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Effect of Zeolite Soil Amendment on Growth, Productivity, and Economic Value of Sweet Corn (*Zea mays*)

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ABSTRAK

Amandemen tanah memainkan peran penting dalam meningkatkan kualitas tanah. Zeolit, bahan pembenah tanah yang umum digunakan, dikenal mampu mempertahankan kelembaban tanah yang lebih tinggi. Penelitian ini bertujuan untuk menilai respon jagung manis terhadap aplikasi zeolit melalui sifat-sifat tanah dan analisis ekonomi. Rancangan acak kelompok lengkap (RAKL) dengan empat ulangan, menggunakan tujuh perlakuan: tanpa zeolit (P0), zeolit pembanding (200 kg/ha; P1), 0.50 (100 kg/ha; P2), 0.75 (150 kg/ha; P3), 1.00 (200 kg/ha; P4), 1.25 (250 kg/ha; P5), dan 1.50 (300 kg/ha; P6) dari dosis yang diujicobakan. Zeolit secara signifikan meningkatkan pH tanah dan kapasitas tukar kation (KTK) dibandingkan dengan perlakuan kontrol. Zeolit juga meningkatkan pertumbuhan tanaman (tinggi dan jumlah daun) dan hasil panen (per plot dan per hektar). Meskipun perbedaan di antara tingkat zeolit tidak signifikan secara statistik, dosis 1.00 menawarkan keuntungan ekonomi tertinggi dan efektivitas agronomi relatif (RAE) sebesar 263%. Oleh karena itu, dosis 200 kg/ha yang diaplikasikan dalam dosis terpisah sangat direkomendasikan.

Kata Kunci: Efektivitas, Kesuburan tanah, Pembenah tanah, Produktivitas

ABSTRACT

Soil amendments play a vital role in enhancing soil quality. Zeolite, a commonly used amendment, is recognized for sustaining higher soil moisture. This study aimed to assess the response of sweet corn to zeolite applications through soil properties and economic analyses. A randomized complete block design (RCBD) with four replications was employed, using seven treatments: no zeolite (P0), comparative zeolite (200 kg/ha; P1), and 0.50 (100 kg/ha; P2), 0.75 (150 kg/ha; P3), 1.00 (200 kg/ha; P4), 1.25 (250 kg/ha; P5), and 1.50 (300 kg/ha; P6) of the tested dosage. Zeolite significantly improved soil pH and cation exchange capacity compared to the control. It also enhanced plant growth (height and leaf number) and yield (per plot and per hectare). Although differences among zeolite rates were not statistically significant, the 1.0 dosage offered the highest economic return and a relative agronomic effectiveness (RAE) of 263%. Thus, 200 kg/ha applied in split doses is recommended.

Keywords: *Effectiveness, Productivity, Soil conditioner, Soil fertility*

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Introduction

Soil amendments are critical in improving soil quality, as they encompass a wide range of synthetic and natural materials that can significantly influence various soil properties. These amendments can enhance soil structure, which is fundamental for adequate aeration and root development. Studies indicate that organic amendments such as compost not only improve soil structure but also contribute to an increase in soil porosity and hydraulic conductivity, facilitating better water and nutrient retention (Dada & Kutu, 2022; Agegnehu et al., 2015). These benefits are particularly essential in water dynamics and nutrient availability, as improved soil amendments help maintain moisture during drought, supporting plant resilience (Stone et al., 2024).

The impact of soil amendments on nutrient availability is multifaceted. Incorporating organic materials like compost can enhance the capacity of soils to store and supply essential nutrients, particularly phosphorus, by reducing sorption and fixation processes (Ding et al., 2020; Radin et al., 2018). The synergy between compost and other amendments, such as biochar, can enhance crop nutrient uptake, benefiting their growth (Agegnehu et al., 2015; Laird et al., 2010). Furthermore, amendments can stimulate microbial activity in the soil, which plays a crucial role in decomposing organic matter and cycling nutrients, ultimately making them more accessible to plants (Oo et al., 2015; Yang et al., 2014).

