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Micro and Macronutrient Availability for Rice Growth on Sandy Soil with Application of *Azolla microphylla* and Poultry Manure

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Abstract

Sandy soil has various constraints, such as the low availability of N, P, and K nutrients. Organic matter should be applied to improve soil conditions. This study's organic materials used as ameliorants included chicken manure and *Azolla microphylla*. This study aimed to determine the effect of *A. microphylla* and chicken manure on the availability of micro and macronutrients and rice growth in sandy soil. The research was conducted on the sandy soil of Samas Beach, Bantul, Yogyakarta. The study used a factorial complete randomized block design consisting of 2 factors. The 1st factor is the dose of Azolla (0 and 7.5 tons ha^{-1}). The 2nd factor is the dose of chicken manure (50, 100, 150 tons ha^{-1}). The results showed no interaction between the application of *A. microphylla* and chicken manure. The application of chicken manure increased NO_3^-, available P, and available K levels. The application of *A. microphylla* increased the height of rice plants. Azolla 7.5 tons ha^{-1} and chicken manure 150 tons ha^{-1} showed the highest values in NO_3^- (0.11 mg l^{-1}), available P (6.74 ppm), and organic C (0.27%). Chicken manure of 150 tons ha^{-1} can increase the number of grains per panicle. These findings offer a potential strategy for addressing nutrient deficiencies in sandy soils and improving rice growth.

Keywords: *Azolla microphylla*; macronutrients; micronutrients; sandy soil; soil characteristics

INTRODUCTION

The decrease in paddy fields due to land conversion has increased because new areas on suboptimal land are opened to support food security. One suboptimal land with the potential for agriculture is sandy soil, which has low soil quality to support plant growth. Indonesia is an archipelagic country where 60% of its territory is water. Throughout Indonesia, sandy soil has an extensive availability, which can be used for the agricultural sector, such as rice, chilies, melons, dragon fruit, shallots, and cabbage. The organic material content affects the condition of the soil aggregate so that unstructured sandy soil. Also, sandy soil has a low cation exchange capacity (CEC) and nutrient content because the mineral content has not been weathered, and leaching exists (Riwandi et al., 2016). Essential nutrient-containing elements are generally difficult to dissolve, so their ability to provide crucial elements is low. Sandy soil has low Ca, N, and K contents, moderate available P, very high total P, and very low electrical conductivity following research conducted by Indradewa (2021) on the sandy soil properties of Samas Beach, Bantul Regency, Yogyakarta, show that the soil has organic C, N, available K, and CEC in the very low category. One of the obstacles to cultivating plants on sandy soil is the low

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availability of nutrients. Following previous research conducted by Suleman et al. (2016), soil with unhealthy criteria requires the application of additional organic materials, such as chicken manure and *Azolla microphylla*.

Given the global food security challenges, especially in nutrient-poor sandy soils, adopting sustainable practices is essential to increase nutrient content and ensure safe food production. While growing food production, conventional and intensive farming systems often lead to severe environmental impacts such as land degradation, soil erosion, water pollution, and biodiversity loss, which threaten food security and agricultural sustainability (Rehman et al., 2022). Thus, efforts to increase nutrient availability in sandy soils can be made using organic matter to support plant growth. Organic matter has a significant role in improving the physical, chemical, and biological properties. Adding organic matter to sandy soil can improve nutrient and water retention and help increase soil fertility by slowly releasing N and other nutrients through mineralization (Iqbal et al., 2019). Several organic materials, such as chicken manure, can improve the soil's physical, chemical, and biological properties (Kamsurya and Botanri, 2022). In another study by Syamsiyah et al. (2023), increased soil physical quality is associated with high organic matter content because it can stimulate biological activity and the formation of aggregations to create stable aggregates and good porosity. Besides that, soil arthropods are essential for the soil community due to their function in soil health sustenance. They are imperative bioindicators in monitoring environmental changes because they can provide comprehensive information that integrates chemical, physical, and biological parameters (Kurniawan et al., 2023).

The decomposition of organic matter produces humus with a greater surface area and adsorption capacity than clay, improving soil aggregation. Previous research conducted by Indradewa (2021) showed that the need for organic material on sandy soil is more than on conventional land, namely around 15 to 20 tons. Applying 20 tons of manure can reduce the use of NPK up to 200 kg ha^{-1}. The application of Azolla with the dose of 2 and 10 tons ha^{-1} manure can increase N and P uptake by 7.6% and 13.7%, respectively. Furthermore, it can also increase the number of tillers by 9.88%, grain yield by 5.63%, and 1,000 grain weight by 4.56%, compared to the application of Azolla (Syamsiyah et al., 2018). Using Azolla and manure increases soil NH_4^+ and NO_3^- content (Mujiyo et al., 2011). The NH_4^+ and NO_3^- are constituents of amino acids, proteins, and chlorophyll pigment components, which are important in photosynthesis. However, research on the availability of micro and macronutrients with the application of *A. microphylla* and chicken manure on coastal sand has never been carried out. This research aims to determine the interaction between *A. microphylla* and chicken manure on the availability of micro and macronutrients and rice yields on coastal sand land.

