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 x 3 randomized block design (RBD) factorial design with three replicates. The first factor was the type of soil conditioner, namely dolomite and fly ash. The second factor was the dose of soil conditioner, namely 5, 10, and 15 tons/ha. The effect of the type of soil ameliorant did not interact significantly with the dose of soil conditioner on 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 tons/ha significantly affects the increase in pH, moisture content, organic carbon, and macro nutrients (P and K). Dolomite and fly ash at an optimal dose of 15 tons/ha 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

ABSTRAK

Kadar keasaman yang tinggi dan ketersediaan unsur alkali seperti Ca, Mg, dan K yang rendah, yang menghambat pertumbuhan tanaman dan mengurangi produktivitas lahan. Studi ini telah mengkaji pengaruh dosis dolomit dan abu terbang terhadap sifat kimia lahan gambut. Studi ini menggunakan rancangan acak kelompok (RAK) faktorial 2 x 3 dengan tiga ulangan. Faktor pertama adalah jenis amelioran, yaitu dolomit dan abu terbang. Sedangkan faktor kedua adalah dosis amelioran, yaitu 5, 10, dan 15 ton/ha. Pengaruh jenis amelioran tidak berinteraksi secara signifikan dengan dosis amelioran terhadap pH, kadar air, C organik, total N, K, P, Fe, Cu, Zn, Mg, Ca, K-dd, dan humat. Dolomit lebih unggul dalam meningkatkan unsur basa (Ca, Mg, dan K) serta proses humifikasi bahan organik, sedangkan fly ash berperan penting dalam peningkatan unsur mikro (Fe, Cu, Zn) dan stabilisasi karbon. Sedangkan, dosis 15 ton/ha amelioran berpengaruh signifikan terhadap peningkatan pH, kadar air, C organik, serta unsur hara makro (P dan K). Dolomit dan fly ash pada dosis optimal 15 ton/ha direkomendasikan sebagai strategi ameliorasi berkelanjutan untuk meningkatkan pH, kesuburan kimia, dan stabilitas karbon tanah gambut tanpa menimbulkan dampak lingkungan negatif.

Kata kunci: Ameliorasi, Degradasi, Dolomit, Abu Terbang, Lahan Gambut

INTRODUCTION

Peatlands are ecosystems that have important ecological functions, particularly in carbon storage, hydrological regulation, and supporting tropical biodiversity. However, degradation due to drainage, land conversion, and fires has caused major problems, including reduced fertility, greenhouse gas emissions, and vulnerability to fires (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 have serious constraints in the form of high acidity, low base content, 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 macro nutrients (Parmar & Meenakshi, 2024). Dolomite plays an important role in improving the chemical properties of peat, which is generally very acidic. Meanwhile, fly ash, a waste product from coal combustion, has high 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 & Marei, 2021). In addition, the use of fly ash also contributes to the reduction of industrial waste, thus providing added value from an environmental perspective. Dolomite and fly ash can improve chemical conditions by raising pH and adding calcium-magnesium, while fly ash improves physical properties and provides additional mineral reserves (Cohen et al., 2019). This can also reduce dependence on chemical fertilizers, thereby supporting sustainable agriculture on peatlands. However, the use of fly ash has potential environmental risks, such as varying heavy metal content (Y. Chen et al., 2024). Therefore, research that integrates soil productivity evaluation, environmental quality, and potential risks is very important. This 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 aspects, the success of soil amendment application in peatlands is also 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 effect of doses from dolomite and fly ash on the chemical properties of peatland to serve as an alternative solution in productive, environmentally friendly land management and contribute to restoration strategies that support 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 x 3 randomized block design (RBD) factorial design with three replicates. The first factor was the type of soil conditioner, namely dolomite and fly ash. The second factor was the dose of soil conditioner, namely 5, 10, and 15 tons/ha.