The enhancement of soil functions through amendments presents a complex challenge, as no single amendment can effectively improve all soil properties, physical, chemical, and biological, simultaneously with a one-time application. While organic materials such as compost, vermicompost, and green manures offer multifunctional benefits, their efficacy generally requires high application rates, typically between 5 to 20 tons per hectare, and often necessitates repeated applications to maintain soil health (Ai et al., 2023; Shaheen et al., 2022). For instance, Liu et al. (2013) demonstrated that amendments could enhance the soil's capacity to retain water and nutrients, which is pivotal in promoting optimal plant growth by improving soil structure and nutrient profiles. Moreover, the specificity of traditional soil amendments is evident; lime is predominantly used for pH adjustment, zeolite enhances cation exchange capacity (CEC), and hydrogels improve water retention in soil (Yazdanpanah, 2016). These amendments address particular deficiencies and can modify properties like soil conductivity and moisture levels to benefit plant growth (Yazdanpanah, 2016). Each type of amendment usually targets specific soil limitations; for example, biosolid applications can enhance microbial diversity, which contributes to improved soil resilience and nutrient cycling (Stavridou et al., 2021).

Zeolite, recognized as a natural inorganic soil amendment, is primarily a hydrated aluminosilicate mineral that originates from igneous rocks or altered volcanic tuffs (Cataldo et al., 2021). Typically found in alkaline lake environments, zeolite deposits result from the sedimentation of volcanic ash and hydrothermal processes, making it a significant component in soil management strategies (Amewode et al., 2023). Its utility as a soil amendment is attributed to its ability to optimize numerous soil properties, particularly its high cation exchange capacity (CEC) and moisture retention capabilities. Notably, to be effective in enhancing CEC, zeolite should possess a CEC value exceeding 60 cmol+ kg^{-1} (Khalifa et al., 2019).

Research suggests that zeolite is adept at maintaining elevated soil moisture levels, ensuring the availability of water for plant use during critical growth phases (Belviso et al., 2022). The fine pore structure of zeolites contributes significantly to their water-retention abilities, as they can achieve lower bulk density and improved porosity, which translates to enhanced soil moisture content in agricultural settings (Mondal et al., 2021). Furthermore, studies indicate that zeolite applications are associated with increased capillary movement, which aids moisture retention, particularly in sandy soils. This characteristic is particularly beneficial in drought-prone regions, where maintaining moisture levels can drastically improve crop yields. The role of zeolite in enhancing soil moisture content offers reassurance about its potential in challenging agricultural conditions.

Zeolite's influence on nutrient dynamics within the soil is also noteworthy. It facilitates the retention and gradual release of essential nutrients, such as ammonium and potassium, while also curbing nutrient leaching, thereby enhancing plant nutrient availability over time (Khalifa et al., 2019; Omar et al., 2020). In this way, zeolite can significantly boost soil fertility, enabling more sustainable agricultural practices by reducing the reliance on chemical fertilizers, which often lead to environmental degradation (Cataldo et al., 2021). The improvement of soil properties through zeolite incorporation aligns with broader sustainability goals in agriculture, promoting both plant productivity and ecological health.

The evaluation of sweet corn's response to zeolite-based soil amendments should encompass not only plant growth assessments but also yield measurement and economic viability. Investigating how zeolite affects both vegetative growth and reproductive outcomes, such as grain yield, is crucial, as it can provide insights into the practical benefits of using zeolite in sweet corn cultivation. Ultimately, the objective of this research, evaluating the response of sweet corn plants to zeolite-based amendments through soil analysis and economic assessment, aims to bridge the knowledge gap surrounding the effective integration of zeolite in agricultural practices. Such research endeavors are essential for promoting sustainable agricultural practices that enhance productivity while conserving resources.

Methodology

Research timeframe and site

The research was conducted at the IPB Experimental Farm in Pasir Sarongge, Cianjur. The study was conducted for four months, from April to August 2018.

Materials

The materials used in this study include hybrid sweet corn seeds, zeolite-based soil amendments, urea, SP-36, and KCl fertilizer. The equipment utilized consists of cultivation tools, sample stakes, measuring tape, and a digital scale. According to laboratory analysis, the composition and properties of the zeolite soil amendment include a cation exchange capacity (CEC) of 112.57 cmol·kg^{-1}, a SiO_2 content of 51.71%, a moisture content of 9.49%, and a fineness level of 96.35%.

Testing method

The experimental design used in this study is a randomized complete block design (RCBD) with four replications. The treatments are arranged in seven levels (Table 1). The experiment consists of four replications, resulting in a total of 28 experimental units. Each unit was a plot with an area of 25 m². Across all treatments, 300 kg/ha of urea, 150 kg/ha of SP-36, and 100 kg/ha of KCl are consistently applied.

