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RESEARCH ARTICLE

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Agronomic Efficiency of Sweet Corn (*Zea mays* saccharata Sturt) under Treatments of Nitrogen Rate and Maggot Frass Enrichment with Zeolite

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ABSTRACT

Nitrogen (N) is a macronutrient needed in significant quantities by corn plants, but the fertilization efficiency is often limited. In this context, organic materials increase soil fertility and efficiency of N. The application of maggot frass enriched with zeolite is also an alternative to increase N efficiency. Therefore, this research aimed to examine the enrichment of maggot frass with zeolite and N fertilizer doses on agronomic traits and efficiency of sweet corn plants. A Complete Randomized Block Design was used with 3 replications at the Experimental Farm, Faculty of Agriculture, Jenderal Soedirman University. The first factor was N dosage with 3 levels, 0kg ha^{-1}, 150kg ha^{-1}, and 300kg ha^{-1}. The second factor was the application of maggot frass consisting of zero maggot frass, maggot frass, maggot frass 95% + zeolite 5%, and maggot frass 90% + zeolite 10%. Meanwhile, the variables included plant height, leaf area index, plant dry weight, sweet corn yield, and agronomic efficiency. The result showed that the application of N increased growth. The highest agronomic efficiency value was achieved at a dose of 150kg ha^{-1} of 18.883kg^{-1}N and treatment of maggot frass + zeolite 5%.

Keywords: Nitrogen, Efficiency, Maggot frass, Zeolite, Agronomy.

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INTRODUCTION

Adequate nutrition is the main key to optimal corn production, and the plant requires several macronutrients. According to Syafrudin (2015), the corn plant needs nitrogen (N) nutrients more than phosphate (P) and potassium (K). Additionally, N fertilization contributes to increasing yields ranging from 30–50%. In N-deficient soil conditions, the application of the nutrient provides a very high yield (Demari et al., 2016). Omar et al. (2022) reported that increased N doses did not affect yields. However, the application of optimal doses of 50-100 kg ha^{-1} increased corn crop yields, including protein and starch levels. N significantly increased corn yields, N_2O emissions, and NH_3 by 50.64%, 64.39%, and 69.25%, respectively (Zhang et al., 2023). Excessive fertilizer application reduces the efficiency of N fertilization due to inefficiencies in terms of costs and technical fertilization.

The use of organic fertilizer is a strategy to increase the efficiency of N fertilization in sweet corn cultivation. A combination of organic and inorganic fertilizers is an effort to improve land productivity sustainably, increase the efficiency of N use, and reduce environmental pollution (Syafrudin, 2015). Mahmood et al. (2017) reported that the growth and yield of corn plants increased. Furthermore, carbon (C) and total N, P, and K increased when inorganic fertilization was applied in combination with organic fertilizers. Long-term application of organic manure is effective in increasing the efficiency of N use by soil organic matter levels, improving soil fertility and plant yields, as reported by Hua et al. (2020). The ratio of fertilizers meets nutrient needs to improve the soil environment and crop yields (Tak et al., 2023). The application of organic fertilizer was able to substitute inorganic with an optimal substitution of 44%, and the application of N was not less than 161kg ha^{-1} (Ren et al., 2023). Turhan & Özmen (2021) reported that the application of organic fertilizer increased the yield components and quality of tomato yields. Meanwhile, Ali et al. (2021) stated that inorganic fertilizers were replaced with organic in eggplant cultivation.

Various types of material sources can be used as organic fertilizer or soil amendment, such as maggot frass.

