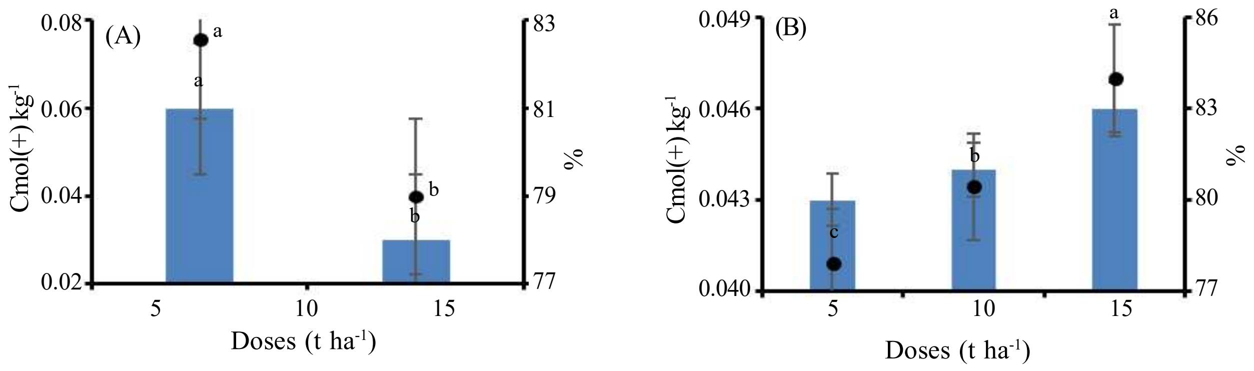

Figure 6. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on K-exch and humate of peatland. ■ : K-exch, ● : Humate.

economic efficiency and environmental sustainability (Corato et al., 2024).

The main effect of the type of ameliorant is significant on K-exch and humate of peatlands (Figure 6A). Peatlands have low exchangeable potassium (K-exch) and high organic matter content. However, most of it is in the form of unstable humic and fulvic acids. The application of ameliorants such as dolomite and fly ash plays an important role in improving the chemical fertility of peat soil by increasing base saturation and stabilizing organic matter. Dolomite produced a K-exch of 0.06 cmol(+) kg^{-1} and humate 82.57%, while fly ash showed lower values of 0.03 cmol(+) kg^{-1} and 78.9%, respectively. This indicates that dolomite is more effective at increasing cation exchange capacity and humifying organic matter. K-exch is higher in the dolomite treatment than in fly ash, suggesting that dolomite plays an active role in increasing exchangeable bases, including potassium. Dolomite containing Ca and Mg carbonate can neutralize soil acidity, thereby strengthening ion exchange between base cations (K^+, Ca^{2+} and Mg^{2+}) and soil colloid complexes (Farhana et al., 2025).

In contrast, fly ash, although containing silicate minerals and base oxides, has slower cation solubility, resulting in a relatively small effect on K-exch enhancement (Utkarsh and Jain, 2024). The higher increase in humate in dolomite (82.57%) compared to fly ash (78.99%) indicates that dolomite is capable of accelerating the humification process in peat soil. Ca^{2+} and Mg^{2+} ions from dolomite can stabilize humic compounds by forming ionic complexes with carboxyl and phenolate groups of organic acids. Meanwhile, fly ash also contributes to humate formation through its alkalinity and the addition of silica minerals, which strengthen organic matter aggregation. However, the reaction is not as strong as in dolomite (Jarosz et al., 2025).

The main effect of the ameliorant dose is not significant on K-exch and humate of peatland (Figure 6B). Increasing the ameliorant dose from 5, 10, and 15 tons/ha showed an upward trend in K-exch from 0.043 cmol(+) kg^{-1} to 0.046 cmol(+) kg^{-1}, as well as humate from 77.92% to 84.01%. This indicates that increasing the dose can expand the availability of exchangeable bases and accelerate the humification reaction of soil organic matter. Increasing the ameliorant dose strengthens the interaction between base cations and functional groups of organic matter, thereby increasing the stability of humic matter and reducing the rate of rapid decomposition in peatland. Dolomite is more effective than fly ash in increasing the K-exch and humate values of peat soil, at both low and high doses. However, fly ash still has potential as a supporting soil conditioner because its silica and mineral content can improve soil structure and prolong the ameliorative effect. Dolomite and fly ash have the potential to synergistically increase the chemical fertility of peat soil and stabilize long-term organic carbon (Pramudya et al., 2025).

CONCLUSIONS

The type of soil ameliorant did not interact significantly with the dose of soil conditioner for pH, water content, organic C, total N, K, P, Fe, Cu, Zn, Mg, Ca, K-exch, and humate. Dolomite was superior in increasing base elements (Ca, Mg, and K) and the humification process of organic matter, while fly ash played an important role in increasing microelements (Fe, Cu, Zn) and carbon stabilization. Meanwhile, an ameliorant dose of 15 t ha^{-1} significantly increases pH, moisture content, organic carbon, and macronutrients (P and K). Dolomite and fly ash at an optimal dose of 15 t ha^{-1} are recommended as a sustainable amelioration strategy to increase pH, chemical fertility, and carbon stability in peat soils without causing negative environmental impacts.

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