MATERIALS AND METHOD

Experimental treatments and design

The experiment was conducted on the sandy soil of Samas Beach, Sogesanden Hamlet, Srigading Village, Sanden Sub-district, Bantul, Yogyakarta, located at 110°16'52" E and 7°59'15" S from April to September 2021. Soil sample analysis was conducted at the Soil Chemistry and Fertility Laboratory, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta. The research used a factorial randomized completely block design (RCBD) consisting of 2 factors, namely: *A. microphylla* (0 (A0) and 7.5 tons ha^{-1} (A1)) and chicken manure (50 (Y1), 100 (Y2), and 150 (Y3) tons ha^{-1}). Each treatment was repeated 4 times so that there were 24 experimental units.

The research began with preparing experimental land as raised beds measuring 2.5 m x 2.5 m and Azolla cultivation ponds measuring 2 m x 3 m. *A. microphylla* and chicken manure were applied to the soil 7 days before rice planting. Azolla application on stage 2 was carried out when the rice was 20 days after planting by making rows on each bed and then immersing it in the soil. The rice used for research is the Ciherang variety because the planting age is only 116 to 125 days and it is more resistant to pests. Maintenance of rice plants consists of watering twice daily every morning and evening, weeding out weeds, controlling plant pests and diseases manually, or using pesticides such as *ad decis* and *furadan*. Observations of plant height and number of tillers were carried out every 10 days. Harvesting is carried out when the rice is 100 days after planting. Soil sampling is done by taking soil directly from each bed to a 0 to 15 cm depth.

The parameters measured were NO_3^- (Morgan Wolf, 2021), NH_4^+ (Morgan Wolf, 2018), available P (Olsen, 2021), available K (Spektrofotometri UV-Vis, 2021), organic C (Walkey and Black, 2023), Fe (Morgan Wolf, 2022), and Mn (Morgan Wolf, 2019). Plant observations included plant height, total tillers number, number of grains per panicle, wet root weight, root volume, and productivity. The characterization of Azolla included the water content using the gravimetric method (Sepdyastutik, 2022) and the N content of Azolla using the Kjeldahl method (Amalia and Fajri, 2020). Characterization of chicken manure includes pH analysis using the electrometric method, total N content using the Kjeldahl method, total P, total K, C/N ratio using the spectrophotometric method (Safari et al., 2023), and organic C using the Walkley and Black method (Agnesia and Sulistyaningsih, 2022).

Data analysis

The data is calculated according to the formula for each parameter and then analyzed using a two-way analysis of variance (ANOVA). The significant differences among the mean data were assessed at the 5% probability level. Duncan's multiple range test (DMRT) was employed to determine significant differences among the mean values.

RESULTS AND DISCUSSION

Soil and fertilizer characteristics

The type of soil on the research land based on soil taxonomy by USDA is Entisols. The characteristics of sandy soil can be seen in Table 1.

The analysis results show that the soil pH is classified as slightly acidic. The available N (NO_3^- and NH_4^+), P, K, Fe, and Mn are very low. It is because high porosity makes it very easy for water that carries nutrients to seep deep into the soil, and as a result, the nutrients needed by plants cannot be reached by the roots. The characteristics of *A. microphylla* and chicken manure used in the research are presented in Table 2.

The chicken manure used in the research has a neutral pH (7.02). The content of the 3 macronutrients N, P, and K has a value of 4.54 ppm and has met the quality standards for organic fertilizer, where the minimum required content is 4 ppm. Apart from that, the C/N ratio (14.50) and the organic C content of manure chicken (28.56) also meet Minister of Agriculture Decree No. 261 Year 2019 (Table 2). *A. microphylla* has higher N levels (2.59%) than P_2O_5 (0.63%) and K_2O (0.87%). *A. microphylla* can have a symbiotic relationship with Cyanobacteria *Anabaena azollae*, which can fix N in the air (Setiawati et al., 2019). The organic C content of Azolla is relatively high (31.62), which means the organic material content is also high. At the same time, the C/N ratio (12.21) indicates that *A. microphylla* is in reasonably good condition (medium criteria) in supplying the nutrients needed by plants (Lestari et al., 2019). The nutrients contained

Table 1. Characteristics of sandy soil

Variable	Value	Unit	Level
pH H_2O	5.98	–	Slightly acid
pH KCl	5.59	–	Slightly acid
NO_3^-	0.10	ppm	Very low
NH_4^+	0.003	ppm	Very low
Available P	3.19	ppm	Very low
Available K	0.13	me 100 g^{-1}	Very low
Organic C	0.10	%	Low
Available Fe	6.68	ppm	Very low
Available Mn	0.09	ppm	Very low

