Available at : https://ejournal.unib.ac.id/index.php/terrajournal ISSN 2621-0207
DOI : https://doi.org/10.31186/terra.8.2.65-70

Effects of *Azolla pinnata* Compost and Carbonate Lime ($CaCO_3$) on Soil Chemical Properties, Nitrogen Uptake, and Yield Components of Sweet Corn Grown in Ultisols

Febri Yunarto[1], Bambang Sulistyo[1*], Hasanudin[1], Esi Asyani Listyowati[2]

[1]*Department of Soil Science, Faculty of Agriculture, University of Bengkulu, Indonesia*
[2]*Department of Agribusiness, Faculty of Agriculture, Islamic University "45" Bekasi, Indonesia*

Corresponding Author : bsulistyo@unib.ac.id

ABSTRACT

Ultisols, covering approximately 705,151 hectares in Bengkulu, represent a marginal soil type with considerable agricultural potential. However, they are limited by low nutrient availability, low pH, low organic carbon, and high concentrations of exchangeable aluminum (Al) and iron (Fe). These constraints significantly affect the growth and productivity of crops such as sweet corn, which is sensitive to acidic conditions and nutrient deficiency. Soil fertility improvement through organic matter application and liming is a promising approach. Azolla, an aquatic fern with high nitrogen content due to its symbiosis with Anabaena azollae, was used in composted form. This study aimed to determine the optimum application rates of Azolla compost and carbonate lime ($CaCO_3$) for improving nitrogen uptake, growth, and yield of sweet corn in Ultisols. The treatments consisted of four Azolla compost levels (0, 5, 10, and 15 tons ha^{-1}) and three lime rates equivalent to neutralizing 0, 1, and 2 units of exchangeable Al. A factorial experiment was arranged in a completely randomized design with three replications. Data were analyzed using analysis of variance (ANOVA), followed by orthogonal polynomial testing. Azolla compost significantly improved soil pH, organic carbon content, stem diameter, plant height, ear weight, biomass (fresh and dry), and nitrogen uptake. Lime application significantly increased soil pH, stem diameter, and plant height. No significant interaction occurred between the two factors. Although positive responses were observed, the yield remained below the potential of the Bonanza F1 variety, likely due to high rainfall and suboptimal treatment levels. These findings support the integration of Azolla compost and lime into soil fertility management practices for sustainable sweet corn production on acidic tropical soils.

Keywords: Azolla, lime, sweet corn, Ultisols

INTRODUCTION

Ultisols are one of the dominant soil orders in Indonesia, covering an estimated area of 45.79 million hectares, or about 25% of the country's total land area. Their distribution is widest in Kalimantan (21.94 million ha), followed by Sumatra (9.47 million ha), Maluku and Papua (8.86 million ha), Sulawesi (4.30 million ha), Java (1.17 million ha), and East Nusa Tenggara (53,000 ha) (Prasetyo & Suriadikarta, 2006). These soils occur across various topographies, from flat lowlands to steep mountainous regions.

In Bengkulu Province, Ultisols cover approximately 705,151 hectares, making them the second most extensive soil order after Inceptisols (Geospatial Information Agency, 2019). Ultisols in this region are characterized by deep profiles, acidic pH (very acidic to slightly acidic), fine to medium texture, good drainage, steep slopes (1–>40%), and low fertility due to poor organic matter content and high concentrations of exchangeable aluminum (Al) and iron (Fe) (Mulyani *et al*., 2010).

These conditions hinder the growth and productivity of crops such as maize, which is highly sensitive to acidic soil, poor aeration, and nutrient deficiency (Andriani *et al*., 2013). Therefore, proper soil management is essential to improve physical and chemical properties for optimal crop development (Pandao *et al*., 2024).

One promising organic amendment is *Azolla*, a nitrogen-rich aquatic fern capable of biological nitrogen fixation through its symbiosis with *Anabaena azollae*. *Azolla* compost is an affordable and locally available source of organic nitrogen and has been shown to reduce the need for synthetic fertilizers by up to 100 kg urea ha^{-1} under favorable conditions (Kusumo, 2008).