Experimental implementation method

Land preparation was conducted using thorough soil tillage, performed twice. Experimental plots measured 5 × 5 meters, with a 50 cm spacing between plots. Each block consisted of seven plots, arranged along a uniform environmental gradient, and treatments were randomly assigned within each replication. Each plot was labeled according to its random treatment assignment.

Hybrid sweet corn seeds were planted at a spacing of 75 × 25 cm, with one seed per planting hole. Resowing was carried out one week after planting. During planting, the insecticide Furadan 3G was applied at a rate of 20 kg/ha directly into each planting hole. Fertilization with urea, SP-36, and KCl was conducted according to the treatment protocol. Zeolite soil amendment was mixed with urea fertilizer before application. The urea-zeolite mixture was applied in two stages: 50% at one week after planting (1 WAP) and 50% at four weeks after planting (4 WAP). SP-36 and KCl were applied as base fertilizers, spread in furrows along the planting rows at the time of planting. Pest and disease management was conducted based on the severity of field infestations.

Table 1. Application of Different Dosage Levels of Zeolite as a Soil Amendment

Treatments	Zeolite Dosage (kg/ha)	Zeolite Dosage of Reference (kg/ha)
Control	-	-
Reference	-	200
0.50 of the zeolite dosage	100	-
0.75 of the zeolite dosage	150	-
1.00 of the zeolite dosage	200	-
1.25 of the zeolite dosage	250	-
1.50 of the zeolite dosage	300	-

Observations

Observations were conducted on growth parameters and yield components, including plant height and leaf count, measured in 10 randomly selected sample plants. Additional observations included ear length, ear diameter, ear weight with husk, ear weight without husk, marketable yield obtained from sample plants, yield per plot, and yield per hectare. Furthermore, soil analysis was performed to measure pH and cation exchange capacity (CEC).

The relative agronomic effectiveness (RAE) value represents the relative yield increase between the tested fertilizer dosage compared to the reference and control treatments. If the EAR value is greater than 100, the soil amendment is considered agronomically effective, as it results in a yield increase surpassing that of the reference treatment relative to the control. The RAE is calculated as follows:

$$\mathrm{RAE} = \frac{\text{Yield from test zeolite}}{\text{Yield from reference zeolite}} \times 100$$

Data analysis

Data were statistically analyzed using analysis of variance (ANOVA). If significant differences were detected, further testing was conducted using Duncan's Multiple Range Test (DMRT) at a 5% significance level. Farm business analysis was performed using economic calculations, with profitability and the revenue-to-cost (R/C) ratio as key variables.

Results and discussion

Results

Effect of Zeolite Soil Amendment on Soil pH and Cation Exchange Capacity (CEC)

Observations indicated that the application of zeolite soil amendments resulted in improved soil pH and increased CEC (Figure 1). Plots without zeolite soil amendments exhibited lower soil pH during both observation periods at 4 and 8 weeks after planting (WAP). Conversely, plots treated with zeolite soil amendments showed an increase in soil pH across all application levels. The observed shift in soil pH from acidic to near-neutral suggests that zeolite soil amendments can enhance soil pH to levels more suitable for plant growth.

A similar trend was observed for CEC (Figure 1). At the beginning of the experiment, the soil exhibited a CEC of 15.75 cmol(+)/kg. In plots without zeolite soil amendments, the CEC decreased at 4 and 8 WAP. In contrast, plots treated with zeolite soil amendments exhibited increased CEC across all treatment levels.