Note: Classification based on Indonesian Soil Research Institute (2019)

Table 2. Characteristics of *A. microphylla* and chicken manure

Variable	Unit	Chicken manure	Standard chicken manure*)	*A. microphylla*	Standard green manure*)
Water content	%	–	–	90.5	8–20
pH	–	7.02	4–9	–	4–9
Total N	%	1.97		2.59	
Total P	%	1.74	Min. 2	0.63	Min. 2
Total K	%	0.83		0.87	
Organic C	%	28.56	Min. 15	31.62	Min. 15
C/N ratio	–	14.50	≤ 25	12.21	≤ 25

Note: *) Based on Minister of Agriculture Decree No. 261 Year 2019 in *A. microphylla* met Minister of Agriculture Decree No. 261 Year 2019.

Effect of treatment on soil chemical properties

Chicken manure and *A. microphylla* were applied to the soil as amendment material. The use of soil amendments is primarily aimed at improving the soil's physical, chemical, and/or biological quality so that soil productivity becomes optimum. The effect of chicken manure and Azolla application can be seen in Table 3.

There was no interaction between chicken manure and *A. microphylla* on micro and macronutrient levels in sandy soil (Table 3). The application of chicken manure affects NO_3^- ($p < 0.01$), available P and K. This is caused by the dose of chicken manure given according to the dose the plants need. Nurjanah et al. (2020) explained that chicken manure contains several macronutrients that plants need, such as N, P, and K, which can help in plant production. Yulianto et al. (2021) also explained that chicken manure is a good source of micro and macronutrients and can increase soil fertility. According to Walida et al. (2020), the increase in N comes from the mineralization of the organic material. The effect of chicken manure application on the availability of micro and macronutrients can be seen in Table 4.

The analysis showed that NO_3^-, available P and K increased along with increasing doses of chicken manure ($p < 0.01$). The C/N ratio of chicken manure of 14 can increase the NO_3^- production rate, making it quickly available to plants and improving soil fertility (Yuniarti et al., 2019). NH_4^+ in the soil is not easily leached, so the ongoing process of weathering organic material will increase the soil's NH_4^+ content (Sukaryorini et al., 2016). In another study, Sari and Arifandi (2019) stated that chicken manure is a source of N, which can increase N availability by up to 50%. Chicken manure can increase CEC or availability of nutrients, especially N, P, and K (Hidayat et al., 2021). This is caused by organic acids produced from the manure decomposition, which can dissolve natural P into available P for plants. In another study, Wahyudi (2009) also explained that the decrease in P sorption and increase in available P was related to organic anions, which act as competing anions for P anions so that P is forced out of the soil sorption complex into available form. Silalahi et al. (2018) explained that the nutrients in chicken manure, especially N, P, and K, are helpful for plant growth. Microbes use K to break down complex organic materials into more straightforward organic materials, producing K elements available to plants (Kaswinarni and Nugraha, 2020). Chicken manure also contains higher K elements than other manures, where the K nutrient functions to help root growth (Riyani et al., 2013).

Based on the results of the analysis, it can be seen that the application of chicken manure does not affect organic C. The increase in soil organic

Table 3. Effect of application of *A. microphylla* and chicken manure on micro and macronutrient levels in sandy soil

Treatment	pH	NH_4^+ (mg l^{-1})	NO_3^- (mg l^{-1})	Available P (ppm)	Available K (cmol kg^{-1})	Fe (mg l^{-1})	Mn (mg l^{-1})	Organic C (%)
Azolla	0.88^{ns}	0.49^{ns}	0.30^{ns}	0.39^{ns}	0.59^{ns}	0.70^{ns}	0.73^{ns}	0.38^{ns}
Chicken manure	0.74^{ns}	0.53^{ns}	0.00^{*}	0.00^{*}	0.00^{*}	0.48^{ns}	0.06^{ns}	0.60^{ns}
Azolla x chicken manure	0.73^{ns}	0.40^{ns}	0.08^{ns}	1.00^{ns}	0.36^{ns}	0.32^{ns}	0.67^{ns}	0.61^{ns}

Note: Variance test results with a confidence level of 95%, * = Significant effect, ns = No significant effect

Table 4. Availability of micro and macronutrients with application of chicken manure

Treatment (tons ha^{-1})	NH_4^+ (mg l^{-1})	NO_3^- (mg l^{-1})	Available P (ppm)	Available K (cmol kg^{-1})	Organic C (%)	Fe (mg l^{-1})	Mn (mg l^{-1})
Y1 (50)	0.01	0.07^{b}	4.28^{b}	0.09^{c}	0.19	0.23	0.09
Y2 (100)	0.01	0.07^{b}	5.37^{b}	0.15^{ab}	0.26	0.23	0.13
Y3 (150)	0.01	0.11^{a}	6.74^{a}	0.26^{a}	0.27	0.23	0.13