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In this context, maggot frass is the result of the digestion process of Black Soldier Fly (BSF) maggot. According to Susilo et al. (2024), this by-product of BSF larval cycle can be used as an organic fertilizer due to the high nutrients. The nutrient content is very dependent on the food supply for BSF larvae. According to Lopes et al. (2023), the total organic C and N content of maggot frass ranges from 3% to 37%. Agustin et al. (2023) reported that maggot frass had chemical characteristics such as a C/N ratio of less than 25, C-organic of more than 15%, pH 4-9, total NPK nutrient value greater than 2% and iron (Fe) below 500 mg/kg. Maggot frass also contains useful microorganisms supporting plant growth (Lomonaco et al., 2024). Therefore, the application has great potential to improve plant growth and yield. In lettuce cultivation with a dose of 15tons ha^{-1}, this organic fertilizer provided the highest yield (Dzepe et al., 2022). The application of maggot frass starting at a dose of 2 tons ha^{-1} has been able to increase spinach crop yields (Purwanto et al., 2023).

The addition of zeolite to maggot frass is expected to increase the effectiveness and efficiency of N fertilization. Zeolite is a natural volcanogenic sedimentary mineral consisting of aluminosilicate with a three-dimensional crystal lattice and loosely bound cations (Cairo et al., 2017). Widigdyo et al. (2022) reported that the enrichment of chicken manure composting with zeolite increased nutrient levels and fertility as well as prevented soil degradation. Minardi et al. (2020) stated that a combination of 5tons ha^{-1} of zeolite and cow manure increased CEC, soil organic C, pH, and soybean crop yields. Enriching fertilizer with zeolite reduced N-release pattern, increasing the efficiency of plants in using N (Suwardi, 2009). Budiyanto (2020) reported that the combination of 6% zeolite and 125kg N per hectare treatment produced fresh biomass of corn plants and increased the efficiency of N-fertilizer nutrient uptake in the vegetative growth of corn plants. Therefore, this research aimed to examine the enrichment of maggot frass with zeolite and N fertilizer doses on agronomic characteristics and efficiency of sweet corn plants.

MATERIALS & METHODS

This research was conducted at the Experimental Farm and Agronomy & Horticulture Laboratory, UNSOED Purwokerto, Central Java, Indonesia, from December 2023 to April 2024. Analysis of plant tissue and soil was carried out at the Central Java Agricultural Instrument Standards Implementation Center. Furthermore, a randomized block design was used with three replications. The first factor was N dosage with 3 levels, namely N_0 (0kg ha^{-1}), N_1 (150kg ha^{-1}), and N_2 (300kg ha^{-1}). The second factor was the application of maggot frass consisting of K_0 (without maggot frass), K_1 (maggot frass), K_2 (maggot frass 95% + zeolite 5%), and K_3 (maggot frass 90% + zeolite 10%). The experimental plot measured 5 x 5m, and the distance between the plants used was 70 x 20cm. The sweet corn variety planted was the Exotic Variety was the sweet corn planted and fertilization was carried out using urea at a standard dose. Urea was applied in two splits, namely half of the treatment dose at 14 days after planting (DAP) and the remaining half at 28 DAP. Additionally, SP-36 fertilizer 150kg ha^{-1} and KCl 150kg ha^{-1} were applied.

Variables observed included leaf area index (LAI), plant height (cm), plant dry weight (g), sweet corn yield (ton ha^{-1}), and agronomic efficiency. Agronomic efficiency was calculated based on Govindasamy et al. (2023) with the following formula.

$$\text{Agronimic Efficiency (AE)}: \frac{Gf - Gu}{Na} \quad \text{(Eq 1)}$$

Where Gf and Gu are the sweet corn yields (kg) of the fertilized and unfertilized plots and Na is the rate of N applied (kg).

The soil and maggot frass chemical analyses were conducted in the Bureau of Applied Agricultural Instrumentation Standards of Central Java. The soil texture of the research plots contains sand (18.76%), silt (58.39%), and clay (22.85%). The soil pH was moderately acidic with the values of pH H_2O at 6.04 and pH KCL at 5.32. The contents of C-organic and N could be categorized as moderate (2.10% and 0.26%), while the available P was high (78.59%). CEC value was low (20.93cmol kg^{-1}) with moderate Mg (1.72cmol kg^{-1}), low K and Ca (0.170 and 5.49cmol kg^{-1}), and very low Na (0.06cmol kg^{-1}). Furthermore, the soil contained P, K, and magnesium (Mg) total of 0.14% (moderate), 0.08% (low), and 0.17% (low), respectively. The soil exchangeable aluminium (Al) and hydrogen were low at 0.92cmol kg^{-1} and 1.56cmol kg^{-1}, respectively.