In addition to organic matter, lime ($CaCO_3$) application is necessary to neutralize soil acidity, increase pH, and improve nutrient availability (Regasa *et al*., 2025). In acidic soils, essential nutrients such as phosphorus are often immobilized by Al and Fe compounds (Hardjowigeno, 2002; Winarso, 2005). Lime works by replacing exchangeable H^+ ions with Ca^{2+}, thereby raising soil pH (Sime, 2001). Lime application significantly increased soil pH in Inceptisols, although it did not significantly enhance total N, organic C, or available P (Auler *et al*., 2019 ; Tampubolon *et al*.,2018).

Despite these findings, limited studies have examined the combined effects of *Azolla* compost and lime on soil improvement and maize performance in Ultisols. This research aims to assess the potential of *Azolla* compost and carbonate lime in improving soil chemical properties, nitrogen uptake, and the growth and yield components of maize cultivated on Ultisols.

MATERIALS AND METHODS

Time and location of research

This research was conducted from October 2021 to February 2022 at the Agricultural Wire House, Faculty of Agriculture, University of Bengkulu. The soil used in the experiment—classified as Ultisols—was collected from an adjacent field site near the wire house. All soil and plant sample analyses were performed at the Soil Science Laboratory of the same faculty.

Tools and materials

The tools used in this study included a 0.5 cm soil sieve, a hoe, a measuring ruler, a digital analytical balance, a 10-kg mechanical scale, 1.5 L plastic bottles, a laboratory oven, and general laboratory equipment. The materials consisted of Bonanza F1 sweet corn seeds, composted *Azolla pinnata*, carbonate lime ($CaCO_3$), Ultisols soil as a planting medium, polybags, and fertilizers including urea, SP-36, and KCl. A soil insecticide (furan) was also used to prevent pest interference.

Experimental design

The experiment was arranged in a two-factor Completely Randomized Design (CRD) with three replications, resulting in 36 experimental units. The first factor was the dosage of *Azolla pinnata* compost, applied at four levels: 0, 5, 10, and 15 tons ha^{-1} . The second factor was the application rate of carbonate lime ($CaCO_3$), equivalent to the neutralization of 0, 1, and 2 units of exchangeable aluminum (Al-dd), corresponding to lime doses of 0, 3.41, and 6.82 tons ha^{-1}, respectively.

Research flowchart

The flow chart below is the steps taken to support the research process that will be made so that research can run more directed and systematic in Figure 1 as follows ;

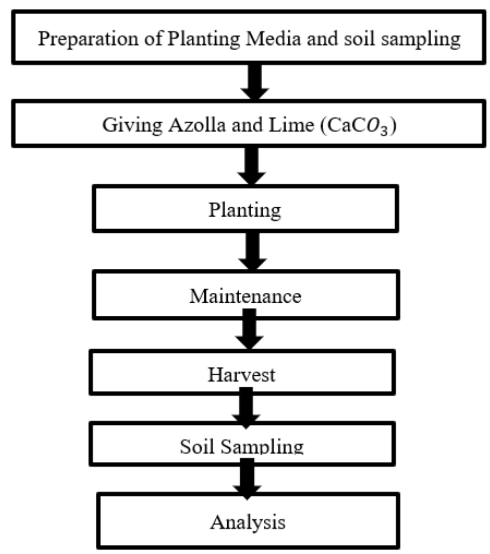


Figure 1. Research flowchart

Research variable

The observed variables were categorized into primary and secondary variables. Primary variables included nitrogen uptake (mg plant^{-1}), soil organic carbon (%), soil pH, rod diameter (cm), plant height (cm), fresh ear weight (g), dry stover weight (g), and husked cob weight (g). Supporting variables included initial soil characteristics (total N, available P and K, organic C, pH), Azolla compost composition (same parameters), and environmental conditions such as rainfall (mm), temperature (°C), and humidity (%).

Data analysis

All collected data were analyzed using analysis of variance (ANOVA) at a 5% significance level to determine the effects of treatments. If significant differences were observed, the means were further examined using orthogonal polynomial tests at the same significance level.

RESULTS AND DISCUSSION

Variant analysis results

The research data collected were analyzed using the *Analysis of Variance* (ANOVA) with the F test at the 5% level. The results of the analysis of variance in *Azolla* and Lime doses as well as their interactions with the observed variables. The summary of the results of the analysis of variance is presented in Table 1.