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 taken from 5 different points in the flooded rice fields for analysis of the initial chemical properties of the soil. Next, the land was divided into 12 main plots measuring 10 m x 7.5 m, and then within the main plots there were 16 sub-plots measuring 2 m x 1.5 m, with a distance of 25 cm between each sub-plot. 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 using 1 M NH_4OAc, 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 analysis used was the analysis of variance (ANOVA) and Duncan’s multiple range test (DMRT). After detecting a significant effect with ANOVA, DMRT was used as a post hoc test to identify which specific group means differ from each other. 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, show the distinctive characteristics of tropical peat ecosystems, which are dominated by organic matter and saturated water conditions. A water content of 38.48% indicates high water retention capacity, which is 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 value of 4.87 indicates acidic soil reaction, which is commonly found in peatlands due to the accumulation of organic acids such as humic and fulvic acids from vegetation decomposition. Soils with a pH below 5 usually have limited availability of certain macro nutrients 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 due to humification processes that occur under anaerobic conditions. Organic carbon plays a major role in cation exchange capacity and water retention, but it can also bind nutrients so that not all of them are immediately available to plants (Prekop et al., 2023).

Table 1. Natural chemical properties of peatlands in Nagari Sunur, Nan Sabaris, Padang Pariaman, Indonesia.

Analysis	Value
Water content (%)	38.48
pH	4.87
Organic C (%)	14.50
Total N (%)	3.25
Total P (%)	0.04
Total K (%)	0.03
Fe (ppm)	12.30

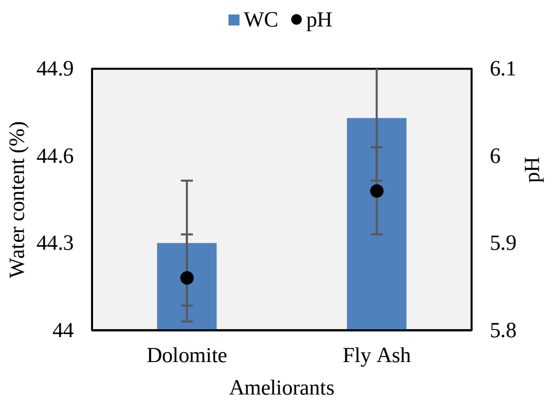
Cu (ppm)	0.93
Zn (ppm)	0.85

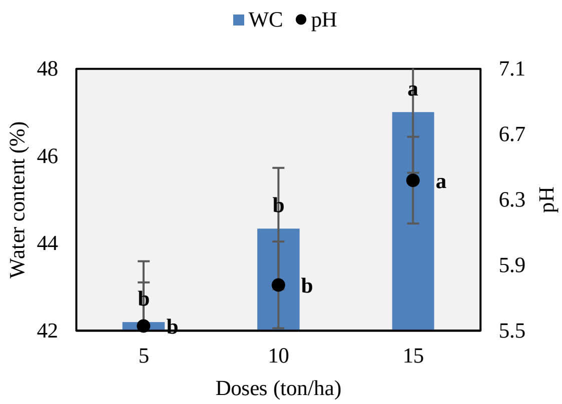
Total N of 3.25% is very high compared to ordinary mineral soils. However, in peat soils, most of the nitrogen is in the form of complex organic compounds, so it must first undergo mineralization to be available to plants. The rate of mineralization is greatly influenced by aeration, temperature, and soil pH (D. 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).

Iron (Fe) levels of 12.30 ppm indicate moderate Fe content. In acidic soil conditions, Fe tends to be more soluble and available. However, under reductive conditions due to water saturation, Fe can change its valence form and increase the concentration of dissolved Fe, 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 experience microelement deficiencies because these elements are strongly bound by organic compounds and low mineral sources. 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 of peatlands lie in acidity, nutrient imbalance, and the dominance of slow-release organic nutrients.