The results from the chemical content analyses of maggot frass are presented in Table 1 and compared to the government standards on organic fertilizers set by the Agricultural Ministry. Maggot frass contained significantly higher than the set standards, while other ingredients were in the requirements.

Table 1: Chemical contents of maggot frass

No	Parameter	Maggot frass	Government Standard
1	Water content (%)	49.94	10-25
2	pH H_2O	7.52	4-9
3	C-Organic (%)	25.49	15-25
4	C/N Ratio	13.30	≤ 25
5	N-total (%)	1.92	-
6	P_2O_5 (%)	0.85	-
7	K_2O (%)	1.73	-
8	N + P_2O_5 + K_2O (%)	4.5	≥ 2

The data were analyzed using Analysis of Variance (ANOVA). The test was continued using the Duncan Multiple Range Test (DMRT) of α 5% when ANOVA results showed significantly different results.

RESULTS & DISCUSSION

Agronomic Traits of Sweet Corn

N fertilization dose influenced leaf area index (LAI), plant dry weight and plant height, while maggot frass treatment affected sweet corn plant height, without influencing LAI and plant biomass. In this context, there was no interaction between N and maggot frass application. Fertilizer doses were seen to significantly increase plant height, where the dose of 150 kg ha^{-1} resulted in higher plant height compared to 0kg ha^{-1} but there was no difference at 300kg ha^{-1}. Plant height at doses of 150 and 300kg ha^{-1} was 165.417 and

171.130cm, respectively (Table 2). The application of maggot frass appears to increase plant height growth. The highest height was achieved in maggot frass treatment enriched with 5% zeolite. This result was significantly different compared to the control or maggot frass treatment enriched with 10% zeolite. The application of maggot frass enriched with zeolite produced the highest plant height of 157.571 cm and corn required large amounts of N for vegetative growth. In addition, N as a macronutrient plays a role in stimulating vegetative growth through the process of cell division. Mahat et al. (2023) stated that increasing the dose of N had a positive effect on plant growth such as the expansion of division cells, elongation, and nucleus formation to improve the photosynthesis rate. This is similar to the application of maggot frass, containing nutrients N and P which are quite stable. According to Lopes et al. (2023), the levels of C and N in maggot frass do not vary, ranging from values of 3 to 37%.

Table 2: The effect of N rate and maggot frass on plant height, leaf area index, and plant dry weight

Treatments	Plant Height (cm)	Leaf Area Index	Plant Dry Weight (g)
N Rates (kg ha^{-1})			
0	117.968a	1.811a	16.259a
150	165.417b	2.744b	41.788b
300	171.130b	3.061c	57.277c
Maggot Frass			
Control	144.467a	2.415a	34.436a
Maggot Frass	152.784ab	2.487a	40.731a
Maggot Frass + Zeolite 5%	157.571b	2.658a	39.810a
Maggot Frass + Zeolite 10%	151.198ab	2.594a	38.789a

Value followed by the same letter in the same column and treatments are not significantly ($P<0.05$) different

In LAI and plant biomass variables, increasing N dose to 300kg ha^{-1} resulted in higher values compared to 0 and 150kg ha^{-1} treatments. LAI of corn plants at 150kg ha^{-1}, 300kg ha^{-1}, and 0kg ha^{-1} were 2.744, 3.06, and 1.811, respectively (Table 2). A similar trend was also seen in plant dry weight, which increased with N dosage. The dry weight of plants at 150kg ha^{-1}, 300kg ha^{-1}, and 0 kg ha^{-1} were 41.788, 57.277, and 16.259g $plant^{-1}$, respectively (Table 2). The application of maggot frass enriched with zeolite has not been able to increase LAI value or dry weight of the plant.