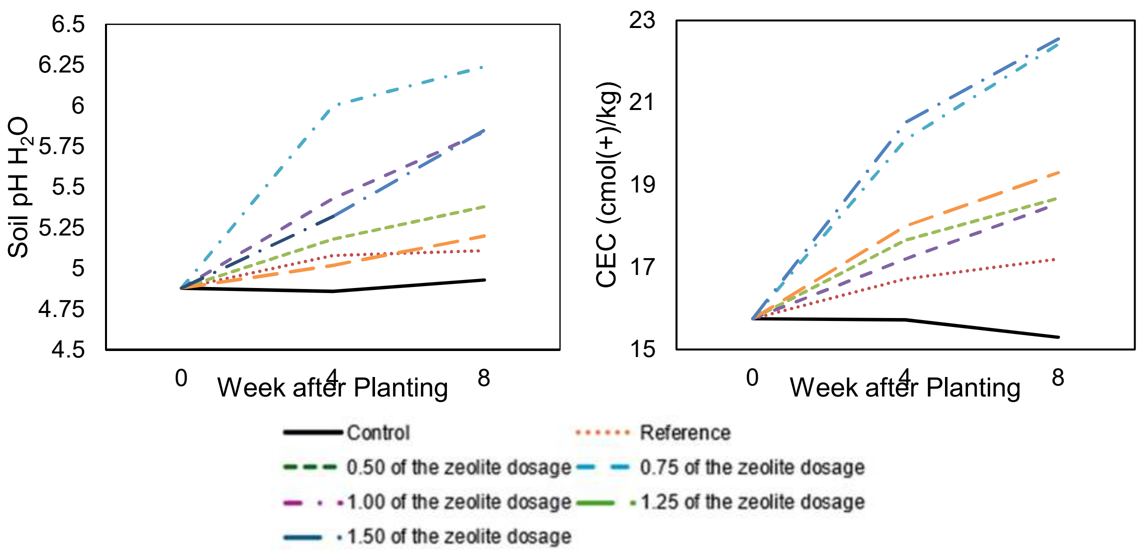

Figure 1. Effect of Zeolite Soil Amendment on Soil pH and Cation Exchange Capacity

Effect of Zeolite Soil Amendment on Sweet Corn Growth

The application of zeolite soil amendments influenced sweet corn plant growth. Plant height exhibited a significant response to zeolite amendment treatments (Table 2). In the early stages of observation, differences in plant height among treatments were not apparent up to 5 weeks after planting (WAP). However, in subsequent weeks, the application of the 1.0 dosage of zeolite soil amendment showed a more favorable response compared to the control in terms of corn plant height. A similar trend was observed at the final observation in week 7, where the treatment with the 1.0 dosage of zeolite amendment resulted in a plant height of 167.6 cm, compared to the control treatment, which had a plant height of only 163.5 cm.

The number of leaves in sweet corn plants also exhibited significant differences in response to the application of zeolite soil amendments (Table 3). During the initial observations up to 5 weeks after planting (WAP), variations in zeolite amendment dosage did not result in noticeable differences in leaf count. However, responses began to emerge starting from 6 WAP. The application of the 1.0 dosage of zeolite soil amendment resulted in a higher leaf count compared to the control treatment. Corn plants receiving this dosage produced more leaves, with an increase of 10.9 leaves per plant.

Table 2. Plant Height of Sweet Corn Under Zeolite Soil Amendment Treatment

Treatment	Plant Height (cm)				
	3 WAP	4 WAP	5 WAP	6 WAP	7 WAP
Control	39.2a	59.0a	83.5a	125.0b	163.5b
Reference	39.4a	62.6a	88.5a	129.3ab	167.9a
0.50 of the zeolite dosage	41.0a	60.6a	82.5a	125.2b	164.2b
0.75 of the zeolite dosage	40.5a	61.6a	87.6a	129.6ab	163.4b
1.00 of the zeolite dosage	43.8a	66.8a	92.6a	132.7a	167.6a
1.25 of the zeolite dosage	40.0a	58.8a	81.9a	124.0b	166.4ab
1.50 of the zeolite dosage	43.2a	61.8a	86.5a	128.3ab	166.0ab

Note: Numbers within the same column followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 3. Leaf Count of Sweet Corn Under Zeolite Soil Amendment Treatment

Treatment	Leaf Count				
	3 WAP	4 WAP	5 WAP	6 WAP	7 WAP
Control	3.4b	5.3ab	7.3a	9.2b	9.9b
Reference	3.6ab	5.5ab	7.6a	9.6ab	10.7ab
0.50 of the zeolite dosage	4.0ab	5.0b	7.5a	9.4ab	10.1ab
0.75 of the zeolite dosage	3.9ab	5.4ab	7.8a	9.8ab	10.5ab
1.00 of the zeolite dosage	4.1a	5.8a	7.9a	10.0a	10.9a
1.25 of the zeolite dosage	3.9ab	5.3ab	7.8a	9.8ab	10.1ab
1.50 of the zeolite dosage	3.9ab	5.1b	7.9a	9.3ab	10.4ab

Note: Numbers within the same column followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 4. Yield Components of Sweet Corn Under Zeolite Soil Amendment Treatment

Treatment	Ear Length (cm)	Ear Circumference (cm)
Control	18.0c	15.2c
Reference	19.4abc	16.0abc
0.50 of the zeolite dosage	20.6a	16.4ab
0.75 of the zeolite dosage	19.8ab	16.6a
1.00 of the zeolite dosage	20.1ab	16.4ab
1.25 of the zeolite dosage	18.9bc	15.9abc
1.50 of the zeolite dosage	20.2ab	15.3bc

Note: Numbers within the same column followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Yield Components and Production

The application of zeolite soil amendments significantly affected the yield components of sweet corn (Table 4). The application of 0.5–1.5 doses of zeolite amendment resulted in optimal ear length compared to the control treatment, with corn ear lengths ranging from 19.8 to 20.6 cm. Similarly, the application of 0.5–1.0 doses of zeolite amendment improved ear circumference compared to the control, with treated plants producing ear circumferences between 16.4 and 16.6 cm.