Modification of peatlands 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 (Fig. 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 (Fig. 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_2O, which can neutralize H^+ ions in acidic soils (Bennehalli et al., 2025). These base contents play a role in neutralizing the high humic and fulvic acids in peat soil, thereby increasing the pH and water stability of the soil (Wang et al., 2025). Meanwhile, the main effect of the ameliorant dose is significant on pH and water content of peatland (Fig. 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%. This 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 H^+ and Al^{3+} ions in the adsorption complex (Bennehalli et al., 2025). High ameliorant doses contributed to an increase in base saturation and improved the chemical conditions of peat soil.





(A) **(B)**

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

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 and increase aggregation, resulting in increased microporosity and soil water retention capacity (Utkarsh & Jain, 2024). In addition, fly ash has a fine texture and acts as a soil structure-forming agent that is more reactive to organic matter in peat soil (Alterary & 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 provides a more significant increase in pH compared to dolomite. Fly ash can increase the pH of peat soil faster than dolomite due to its more reactive base metal and silicate content. However, the relative effectiveness between types of soil conditioners also depends on the initial characteristics of the peat soil, including the level of decomposition, ash content, and organic acidity (Säurich et al., 2019). Fly ash provides slightly higher results than dolomite, while a dose of 15 tons/ha is the most effective application rate in improving the physical and chemical properties of the soil. 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 needs to be balanced with monitoring of potential heavy metal content so as not to cause long-term environmental impacts (Y. Chen et al., 2024).

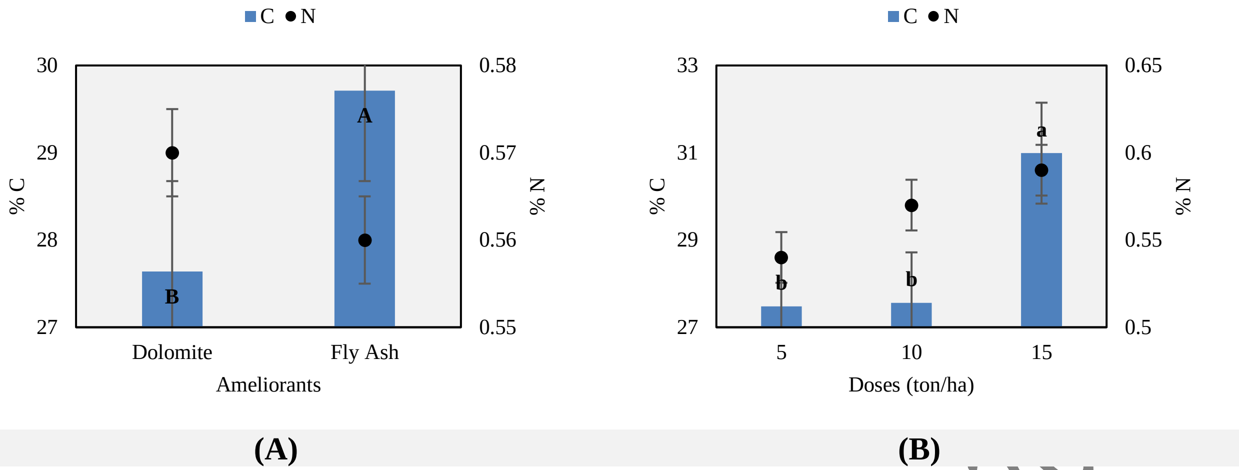
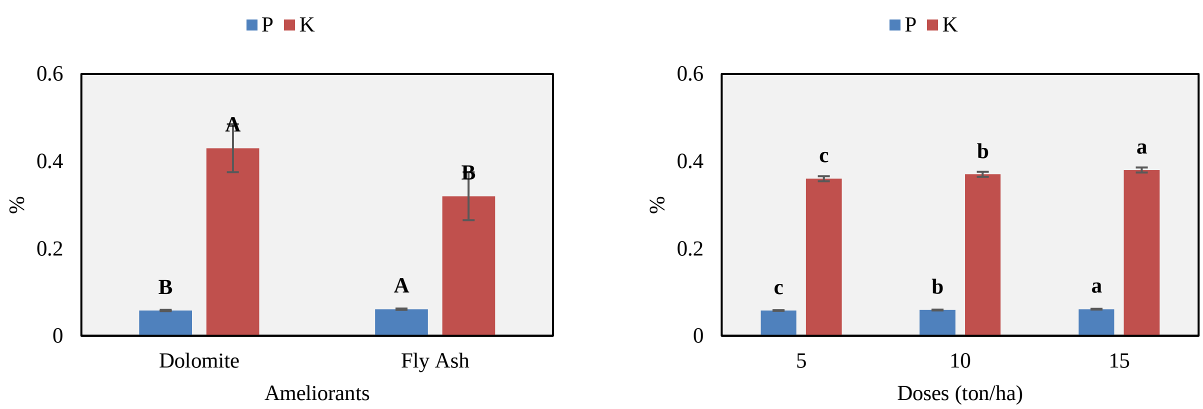