LAI variable plays a very big role in plant metabolic processes by capturing solar energy for plant photosynthesis. The value is greatly influenced by the area of plant leaves and cannot be separated from the role of N in plant vegetative growth. N application at 150 kg ha^{-1} significantly increases LAI value and N dose to 300kg ha^{-1}. According to Tian et al. (2020), LAI value reflects nutritional status and the potential ability of leaves to conduct photosynthesis. The application of fertilizer doses improves LAI value by increasing the number and leaf area. Amanullah et al. (2014) reported that the value of corn plants increased starting from 150kg ha^{-1} of N. Furthermore, Mahat et al. (2023) stated that the dosage of N dose increased LAI value and N at 240kg ha^{-1} to produce a maximum of 8.84.

An increase in LAI value of corn plants is followed by plant dry weight. Furthermore, plant biomass increased with N dosage. N fertilizer was able to increase plant dry weight by 204.65% compared to the control. The fertilizer at doses of 150 and 300kg ha^{-1} improved the dry weight of plants by 157.04 and 252.28% compared to the control. Application of a dose of 300kg/ha produced the plant dry weight of 57.277g $plant^{-1}$. Even though maggot frass does not show a significant difference, there is a tendency to increase with the application. This result is in line with Zhai et al. (2022) where N fertilization can extend the duration of accumulation by delaying the cessation period of rapid dry matter accumulation. This occurs as a result of increasing LAI values allowing plants to carry out photosynthesis and produce large amounts of dry plant matter. According to Szabó et al. (2022), LAI is important and determines the percentage of sunlight absorbed by plants. Qi et al. (2020) reported that increasing shoot biomass was related to LAI and root growth.

Sweet Corn Yield

N fertilization at various doses significantly increases the yield of sweet corn plants. The application at doses of 150 and 300kg ha^{-1} can produce sweet corn of 3.789 and 3.908ton ha^{-1} while the control treatment (0kg ha^{-1}) only produced 0.957ton ha^{-1} (Table 3). N starting at 150 kg ha^{-1} to 300kg ha^{-1} increases the yields. Therefore, increasing the dose above 150 kg ha^{-1} did not enhance the yield of sweet corn. High-dose N fertilization has no impact on increasing yields due to the large loss of nutrients to the plant environment. Syafrudin (2015) stated that plants absorbed N in the form of NO^{3-} and NH^{4+}. Organic matter through the mineralization process will become NH_4^+ and nitrification of NH^{4+} to NO^{3-}. Besides being absorbed by plants, N nutrients in the form of NH^{4+} and NO^{3-} are lost through the evaporation process and some are subjected to leaching and denitrification to become N_2O and NO gas. According to Zhao et al. (2024), N plays an important role in yield formation, and rational fertilization is the key to high yields. Excessive application causes a high loss rate to the environment such as agricultural pollution. Omar et al. (2022) reported that optimal corn plant fertilization ranged from 50-100kg ha^{-1} and had the potential to increase yields as well as protein and starch content in seeds. Córcolesa et al. (2020) also suggested that the N fertilizer dose of 130kg ha^{-1} was lower than the amount needed to obtain maximum yields. However, the dose of 150 kg ha^{-1} did not show a significant difference compared to 300 kg ha^{-1}.