Note: Numbers followed by different letters indicate significantly different results in the DMRT test ($\alpha = 0.05$)

Table 5. Analysis of the influence of *A. microphylla* and chicken manure on rice growth

Treatment	Plant height (cm)	Root wet weight (g)	Root volume (cm^3)
Azolla	0.033*	0.091ns	0.098ns
Chicken manure	0.371ns	0.374ns	0.296ns
Azolla x chicken manure	0.274ns	0.932ns	0.840ns

Note: Variance test results with a confidence level of 95%, * = Significant effect, ns = No significant effect

Table 6. Growth of rice with the application of *A. microphylla*

Treatment	Plant height (cm)	Root wet weight (g)	Root volume (cm^3)
A0	46.76ab	10.48	12.14
A1	54.56a	10.96	12.64

Note: Numbers followed by different letters indicate significantly different results in the DMRT test (α = 0.05)

C levels is caused by organic C contained in chicken manure, which is the main constituent of organic matter itself, so adding chicken manure can increase soil organic C levels. Hasibuan (2015) also explained that increasing organic C cannot be separated from the role of compost, which contributes to producing organic material. Compost can speed up the process of breaking down organic matter into humus in the soil to reduce the soil volume and increase the soil's total porosity. Manure can improve soil quality by increasing organic C levels and the activity of soil biota so that porosity can increase (Surya et al., 2017).

Fe in chicken manure comes from adding Fe to chicken feed as salt (Shofiah et al., 2024). The Fe nutrient is a micronutrient that functions as an enzymatic cofactor, plays a catalytic role, and is only needed by plants in small amounts. If the level of Fe in the soil is excessive, it can poison the plant. Fe levels in the 3 treatments showed the same value. The chicken manure decomposition can break bonds with the elements Fe and Mn. Mn is a metal element that plants need in small amounts. In the soil, Mn^{4+} is located in MnO_2 compounds, which are insoluble in water and contain CO_2. In reducing (anaerobic) conditions due to the decomposition of organic material with high levels, Mn^{4+} in MnO_2 compounds undergoes reduction to soluble Mn^{2+}. Mn^{2+} binds to NO_3^-, SO_4^{2-}, and Cl^- and is soluble in water (Seran, 2017). Mn plays a role in chlorophyll synthesis as a coenzyme and an activator of respiratory enzymes in N metabolism reactions and photosynthesis. If the soil's Mn content is too high, it can poison plants and thus disrupt plant productivity (Saragih and Sitanggang, 2021). Chicken manure contains Mn, which plants need to maintain nutrient balance in the soil (Hs et al., 2022).

Effect of application of *A. microphylla* and chicken manure on rice growth

Organic material functions as a soil improver and can also help plants absorb nutrients. The effect of applying *A. microphylla* and chicken manure can be seen in Table 5. The results of the analysis show that there is no interaction between *A. microphylla* and chicken manure on rice growth Table 6. However, a single application of *A. microphylla* significantly affected rice plant height. The N content in Azolla is relatively high, causing the availability of N in the soil to increase and increase plant height (Setiawati et al., 2019).

The application of *A. microphylla* significantly affects the plant height. *A. microphylla* dose of 7.5 tons ha^{-1} showed higher plant height than without Azolla. The high N content in *A. microphylla* causes the availability of N in the soil to increase the plant height in rice. The study of Waskito et al. (2017) explains that N can increase the number of meristems produced by plants and increase vegetative growth. From the results of measuring the weight of rice roots, it can be seen that the application of high doses of organic fertilizer affects the weight of rice roots. The more organic fertilizer applications, the better the root area. Root growth is influenced by organic matter, which can improve soil structure so that rice roots develop well (Oh, 1979). Good root development will affect plant growth. The wider the root area, the more fertile the plant will grow. Soedharmo et al. (2016) also suggested that the distribution of dry matter accumulation in plant parts such as roots, stems, and leaves can reflect plant productivity.

CONCLUSIONS

There is no interaction between applying *A. microphylla* and chicken manure on micro and macronutrients and rice growth. Applying chicken manure in sandy soil can increase NO_3^-, available P and K. The application of *A. microphylla* significantly increased the height of rice plants on coastal sandy soil. The best combination is 7.5 tons ha^{-1} *A. microphylla* and 150 tons ha^{-1} chicken manure showing the highest values for nitrate (0.11 mg l^{-1}), available P (6.74 ppm), and organic C (0.27%). Besides that, there is a need for further research, such as increasing the dose of chicken manure and *A. microphylla*. The shortcomings in this research are so that better results can be seen.

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