Table 1. Summary of the results of the analysis of variance

Observation Variable	F-value		
	Azolla dosage	Carbonate lime dose	Interaction
N uptake	6.57*	1.13^{ns}	0.52^{ns}
C-organic	4.41*	1.22^{ns}	0.72^{ns}
Soil pH	6.80*	33.13*	1.77^{ns}
Plant height	7.84*	10.54*	1.34^{ns}
Rod diameter	6.86*	4.42*	0.67^{ns}
Wet stover weight	6.61*	2.51^{ns}	0.58^{ns}
Dry stover weight	3.64*	1.04^{ns}	0.41^{ns}
Cob weight	6.42*	2.59^{ns}	0.64^{ns}

Note : * = significant (P < 0.05) ; ns = non-significant

The results of the analysis of variance showed that the *Azolla* dose had a significant effect on all observed variables. Lime dose significantly affected soil pH, plant height, and rod diameter, but had no significant effect on N, C-organic uptake, wet stover weight, dry stover weight, and cob weight. Meanwhile, the interaction of the *Azolla* dose and Lime dose had no significant effect on all observation variables (Table 1).

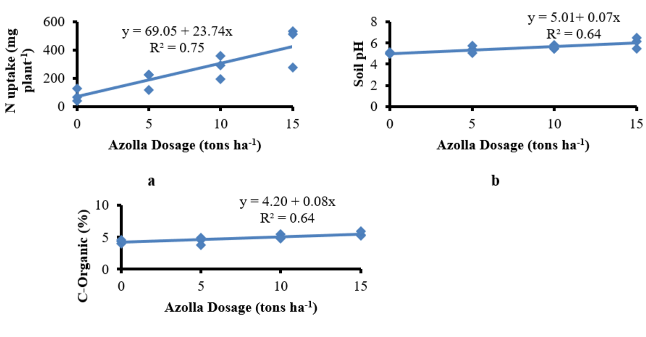


Figure 2. Relationship between Azolla lime dose and N uptake (a), soil pH (b), and C-Organic (c)

High values were obtained Azolla dose of 15 tons ha^{-1} with N uptake of 440.64 mg plant^{-1}. Djuniwati *et al.* (2003) also showed that the application of organic matter combined with inorganic fertilizers can increase the levels and nutrient uptake of N, P, and K of plants, thereby increasing the production of maize. High values were obtained *Azolla* dose of 15 tons ha^{-1} with a soil pH of 6.05. Increased soil pH due to the application of manure given to paddy fields, because the added manure will decompose further/mineralize, releasing minerals in the form of alkaline cations (Ca, Mg, Na, and K), which causes the concentration of OH- ions to increase, resulting in pH up (Bugis, 2011). The high value was obtained at a dose of *Azolla* of 15 tons ha^{-1} with a C-organic of 5.48%. When compared with the control treatment of 4.81%, an increase of 13%. Meanwhile, compared to the initial soil analysis of 2.09%, an increase of 160%. Organic matter or cover litter on land increases C-organic levels, where the higher the organic matter content of a soil, the higher the C-organic content (Kusumawati, 2019 ; de-Torres *et al*., 2021). This means that with every addition of organic matter, the higher the C-organic.

Effect of Azolla compost on corn plants

Azolla dose treatment on rod diameter had a significant effect, which was further based on the orthogonal polynomial test showing a linear equation Y = 0.76 + 0.02x with an R^2 of 0.60 which means that an increase follows each increase of one unit in rod diameter of 0.02 units. (a). *Azolla* dose treatment on plant height had a significant effect, which was then based on the orthogonal polynomial test showing a linear equation Y = 109.02 + 1.76x with an R^2 of 0.70, which means that an increase follows each increase of one unit in plant height of 1.76 units. (b). *Azolla* dose treatment on the weight of the wet stove had a significant effect, which was then based on the orthogonal polynomial test showing a linear equation Y = 39.32 + 3.92x with an R^2 of 0.80, which means that each increase of one unit is followed by the addition of the weight of the wet stove by 3.92 units, presented in (c). *Azolla* dose treatment on dry stover weight had a significant effect, which then based on the orthogonal polynomial test, showed a linear equation Y = 6.24 + 0.70x with R^2 of 0.65, which means that each increase of one unit is followed by an increase in dry stover weight of 0.70 units, presented in (d). *Azolla* dose treatment on the weight of cob cobs had a significant effect, which then based on the orthogonal polynomial test, showed a linear equation Y = 43.19 + 3.40x with an R^2 of 0.81, which means that each increase of one unit is followed by an additional weight of cob of 3.40 units, presented in (e).