Table 3: The effect of N rate and maggot frass on the yield of sweet corn

Treatments	Yield (tons ha^{-1})
N Rates (kg ha^{-1})	
0	0.957a
150	3.789b
300	3.908b
Maggot Frass	
Control	1.722a
Maggot Frass	3.123a
Maggot Frass + Zeolite 5%	3.291a
Maggot Frass + Zeolite 10%	3.393a

Values followed by the same letter in the same column and treatments are not significantly ($P<0.05$) different according to DMRT

Maggot frass has not shown any effect on sweet corn yields. There is a tendency to increase yields, where the application can produce sweet corn of 3.123tons ha^{-1}. The application of maggot frass enriched with 5 and 10% zeolite were 3.291 and 3.393ton ha^{-1} respectively. Meanwhile, treatment without maggot frass was only 1.722tons ha^{-1}. The effect of maggot frass on sweet corn yields is related to the application dose. Mulyati et al. (2021) reported that organic manure at 10 tons ha^{-1} had an effect on corn yields, and increasing the dose to 20 tons ha^{-1} showed no difference. Short-term application of organic fertilizer cannot provide an effect on yield. However, long-term application increases soil fertility and corn yields. This is consistent with Lu et al. (2024) where the application of organic fertilizer increased corn yields significantly compared to long-term chemicals. The addition of organic fertilizers increased the concentration of protein, Fe, Mn, Cu, and Zn in corn seeds.

Agronomic Efficiency

The results showed that the dose of N affected agronomic efficiency of sweet corn plants. N fertilization at 150kg ha^{-1} was 18.883kg kg^{-1}N, and increasing the dose to 300kg ha^{-1} reduced agronomic efficiency value of 10.988kg kg^{-1}N. This is in line with Ding et al. (2018) where excessive fertilizer doses reduced Agronomic Efficiency value of rice plants. Ray et al. (2018) stated that Agronomic Efficiency value varied between 5.6 to 23.6kg kg^{-1} of applied N. The value can reach above 30kg kg^{-1} when managed well and cultivated on soil with low N levels.

The application of maggot frass has an increased agronomic efficiency value. Furthermore, maggot frass enriched with 5% zeolite has higher agronomic efficiency than maggot frass or those with 10% zeolite. Maggot frass enriched with 5% zeolite had an agronomic efficiency value of 18,359kg kg^{-1}N. In addition, maggot frass enriched with 10% zeolite and only maggot frass had an agronomic efficiency value of 16.832 and 14.125kg kg^{-1} N, respectively. The control treatment without maggot frass application only reached 10.426kg kg^{-1}N (Table 4). Wang et al. (2024) reported that bio-organic fertilizer treatment from mealworm manure increased N efficiency. Maggot frass enrichment of 5% showed a higher agronomic efficiency value compared to other treatments. Zeolite enrichment in maggot frass can improve the quality of organic fertilizer and soil fertility as well as reduce N loss. Santoso et al. (2022) stated that the combination of cow manure and zeolite increased pH, soil N levels, C-organic, and growth of ramie plants. Increasing agronomic efficiency is greatly influenced by N absorption level of corn plants and the metabolic processes. Enriching maggot frass with zeolite reduces N loss and the application of 5tons ha^{-1} increases total N and uptake by 35.13% and 53.37%, respectively (Triatmoko et al., 2019). Budiyanto (2020) suggested that the combination of 6% zeolite and 125kg N per ha increased vegetative growth and the efficiency of nutrient uptake of N fertilizer for corn plants in sandy soil.

Table 4: Agronomic efficiency of sweet corn plant

Treatments	Agronomic Efficiency (kg kg^{-1}N)
N Rates (kg ha^{-1})	
150	18.883a
300	10.988b
Maggot Frass	
Control	10.426a
Maggot Frass	14.125a
Maggot Frass + Zeolite 5%	18.359a
Maggot Frass + Zeolite 10%	16.832a

Values followed by the same letter in the same column and treatments are not significantly ($P<0.05$) different according to DMRT

Conclusion

In conclusion, the application of N doses improved the growth and yield of corn plants and the best result was at a dose of 150kg ha^{-1}. Increasing the dose of N decreased agronomic efficiency, and the highest value was achieved at 150kg ha^{-1} of 18.883kg kg^{-1} N. The application of maggot frass did not show an effect on the growth and yield of sweet corn. Maggot frass enriched with 5% zeolite had indications of increasing agronomic efficiency of sweet corn plants.

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