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Amelioration's Effects on Soil Chemical Properties in Maize Cultivation in Dryland Aceh, Indonesia

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ABSTRACT

Background: Amelioration is the technique of adding amendments to sub-optimal drylands to improve their chemical quality. The effectiveness of this amendment depends on the type and dosage of the amendment.

Methods: This pot experiment was carried out using a randomized block design (RBD) in 3 replications. Treatment of amendment materials (A) which consists of 8 (eight) treatments, namely: A_0 (no amendment); A_1 (biochar 20 t ha^{-1}); A_2 (compost 20 t ha^{-1}); A_3 ($CaCO_3$ 4 t ha^{-1}); A_4 (SP-36 fertilizer 4 t ha^{-1}); A_5 (biochar 10 t ha^{-1} + $CaCO_3$ 4 t ha^{-1}); A_6 (compost 10 t ha^{-1} + $CaCO_3$ 4 t ha^{-1}); and A_7 (biochar 10 t ha^{-1} + compost 10 t ha^{-1}). The top soils (0-20 cm) were used in the experiment taken from three soil orders of sub-optimal dryland of Aceh Besar Regency, Aceh (Indonesia), including Andisols, Inceptisols and Ultisols.

Result: Providing amendments affects several soil chemical parameters in the drylands of Aceh and this effect depends on the type of ameliorant material and the dose applied as well as the soil order. By applying amendments, soils with a slightly acidic pH could turn slightly alkaline, resulting in an increase in available P, K and cation exchange capacity (CEC) of dryland soils.

Key words: Soil amendments, Soil chemical properties, Sub-optimal dryland.

INTRODUCTION

Additionally, dryland areas offer enormous potential for development in agriculture, involving food crops, horticulture, plantations and animal husbandry. This is because its potential is quite large, so it has the potential to support efforts to strengthen world food security, especially in Indonesia and currently, the development of dryland agriculture has become a strategic choice. Indonesia has a dryland characterized by a tropical climate spread throughout the archipelago. On the island of Sumatra, this dryland is spread from Aceh Province to Lampung Province which is part of a hill system known as "Bukit Barisan". In contrast to most drylands in other parts of the world, this typology of tropical dryland has its characteristics (Sufardi *et al*., 2023). The potential for dryland suitable for crops is also quite extensive, namely around 20.5 million hectares.

Several studies have shown that these tropical drylands generally have low levels of soil fertility (McLeod *et al*., 2021, Mustaqimah *et al*., 2022). The composition of clay minerals is generally dominated by the 1:1 type and Fe and Al oxide-hydroxide fractions (Apriani *et al*., 2019, Sufardi *et al*., 2021) as well as low C or soil organic matter content (Sufardi *et al*., 2022) and contains low N (Sufardi *et al*., 2023). This condition is further exacerbated by the limited use of organic amendments or organic fertilizers, especially for annual crops. The productivity of dryland is currently on average still relatively low or not yet optimal, but this condition also depends on the soil order so it has different problems. The development of agriculture on dryland for food crops needs to be supported by various technological innovations.

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Factors that need to be considered in increasing corn production in sub-optimal dryland are that apart from choosing adaptive corn varieties and fertilizing, we can also apply amendments to improve soil quality. The type and dosage of amendments will determine their effectiveness in raising crop yields and soil quality, especially if there are variations in soil order due to different soil properties and characteristics (McLeod *et al*., 2021). The three soil orders known as Inceptisols, Ultisols and Andisols are frequently found in dryland agricultural areas in Indonesia, including in Aceh Province. These soils are frequently deficient in organic matter, have an acidic to slightly acidic chemical reaction (pH 4.5-6.5) and are not as fertile as other soils. As a result, plant growth can often be hindered by these conditions. Especially in the Ultisols order, Al poisoning is also a frequent problem, including low organic matter and CEC content and base saturation (Arabia and Fuadi, 2020). In the Andisols order, although physically this soil is better than Ultisols and Inceptisols, there is one problem that is most prominent in this soil, namely the high level of P fixation because the soil composition is dominated by allophane and imogolite minerals (Arifin *et al*., 2022). This allophane mineral will react to form a chelate complex with organic material so that the material is protected from attack by decomposing microbes and remains accumulated in the soil.

To overcome this problem, the soils in tropical drylands require amelioration, for example by applying organic materials, lime and phosphate fertilizer. The use of organic amendments can increase the resistance of plants to nutrient stress in drylands (Bukhari *et al*., 2022). In this experiment, three soil types in suboptimal dryland in Aceh, Indonesia, are examined to see how effectively different amendments work to improve important soil chemical properties under maize plantation.