Figure 2. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on organic C and total N of peatland.

The main effect of the type of ameliorant is significant on organic C of peatland and not significant on total N of peatland (Fig. 2A). The use of fly ash produces a higher organic C content (29.71%) compared to dolomite (27.64%), while the total N content is relatively similar (0.56% - 0.57%). The increase in organic C in fly 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 functions primarily as a source of base cations (Ca^{2+} and Mg^{2+}) that increase 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 through acidity control and increased 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 to preserve 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 (Fig. 2B). In terms of dosage, increasing the ameliorant from 5 tons/ha 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%. This increase indicates that amelioration at high doses improves the biogeochemical conditions of the soil that support the accumulation of organic matter. Higher doses accelerate the formation of organic-mineral complexes and reduce the activity of decomposer microbes, which are too intense due to high acidity (Atasoy et al., 2024). This process supports carbon and nitrogen retention through reduced mineralization of peat organic matter. The increase in C and N at high doses indicates an improvement in the soil nitrogen cycle due to improved 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 in the form of stable ammonium due to a decrease in 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 tons/ha is the optimum point for enriching C and N without causing loss of organic matter due to excessive oxidation. Inorganic base amendments can improve peat soil fertility through physical and chemical mechanisms that stabilize nutrients (B et al., 2024).



(A) **(B)**

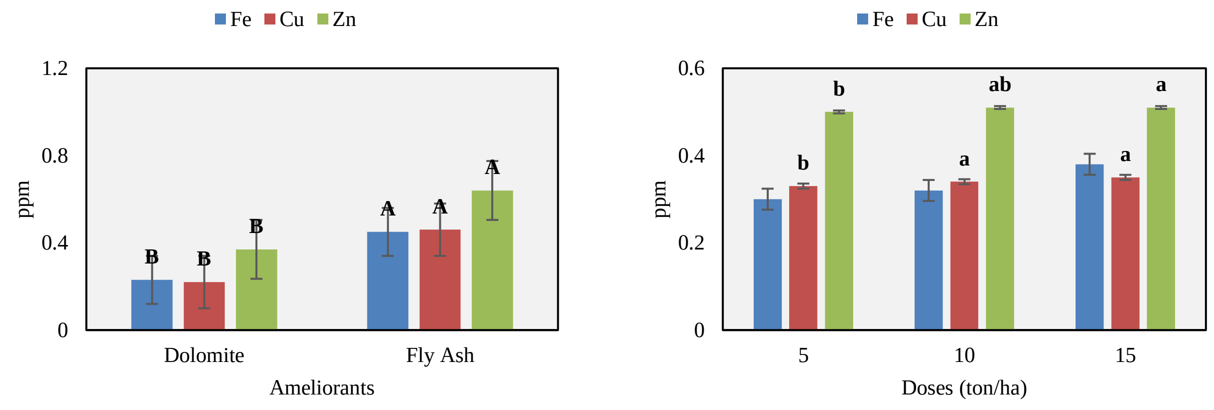
Figure 3. The effect of type (A) and dose (B) of ameliorant (dolomite and fly ash) on total P and K of peatland.