High values were obtained *Azolla* dose of 15 tons ha^{-1} with a rod diameter of 1.04 cm. When compared with the control treatment, 0.57 cm increased by 75%. Meanwhile, compared to the description of the plant by 2.0, it decreased by 50%. Safuan & Bahrun (2012) plant growth and production are determined by nutrient-controlled photosynthesis. High values were obtained Azolla dose of 15 tons ha^{-1} with a stem diameter of 132.22 cm. When compared with the control treatment of 93.67 cm, an increase of 41%. Meanwhile, compared to the description of the plant by 220 cm, it decreased by 66%. According to Zubachtirodin & Subandi (2008), plant height is affected by nitrogen administration. The provision of nitrogen can serve to stimulate growth and give a green color to the leaves. The green color of the leaves will help in the metabolic process for plants. High values were obtained *Azolla* dose of 15 tons ha^{-1} with a maximum wet stove weight of 97.00 g. When compared with the control treatment, 23.33 g increased by 315%. Generally, taller plants will have more leaves, larger stem diameters, and higher leaf green color. These variables influence the absorption of light energy for metabolism in plant organs, improving and meeting their needs, thus impacting crop yields (Rahmawati, 2013). So that the weight of the wet stove increases in weight. High values obtained *Azolla* dose of 15 tons ha^{-1} with dry stover weight of 16.87 g. When compared with the control treatment of 3.67 g, an increase of 359%. Guritno (1995) said dry weight reflects nutritional status because plant dry matter depends on photosynthesis and respiration. The highest value was obtained with a dose of *Azolla* of 15 tons ha^{-1} with a weight of 94.44 g of cob. When compared with the control treatment 30 g increased by 215%. Meanwhile, compared to the description of the plant at 467 g, it decreased by 395%. The results of Idris's research (2008) showed that fertilization of organic matter was able to increase the wet weight of cobs with cob and the dry weight of corn kernels compared to conventional fertilization. However, additional fertilizer is needed during generative growth. The research results of Maswada *et al*. (2020) also shows that the application of Azolla extract is an eco-friendly and cost-effective organic fertilizer to reduce more than 30% of urea fertilizer without affecting grain yield of maize plants.

Effect of lime carbonate on soil pH

The lime dose treatment had a significant effect on soil pH, which then based on the orthogonal polynomial test, showed a linear equation Y = 4.68 + 0.24x with an R^2 of 0.92, which means that each increase of one unit is followed by the addition of soil pH of 0.83 units (Figure 4).

High values obtained lime dose of 6.82 tons ha^{-1} with a soil pH of 6.33. When compared with the control treatment of 4.42, an increase of 43%. Meanwhile, compared to the initial soil analysis of 4.72, an increase of 34%. Liming can increase soil pH so that applying lime to acid soils will stimulate the formation of crumb structure, and affect weathering of organic matter, and humus formation (Buckman & Brady, 1964). Agricultural lime ($CaCO_3$), with its neutrality, 75-70% is effective in improving soil chemical properties. According to research by Sulistiyanto *et al*. (2007), soil pH will increase from 4.3 to 4.5 along with increasing lime application.

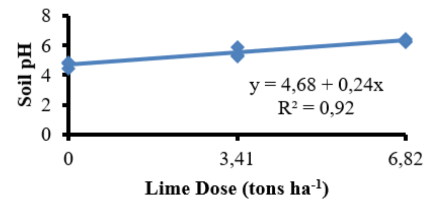
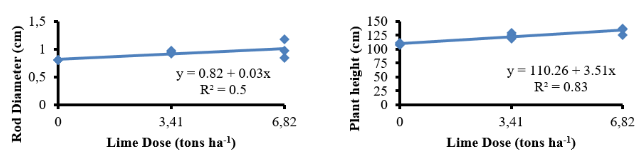