MATERIALS AND METHODS

This research was carried out in the Greenhouse of the Faculty of Agriculture, Syiah Kuala University, which is located at the Darussalam Experimental Station, Banda Aceh, Indonesia with geographical coordinates: 05°17′05.2″N and 95°28′13.1″E. The experiment was carried out for six months starting from July 2019-January 2020. The topsoil (0-20 cm) used for the experiment came from three soil orders found in sub-optimal dryland in Aceh Besar Regency, Aceh Province which includes Andisols Saree (05°27′03.2″N; 95°43′45.2″E), Inceptisols Cucum (05°18′18.37″N; 95°32′48.04″E) and Ultisols Jantho, (05°16′58.41″N; 95°37′51.82″E). The amendment materials used consisted of compost of Thitonia, rice husk biochar, $CaCO_3$ and SP-36 fertilizer. The basic fertilizer used for corn growth is the fertilizer of Nitrofoska (which contains 15% N, 15% P_2O_5 and 15% K_2O).

Experimental design

A bifactorial randomized block design (RBD) was used in this pot experiment study. Applying amendment material (A) is the first factor. It has eight treatments of giving soil amendment: A_0 (no amendment), A_1 (biochar 20 t ha^{-1}), A_2 (compost 20 t ha^{-1}) A_3 ($CaCO_3$ 4 t ha^{-1}), A_4 (SP-36 fertilizer 4 t ha^{-1}), A_5 (biochar 10 t ha^{-1} combine with $CaCO_3$ 4 t ha^{-1}), A_6 (compost 10 t ha^{-1} combine with $CaCO_3$ 4 t ha^{-1}) and A_7 (biochar 10 t ha^{-1} combine with compost 10 t ha^{-1}). This experiment used three soil orders, namely: Andisols (Typic Hapoludands), Inceptisols (Oxic Hapludepts) and Ultisols (Typic Kanhapludults). Before using it in experiments, the soil taken from each location was first air-dried for two weeks, then crushed and passed through a 2-cm sieve. This soil is then put into a plastic pot of as much as 10 kg equivalent to absolute dry weight. Before planting the corn seeds, the soil is given amendment material according to the type and dose of treatment, then NPK Nitroposka (15-15-15) fertilizer equivalent to 400 kg ha^{-1} or 3.60 g per pot. Soil samples for chemical property analysis were taken after corn harvest (95 days after planting). Each pot's soil sample was taken out, left to air dry for a week and then sieved through a 1-mm mesh. The chemical properties of the soil analyzed are pH (H_2O) using the electrometric method, utilizing the Walkey and Black method for C-organic, the Kjeldahl method for total N and the Bray I method for available P, using the 1*N* NH_4OAc pH 7 technique to determine available K or exchangeable K and CEC.

Data analysis

Analysis of variance (F test) at significance level P (0.05) was used to assess the experimental data. If a significant effect was found, the Honestly Significance Different Test (HSD) at P (0.05) followed. Soil chemical analysis assessment criteria use standards from SRC (2005).

RESULTS AND DISCUSSION

Preliminary soil chemical properties

As can be seen in Table 1, soils of the Andisols have slightly acidic pH, high levels of organic C, moderate total N and high CEC, but also have very low available P and exchangeable K. The soil pH in Inceptisols is acidic which is accompanied by low levels of organic C, total N, available P, exchangeable K and CEC. Furthermore, the Ultisols showed a slightly acidic pH, very low organic C, low total N, very low available P, moderate CEC and low exchangeable K. This initial soil analysis data shows that there are two types of soil chemical constraints found in Andisols, namely low available P and low exchangeable K. In Inceptisols and Ultisols, it turns out that these two soil orders have more problems than the problems in Andisols. The problem is an acidic soil reaction, low to very low total C and N as well as available P and exchangeable K content and low soil CEC.

Table 1: Chemical properties of three orders of dryland soil before the experiment.