The main effect of the type of ameliorant is significant on total P and K of peatland (Fig. 3A). Fly ash amendments provide a slightly higher total P content (0.061%) than dolomite (0.058%), while 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 [$Ca_3(PO_4)_2$], while 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 effect of increased pH, which improves the solubility of organic P compounds in peat soil. Acidic peat soils generally have P bound by Fe and Al, but the increase in pH due to ameliorants reduces this binding and increases available P (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 H^+ 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 (Fig. 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%. This 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 nutrients from unavailable to soluble forms, mainly through increases in 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 application is necessary to maintain consistent P and K availability due to the high leaching process in peat soils. 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 increasing macro nutrients at the highest dose (15 tons/ha), 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 of peatlands (Fig. 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 & Jonczak, 2025). The main effect of the ameliorant dose is not significant on Fe in peatland, and significant on Cu and Zn of peatland (Fig. 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 the availability of micronutrients through increased soil pH and more active cation exchange reactions (Razzaghi et al., 2021). With the increase in pH due to amelioration, metal elements that were originally bound in an unavailable form become more easily absorbed by plants (Efficiency et al., 2022).

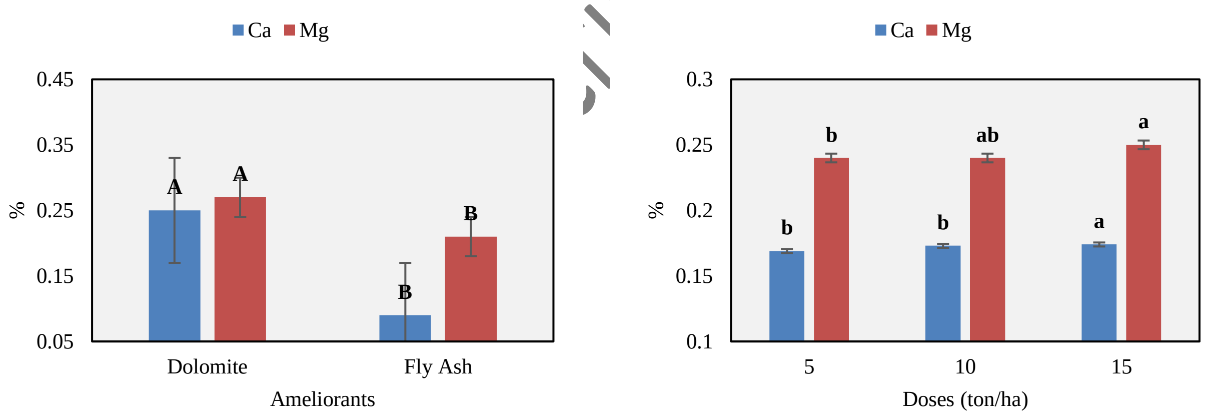
Fly ash contributes more to the increase in micronutrients than dolomite because it contains metal oxides such as Fe_2O_3, CuO, and ZnO that can be dissolved in acidic soil conditions. In addition, the silicate and aluminate components in fly ash play a role in increasing cation exchange capacity (CEC) so that micronutrients become 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 due to the application of ameliorants has a positive impact on peatland productivity, especially for crops that require sufficient 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 so as not to cause heavy metal accumulation beyond the threshold that can cause toxicity to plants and the environment. The application of soil amendments, particularly fly ash at optimal doses (10 and 15 tons/ha), is effective in increasing 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).



(A) **(B)**

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

The main effect of the type of ameliorant is significant on Ca and Mg of peatlands (Fig. 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, while in fly ash, it is 0.09% and 0.21%. 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 has a direct effect on increasing Ca and Mg levels in the soil. The data show that the use of dolomite contributes more to increasing soil Ca than fly ash. Conversely, fly ash also plays a role in increasing Mg, although in slightly lower amounts than dolomite. Fly ash contains several metal oxides, such as CaO and MgO, but with lower solubility than dolomite (Jadaa, 2024).