Figure 4. Relationship between Azolla lime dose and soil pH

Effect of lime carbonate on corn plants

The lime dose treatment had a significant effect on stem diameter, which then based on the orthogonal polynomial test showed a linear equation Y = 0.82 + 0.03x with an R^2 of 0.5 which means that each increase of one unit is followed by an increase in the diameter of the stem by 0.1 units. (a). The lime dose treatment had a significant effect on plant height, which then based on the orthogonal polynomial test showed a linear equation Y = 110.26 + 3.51x with an R^2 of 0.83 which means that an increase follows each increase of one unit in plant height of 11.96 units. (b).



a b

Figure 5. Relationship between *Azolla* lime dose and stem diameter (a), and Plant Height (b)

High values obtained lime dose of 6.82 tons ha^{-1} with a stem diameter of 1.00 cm. Applying too much lime to the soil resulted in stunted plants, Mn and P being unavailable (Osman, 2013). High values obtained lime dose of 6.82 tons ha^{-1} with a plant height of 133.00 cm. Nitrogen deficiency causes the process of cell division to be inhibited and results in stunted plant growth (Broadley *et al*., 2000). In addition, deficiency of protein compounds causes an increase in the C/N ratio, and excess carbohydrates will increase the cellulose and lignin content. This causes nitrogen-deficient maize plants to appear small, dry, and not succulent, and the angle of the leaves to the stems is very sharp (Poerwowidodo, 1992).

CONCLUSIONS

There was no significant interaction between *Azolla* compost and lime application on soil organic carbon (C-organic), soil pH, stem diameter, fresh stover weight, dry stover weight, plant height, cob weight, or nitrogen uptake in sweet corn. Furthermore, no optimum dose was identified for either treatment within the tested range. *Azolla* compost application significantly improved C-organic content, soil pH, stem diameter, fresh and dry stover weights, plant height, cob weight, and nitrogen uptake. However, optimal response levels were not achieved. The highest recorded values were: 5.48% (C-organic), pH 6.05, 1.04 cm (stem diameter), 97.00 g (fresh stover), 16.87 g (dry stover), 132.22 cm (plant height), 94.44 g (cob weight), and 440.64 mg plant¹ (N uptake). Lime application ($CaCO_3$) did not significantly affect C-organic, soil pH, or any measured growth or yield parameters of sweet corn, and no optimal lime dose was determined under the conditions of this study. The overall growth and yield of dwarf sweet corn were substantially below the phenotypic characteristics of the Bonanza F1 variety. This outcome was likely influenced by excessive rainfall during the growing period, which may have hindered both vegetative and generative development. Future research should carefully consider the timing of planting to avoid periods of high rainfall, which negatively affect maize growth.It is also recommended to extend the range of *Azolla* and lime dosages and explore additional organic and inorganic amendments to determine the optimum input levels under Ultisol conditions.

References

Auler, A.C., Caires, E.F., Pires, L.F., Galetto, S.L., Romaniw, J. & Charnobay, A.C. (2019). Lime effects in a no-tillage system on Inceptisols in Southern Brazil. *Geoderma Regional*, 16. DOI: https://doi.org/10.1016/j.geodrs.2019.e00206.

Badan Pusat Statistik. (2019). *Produksi jagung di Indonesia tahun 2018*. Badan Pusat Statistik Indonesia.

Broadley, M.R., Escobar-Gutiérrez, A.J., Burns, A. & Burns, I.G. (2000). What are the effects of nitrogen deficiency on growth components of lettuce?. New Phytologist, 147(3), 519 – 526. DOI: https://doi.org/10.1046/j.1469-8137.2000.00715.x.

Buckman, H. O. & Brady, N. C. (1964). *The nature and properties of soil* (6th ed.). The MacMillan Company.

Bugis, C. C. (2011). *Effects of composting on several soil chemical properties of Ultisols, growth, and production of peanut (Arachis hypogaea L.)* [Undergraduate thesis, Pattimura University].

de-Torres, M.A.R.R., Bojollo, M.R.C., Garcia, M.M., Fernandez, R.O., Lizana.A.R. (2021). Soil organic matter and nutrient improvement through cover crops in a Mediterranean olive orchard. *Soil and Tillage Research*, 210. DOI: https://doi.org/10.1016/j.still.2021.104977

Djuniwati, S., Hartono, A. & Indriyati, L. T. (2003). Effect of organic matter (*Pueraria javanica*) and natural phosphate on growth and P uptake of corn (*Zea mays*) in Andisol Pasir Sarongge. *Jurnal Ilmu Tanah dan Lingkungan*, 5(1), 17–22.