Soil chemical	Andisols		Inceptisols		Ultisols	
characteristics	Value	Criteria	Value	Criteria	Value	Criteria
pH H_2O	5.56±0.02	Slightly acid	5.45±0.12	Acid	5.97±0.41	Slightly acid
Organic C (%)	3.95±0.01	High	1.38±0.02	Low	0.53±0.05	Very low
Total N (%)	0.32±0.02	Medium	0.08±0.03	Very low	0.12±0.02	Low
Available P (mg kg^{-1})	2.30±0.12	Very low	2.50±0.16	Very low	4.85±1.36	Very low
Exchangeable K (cmol kg^{-1})	0.27±0.02	Low	0.12±0.03	Very low	0.24±0.02	Low
CEC (cmol kg^{-1})	18.6±1.34	Medium	11.2±1.24	Low	15.4±1.19	Low

Changes in soil chemical properties

Soil acidity (pH)

One chemical indicator that is crucial for plant growth, especially corn, is soil reaction (pH). The three soil orders from Aceh dryland after the use of soil amendments had a significant effect on the increase of soil pH (H_2O) of Andisols, Inceptisols and Ultisols. After the application of various types of amendment materials, it turns out that the pH of H_2O is above pH 5.5 (.....line) and this is found in all three soil orders (Fig 1). Based on this experiment, it can be said that the application of biochar amendments, compost, $CaCO_3$ lime and phosphate fertilizer can improve the chemical quality of the soil as indicated by an increase in soil pH from acid to neutral to slightly alkaline. The highest increase in H_2O pH in Andisols was achieved in the A_3 treatment (application of $CaCO_3$ dose of 4 t ha^{-1}). The same results were also found in the soils of the Inceptisols and Ultisols orders. $CaCO_3$ lime is a type of carbonate compound that is often used to improve soil acidity, especially to reduce the solubility of Al which is often found in tropical acid mineral soils (Sanchez, 2019). An increase in pH above pH 5.5 causes exchangeable Al to become inactive because it has changed to form the compound $Al(OH)_3^0$ which does not dissolve or precipitate, thereby reducing the solubility of H^+ ions in the soil solution (Gillespie *et al*., 2021). As a result, the soil pH value increases.

Almost all of the amendment materials used can increase the pH of soil H_2O. Biochar is a material containing high C resulting from the pyrolysis process which has a lot of pore space so that it can bond H ions in soil solution so that they do not dissolve (Solaiman and Anawar, 2015). Compost is an organic amendment that has functional groups that can bind to Al^{3+} and H^+ cations which cause acidity, thereby reducing soil acidity. The phosphate fertilizer will dissolve to produce phosphate ions in the form of $H_2PO_4^-$ and HPO_4=. These ions will balance the positive charge on the surface of soil colloids so that they can increase the pH and are also able to release P from Al and Fe as well as from clay minerals (Sufardi *et al*., 2021).

Soil carbon and nitrogen

Fig 2 shows that after applying amendments, the soil SOC content of Ultisols and Inceptisols was beyond the low limit (.....line). The types and doses of amendments that

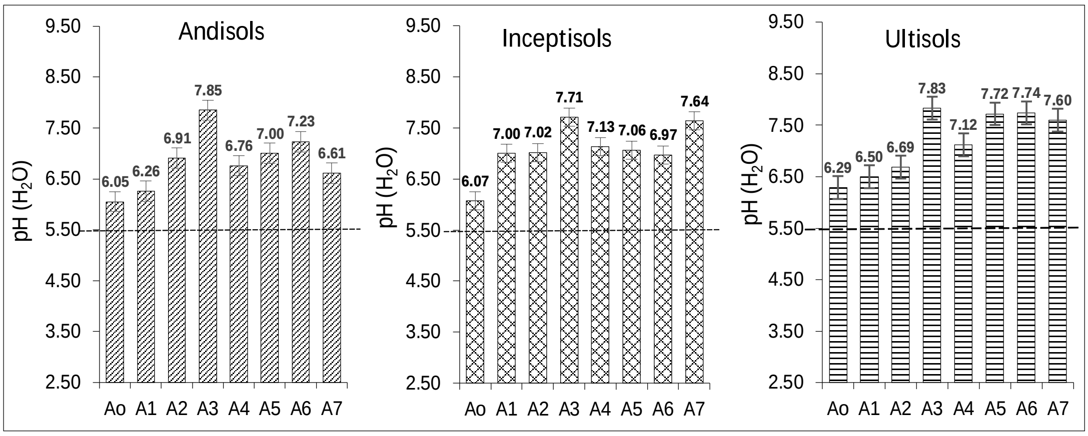

Fig 1: The pH H_2O values in three soil orders after corn planting due to the influence of amendments.