Zeolite soil amendments also had a significant effect on ear weight with husk and ear weight without husk (Table 5). The application of 0.75, 1.0, and 1.5 doses of zeolite amendment resulted in higher ear weights with husk, ranging from 413.4 to 466.6 g, compared to the control treatment, which produced only 359.2 g. The same trend was observed for ear weight without husk, where treated plants yielded between 345.7 and 362.3 g, compared to the control treatment.

Additionally, the application of zeolite soil amendments enhanced sweet corn yield per plot and hectare (Table 6). Observations indicated that the application of 0.75–1.5 doses of zeolite amendment improved yield per plot and hectare compared to untreated sweet corn plants. Treated plants yielded 18.7 to 19.7 kg per plot, whereas untreated plants yielded only 14.5 kg per plot. Similarly, yield per hectare was higher for treated plants, producing between 7.35 and 7.90 tons per hectare, compared to the control treatment, which yielded only 5.80 tons per hectare.

Relative Agronomic Effectiveness (RAE)

The agronomic effectiveness analysis is presented in Table 7. The results indicate that the application of 0.5–1.5 doses of zeolite soil amendment is agronomically effective, with RAE values exceeding 100. This means that the yield improvement caused by zeolite amendment is higher than that induced by the reference soil amendment. In this experiment, the 1.0 dosage of zeolite amendment was found to be the most agronomically effective, yielding the highest RAE value of 263%.

Table 5. Sweet Corn Yield Under Zeolite Soil Amendment Treatment

Treatment	Ear Weight With Husk (g)	Ear Weight Without Husk (g)
Control	359.2b	304.9b
Reference	399.3a	330.3ab
0.50 of the zeolite dosage	366.0b	310.2b
0.75 of the zeolite dosage	429.6a	362.3a
1.00 of the zeolite dosage	466.6a	348.6a
1.25 of the zeolite dosage	392.6ab	327.1ab
1.50 of the zeolite dosage	413.4a	345.7a

Note: Numbers within the same column followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 6. Sweet Corn Yield Under Zeolite Soil Amendment Treatment

Treatment	Yield/Plot (kg)	Yield/ha (kg/ha)
Control	14.5b	5800b
Reference	16.5ab	6600ab
0.50 of the zeolite dosage	18.0ab	7200ab
0.75 of the zeolite dosage	19.1a	7650a
1.00 of the zeolite dosage	19.7a	7900a
1.25 of the zeolite dosage	18.3a	7350a
1.50 of the zeolite dosage	18.7a	7500a

Note: Numbers within the same column followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level.

Table 7. Relative Agronomic Effectiveness (RAE) Under Zeolite Soil Amendment Treatment

Treatment	Relative Agronomic Effectiveness (%)
Control	-
Reference	-
0.50 of the zeolite dosage	175
0.75 of the zeolite dosage	231
1.00 of the zeolite dosage	263
1.25 of the zeolite dosage	194
1.50 of the zeolite dosage	213

Table 8. Farm Business Analysis of Zeolite Soil Amendment Treatment

Treatment	Cost (Rp)	Revenue (Rp)	Profitability (Rp)	R/C
Control	11,615,000	23,200,000	11,585,000	2.00
Reference	12,615,000	26,400,000	13,785,000	2.09
0.50 of the zeolite dosage	12,115,000	28,800,000	16,685,000	2.38
0.75 of the zeolite dosage	12,335,000	30,600,000	18,265,000	2.48
1.00 of the zeolite dosage	12,585,000	31,600,000	19,015,000	2.51
1.25 of the zeolite dosage	12,865,000	29,400,000	16,535,000	2.29
1.50 of the zeolite dosage	13,085,000	30,000,000	16,915,000	2.29

Farm Business Analysis

To assess economic effectiveness, a farm feasibility analysis was conducted using profitability and the revenue-to-cost (R/C) ratio as key variables. A soil amendment is considered economically effective if it results in higher profitability and R/C ratios compared to the control treatment. The results of the farm business analysis for the zeolite soil amendment effectiveness test are presented in Table 8.