Guritno, B. (1995). *Plant growth*. UGM Press., Yogyakarta.

Hardjowigeno, S. (1985). *Soil science*. Akademika Pressindo.

Hardjowigeno, S. (2002). *Soil science* (Rev. ed.). Akademika Pressindo.

Idris, A. R., Djuniwati, S. & Idris, K. (2008). Effect of organic matter and NPK fertilizer on nutrient uptake and maize production in Inceptisol Ternate. *Jurnal Tanah dan Lingkungan*, 10, 7–13.

Kusumawati, I. A. & Prayogo, C. (2019). The impact of land use changes in UB Forest on microbial biomass carbon and total bacterial population. *Jurnal Tanah dan Sumberdaya Lahan*, *6*(1), 1165–1172.

Kusumo, D. (2008). Some research results on Azolla. http://kolamazolla.blogspot.com/2009/10/penelitian-azolla-di-faperta-ugm.htm

Maswada, H.F., Abd El-Razek, U.A., El-Sheshtawy, AN.A. & Mazrou, Y.R.A. (2020). Effect of *Azolla filiculoides* on growth, physiological and yield attributes of maize grown under water and nitrogen deficiencies. *J Plant Growth Regul.,* 40, 558–573. DOI: https://doi.org/10.1007/s00344-020-10120-5

Mulyani, A., Rachman, A. & Dariah, A. (2010). Distribution of acid land, potential, and availability for agricultural development. *Jurnal Penelitian Tanah dan Agroklimat*, 2(1), 23–34.

Osman, K.T. (2013). Plant Nutrients and Soil Fertility Management. In: Soils. Springer, Dordrecht. DOI: https://doi.org/10.1007/978-94-007-5663-2_10.

Pandao, M.R., Thakare, A.A., Choudari, R.J., Navghare, N.R., Sirsat, D.D. & Rathod,S.R.

(2024). Soil Health and nutrient management. *International Journal of Plant & Soil Science*, 36(5), 873-883.

Prasetyo, B. H. & Suriadikarta, D. A. (2006). Characteristics, potential, and technology of Ultisol soil management for the development of dryland agriculture in Indonesia. *Jurnal Litbang Pertanian*, 25(2), 39–47.

Poerwowidodo, M. (1992). *Study of soil fertility*. Angkasa.

Rahmawati, A. (2013). *Responses of several genotypes of sorghum intercropped with cassava (Manihot esculenta Crantz)* [Thesis, University of Lampung].

Regasa, A., Haile, W. & Abera, G. (2025). Effects of lime and vermicompost application on soil physicochemical properties and phosphorus availability in acidic soils. *Sci Rep* 15, 25544 (2025). DOI: https://doi.org/10.1038/s41598-025-02053-4.

Safuan, L. O., & Bahrun, A. (2012). Effect of organic matter and potassium fertilizer on growth and production of melon (*Cucumis melo L.*). *Jurnal Agroteknos*, 2(2), 69–76.

Schnitzer, M. (1986). Binding of humic materials. In P. M. Huang & M. Schnitzer (Eds.), *Interactions of soil minerals with natural organics and microbes* (pp. 77–101). Soil Science Society of America.

Sime, D. (2001). *Lime: The essential element in New Zealand agriculture*. The Northland Lime Millers Association.

Sulistiyanto, Y., Sustiyah, R., Miher, & Elijah, A. (2007). Leaching of some nutrients in inland peat soil that has been given dolomite lime. In *Proceedings of HITI* (Vol. 2). Yogyakarta.

Tampubolon, E., Damanik, M. M. & Marpaung, P. (2018). Effects of chicken manure and $CaCO_3$ lime on some soil chemical properties and growth of corn (*Zea mays L.*) on Inceptisol Kwala Bekala soil. *Online Journal of Agro-ecotechnology*, 6(1), 158–166.

Winarso, S. (2005). *Basic soil fertility (Soil health and quality)*. Gava Media.

Zubachtirodin, & Subandi. (2008). Increased efficiency of N, P, and K fertilizers and maize productivity on Ultisol dryland in South Kalimantan. *Jurnal Tanaman Pangan*, 27(1), 32–36.