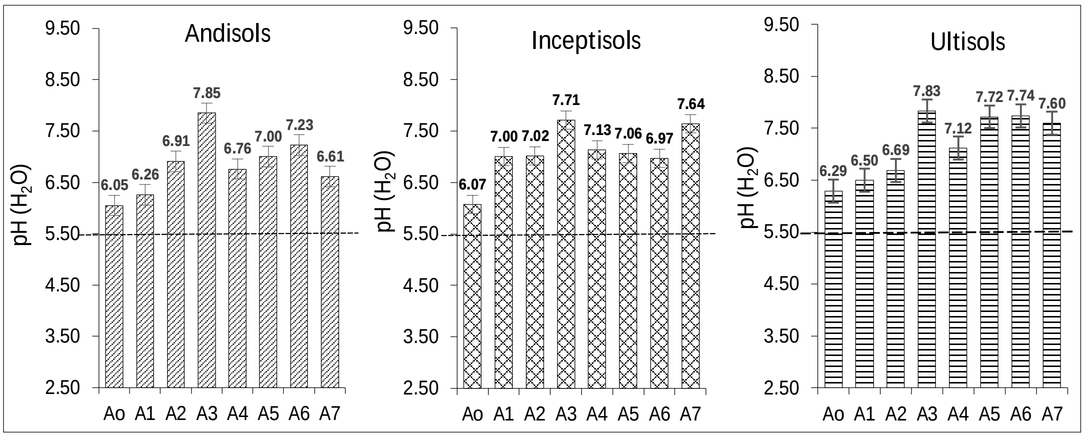

Fig 2: SOC content in three soil orders after corn planting due to the influence of amendments.

provide soil SOC content in the three soil orders in the sub-optimal dryland of Aceh were obtained in treatment A_7 (Biochar 10 t ha^{-1} + Compost 10 t ha^{-1}) and the lowest in treatment Ao (without amendment). Likewise, the best effect on total soil N content was also obtained in treatment A_7 and the lowest in control or without amendment (Fig 3). From the three soil orders, it can also be seen that the total SOC and N content of the soil in Andisols Saree is higher than in Inceptisols Cucum and Ultisols Jantho. This is an Andisols soil cicir which is formed from volcanic parent material that is dominated by Alofan and Imogolite minerals (Apriani *et al*., 2019, Sufardi *et al*., 2021).

The increase in SOC due to the application of compost and biochar is because these two materials contain relatively high levels of C, thereby increasing C reserves in the soil (Yunilasari *et al*., 2020). This carbon in the soil provides many functions. Palansooriya *et al*. (2019) stated that soil organic C is a source of energy for soil microorganisms so it can increase soil microbial activity. This microbial activity can cause various enzymatic reactions to occur which can stimulate the transformation of the nutrients N, P and K, solubilization of P and fixation of N. As the C content or soil organic matter increases, the soil N content also increases. N as a plant macronutrient is mostly supplied through the decomposition of organic matter and N fixation (Marschner and Rengel, 2023).

Available P and exchangeable K

The available P and exchangeable K content of the soil in Aceh dryland was affected by the use of various types and doses of amendment materials. The application of compost, biochar, $CaCO_3$ and SP-36 amendments can increase the available P content in Andisols, Inceptisols and Ultisols, however. The increase in available P is very dependent on the type and combination of amendments. The highest increase in available P occurred when applying SP-36 fertilizer 4 t ha^{-1} (A_4). In Andisols, available P increased from very low to high criteria (SRC, 2005). This increase in available P is very drastic because the Andisols are characterized by very high P fixation or >92% (Soil Survey Staff, 2014) which makes it difficult to dissolve P because of the high affinity and capacity adsorption by allophane minerals (Sufardi *et al*., 2013). A dose of 4 t ha^{-1} of SP-36 fertilizer, which contains 36% P_2O_5, has been shown to raise P in Andisols. This happens because all the surfaces of the adsorption sites have been saturated with phosphate anions ($H_2PO_4^=$) and the positive charge is reduced (Spohn *et al*., 2022).