The application of zeolite soil amendments yielded favorable farm business analysis results, as indicated by an R/C ratio greater than 1. The 1.0 dosage of zeolite amendment demonstrated the highest economic profitability, generating a profit of Rp. 19,015,000 and achieving an

R/C ratio of 2.51, outperforming other treatments.

Discussion

The experimental results showed that soil pH increased before and after the application of zeolite soil amendment, rising from 4.88 at the start of the experiment (pre-application) to 6.24 in the 1.0 dosage treatment at 8 weeks after planting (WAP). This demonstrates that zeolite amendments can improve soil chemical properties by raising soil pH (Zheng et al., 2020; Indraratne et al., 2023). The previously acidic soil became nearly neutral with the addition of zeolite, creating a more favorable environment for plant growth, as optimal conditions for plant growth typically occur at a soil pH range of 6–7 (Allaway, 1957). In contrast, the control treatment, which did not receive zeolite amendment, showed minimal pH changes, remaining between 4.86 and 4.93.

Cation exchange capacity (CEC) also increased with the application of zeolite soil amendment. At the beginning of the experiment, before application, the soil had a CEC of only 15.75 cmol+/kg. However, following zeolite amendment application, CEC rose to 22.55 cmol+/kg in the 1.5 dosage treatment. This indicates that zeolite, which primarily consists of aluminosilicate minerals, can enhance soil CEC. An increase in soil CEC improves nutrient retention, making essential elements more available for plant uptake (Al-Jabri, 2010). Additionally, the zeolite amendment used in this study contained 51.71% SiO_2, one of the components known to contribute to higher CEC in soils (Al-Jabri, 2010; Sabilu, 2016).

Sweet corn plant growth improved with the application of zeolite soil amendments. Plant height increased by 2.5% compared to the control in the 1.0 dosage treatment, though other treatments showed no significant differences. A similar trend was observed in leaf count, where plants treated with the 1.0 dosage of zeolite amendment produced 10.1% more leaves than the control treatment. Dariah et al. (2010) reported that soil amendments applied to degraded Typic Kanhapludults significantly enhanced corn growth. Arafat et al. (2016) similarly found that the addition of zeolite in corn cultivation improved plant growth. Fauziah & Sa'adah (2017) also stated that applying soil amendments in corn cultivation enhanced growth rates.

Corn yield components were also affected by zeolite amendments. Ear length and circumference increased by 10.0–14.4% and 7.9–9.2%, respectively, compared to the control. Additionally, ear weight with husk and ear weight without husk rose by 15.1–29.9% and 13.4–18.8%, respectively, in comparison to untreated plants. A similar trend was observed in plot and per-hectare yield. Corn plants receiving 0.75–1.5 doses of zeolite amendments exhibited increased plot and per-hectare yield by 26.2–35.9% and 26.7–36.2%, respectively, compared to the control treatment. These findings align with previous studies that reported soil amendments enhance plant growth and ultimately increase crop yields compared to untreated plants (Ernawanto et al., 2011; Balqies et al., 2018).

The application of zeolite soil amendments at a dosage of 200 kg/ha provided the highest profitability for farmers, as illustrated in the farm business analysis table (Table 8). This is due to the linear effects of improved growth, enhanced yield components, and higher total yield per hectare. Consequently, applying 200 kg/ha of zeolite soil amendment maximizes economic returns for corn farmers. Fauziah & Sa'adah (2017) concluded that soil amendments applied alongside recommended fertilizer rates significantly improved corn plant growth and resulted in the highest yields.

CONCLUSION AND SUGGESTIONS

Conclusion

The results of the experiment indicated that the application of zeolite soil amendment improved soil pH and cation exchange capacity (CEC) compared to the control treatment. Additionally, the application of zeolite amendment resulted in significantly better plant growth (increased plant height and leaf count) and corn yield (higher plot and per-hectare yield) compared to the control. Although differences among zeolite amendment treatments were not statistically significant, the 1.0 dosage of zeolite amendment provided the highest economic benefits, and it was agronomically effective, achieving a relative agronomic effectiveness (RAE) value of 263%. The recommended application rate for corn crops is 200 kg/ha, applied in two stages: 50% at one week after planting (WAP) and the remaining 50% at four WAP.

Suggestion

The soil type needed further experiement to see whether the application of zeolite will give a different response in different types of soil. Especially in different agroecosystems.

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