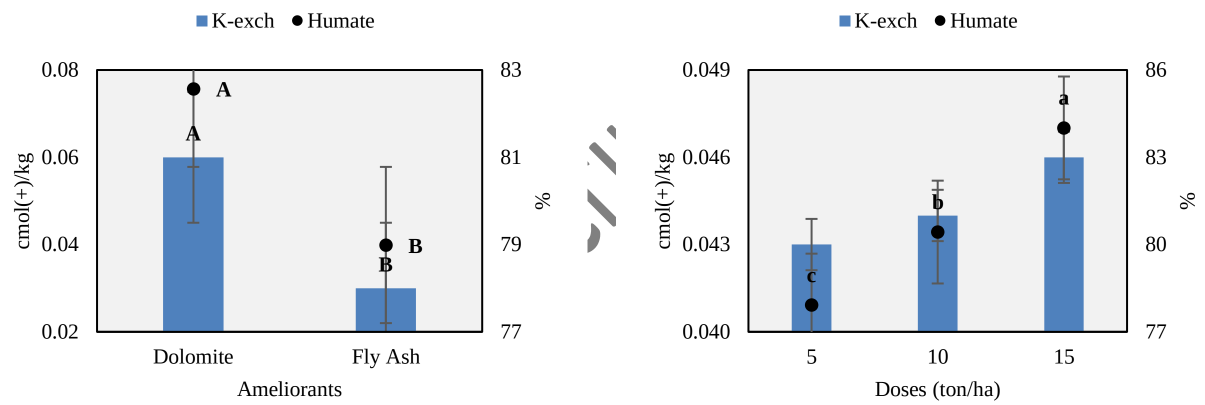


(A) **(B)**

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

The main effect of the ameliorant dose is not significant on Ca and Mg of peatland (Fig. 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 have the potential to increase soil pH and Ca-Mg availability more quickly, while fly ash with silicate content can play a role in improving soil structure and reducing 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 the physical and chemical properties of the soil. The use of soil conditioners must be tailored to the specific needs of the soil and plants, while also considering economic efficiency and environmental sustainability (Corato et al., 2024).



(A) (B)

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

The main effect of the type of ameliorant is significant on K-exch and humate of peatlands (Fig. 6A). Peatlands have low exchangeable potassium (K-exch) and high organic matter content, but 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 through increased base saturation and stabilization of organic matter. Dolomite produced a K-exch of 0.06 cmol(+)/kg and humate 82.57%, while fly ash showed lower values of 0.03 cmol(+)/kg and 78.9%, respectively.

This indicates that dolomite is more effective in increasing cation exchange capacity and humification of 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 & 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 through the formation of ionic complexes with carboxyl and phenolate groups from organic acids. Meanwhile, fly ash also contributes to humate formation through its alkalinity effect and the addition of silica minerals that strengthen organic matter aggregation, but the intensity of 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 (Fig. 6B). Increasing the ameliorant dose from 5, 10, and 15 tons/ha showed an upward trend in K-exch from 0.043 cmol(+)/kg to 0.046 cmol(+)/kg, 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 shows higher effectiveness than fly ash in increasing the K-exch and humate values of peat soil, both at low and high doses. However, fly ash still has the potential to be used as a supporting soil conditioner because its silica and mineral content can improve soil structure and prolong the amelioration effect. Dolomite and fly ash have the potential to provide a synergistic effect on increasing the chemical fertility of peat soil and stabilizing long-term organic carbon (Pramudya et al., 2025).

CONCLUSIONS

The effect of the type of soil ameliorant did not interact significantly with the dose of soil conditioner on 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 tons/ha significantly affects the increase in pH, moisture content, organic carbon, and macro nutrients (P and K). Dolomite and fly ash at an optimal dose of 15 tons/ha 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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