In Inceptisols and Ultisols, the increase in available P is even higher from very low to very high. In Ultisols it was also seen that soil available P decreased with the application of $CaCO_3$ as much as 4 t ha^{-1} (Fig 4). This is thought to be because when $CaCO_3$ lime is given in high doses it can react with phosphate anions to form Ca-P precipitation. Sufardi *et al*. (2013) stated that the provision of amendments can increase the availability of P in the soil. The results can also show that the application of amendments, especially organic types such as compost and biochar or a combination, can increase soil K availability. Preliminary analysis shows that the exchangeable K content of the soil is low and apparently with amendments it can be increased from low to medium. The highest increase was obtained due to the application of Biochar 10 t ha^{-1} + Compost 10 t ha^{-1} (A_7). As can be seen in Fig 5. Based on this experiment, it can be said that the problem of P and K nutrient deficiencies in sub-optimal drylands in Aceh can be overcome by providing appropriate amendments like biochar as reported by Odugbenro *et al*. (2019). High P fixation in most tropical drylands can be managed by adding organic amendments or by applying phosphate because these two materials enhance soil quality in a favorable way (Bukhari *et al*., 2022). Organic acids from organic amendments such as compost and biochar can dissolve soil P from binding by clay minerals so that more P is available (Ippolito *et al*., 2012). Likewise with the availability of soil K. Soil potassium is generally sourced from the primary mineral feldspar or the secondary minerals illite and mica (Arifin *et al*., 2022) and it can dissolve K from minerals or increase the solubility from the colloidal surface of the soil.

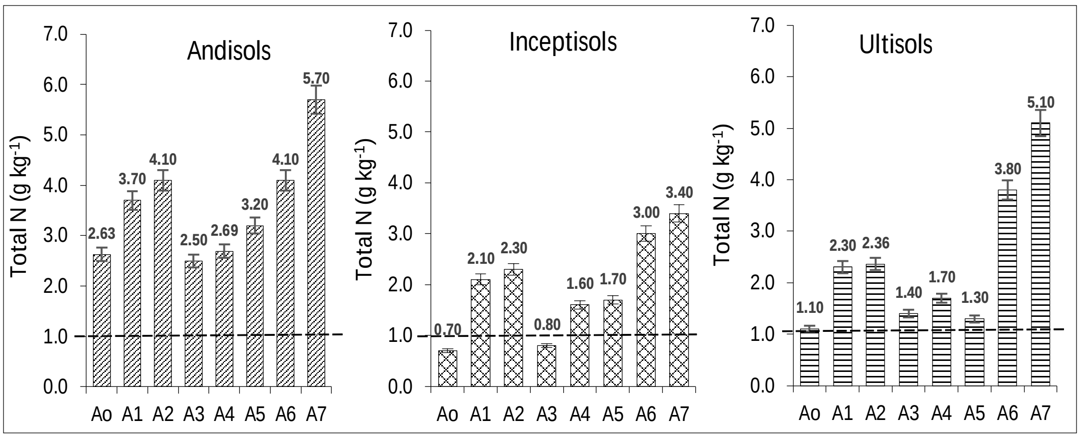

Fig 3: N total content in three soil orders after corn planting due to the influence of amendments.

Cation exchange capacity (CEC)

In Andisols, Inceptisols and Ultisols, adding various amendments significantly increased soil CEC. According to Table 2, the CEC of the Andisols increased from 20 to 25.6 cmol kg^{-1}, while the Ultisols and Inceptisols had increased from 18.6 to 27.2 cmol kg^{-1} and 11.6 to 25.6 cmol kg^{-1}, respectively. The application of Biochar 10 t ha^{-1} + Compost 10 t ha^{-1} (A_7) resulted in the largest increase in soil CEC. The experiment also shows that organic amendments have relatively better effects compared to inorganic $CaCO_3$ amendments. This is related to changes in the soil colloid system because organic amendments increase the amount of negative charge in soil colloids so that the CEC also increases (Atmaja *et al*., 2017). Even though $CaCO_3$ is superior in increasing soil pH, the contribution of negative charges is low because this material tends to increase positive charges and other soil properties (Ghedabna *et al*., 2023, Sufardi *et al*., 2020).

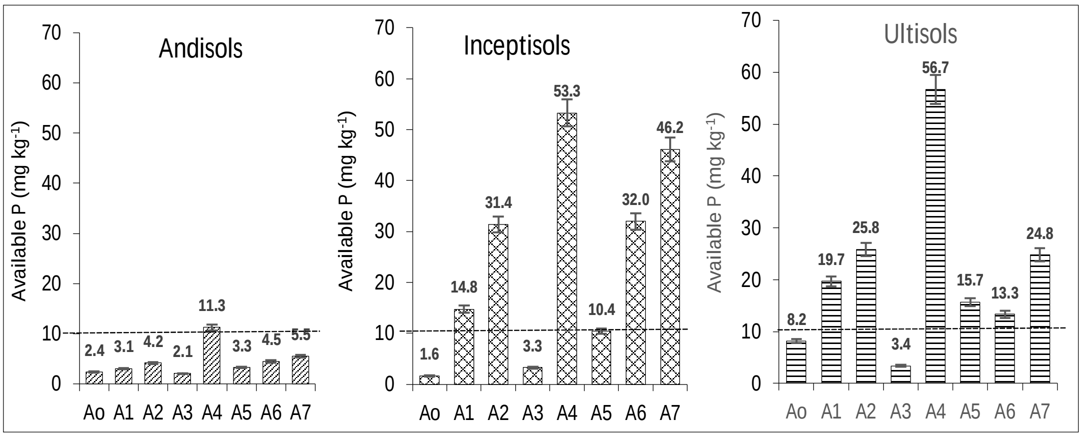

Fig 4: Soil available P content in three soil orders after corn planting due to the influence of amendments.

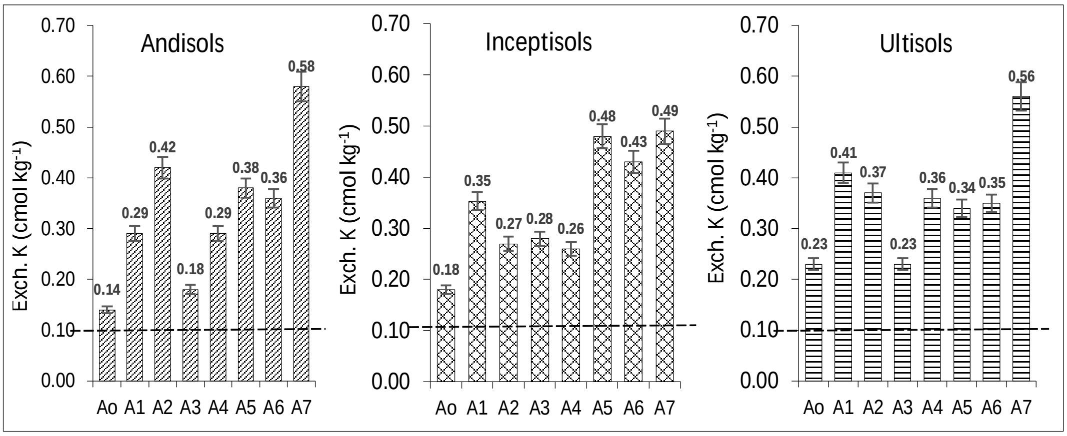

Fig 5: Exchangeable K content in three soil orders after corn planting due to the influence of amendments.

Table 2: Effects of amendments on soil CEC of three soil orders in the dryland of Aceh.

Soil amendment application	Andisols	Inceptisols	Ultisols
A_0 (no amendment)	20.0 ab	11.6 b	18.6 a
A_1 (Biochar 20 t ha^{-1})	22.6 b	29.8 c	24.0 ab
A_2 (Compost 20 t ha^{-1})	24.0 c	28.6 c	23.4 ab
A_3 ($CaCO_3$ 4 t ha^{-1})	18.4 a	18.4 a	22.6 ab
A_4 (SP-36 4 t ha^{-1})	22.0 b	26.4 c	24.6 ab
A_5 (Biochar 10 t ha^{-1} + $CaCO_3$ 4 t ha^{-1})	22.6 b	27.4 c	22.8 ab
A_6 (Compost 10 t ha^{-1} + $CaCO_3$ 4 t ha^{-1})	23.2 bc	30.4 c	23.0 ab
A_7 (Biochar 10 t ha^{-1} + Compost 10 t ha^{-1})	25.6 c	29.8 c	27.2 b

Numbers followed by the same letter in the same column are not significantly different according to the HSD test (0.05).

Noor *et al*. (2020) state that compost can increase soil CEC because it can improve soil chemical properties, such as soil pH and dissolve basic cations (Ca, Mg, K). This increase in CEC will increase nutrient availability in plants. The application of organic amendments is very important for improving soil fertility (Bukhari *et al*., 2022) and able to improve the availability of N soils and plant growth as reported by Latifah *et al*. (2019); Shukla *et al*. (2024).

CONCLUSION

Providing compost, biochar, $CaCO_3$ and phosphate (SP-36) amendments can improve soil chemical quality in sub-optimal dryland in Aceh. The capacity of amendments to improve soil chemistry depends on the type of ameliorant material and application dose as well as soil order. The use of amendments can raise the pH of soil H_2O from acidic to slightly alkaline, as well as increase total C and N, which leads to an increase in available P, exchangeable K and soil CEC of Andisols, Inceptisol and Ultisols in the drylands of Aceh.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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