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Dynamics of N-NH_4^+, N-NO_3^-, and total soil nitrogen in paddy field with azolla and biochar

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Abstract. Nitrogen (N) is one of macronutrients which is dynamic in the soil and becomes constraint factor for rice crops. The addition of nitrogen fertilizers and its absorption in paddy field causes the dynamics of nitrogen, thus declines of N absorption efficiency. The aim of this research is to know influence Azolla, biochar and different varieties application on N-NH_4^+, N-NO_3^-, and total soil N in paddy field. This research was conducted in a screen house located in Jumantono Laboratory, Faculty of Agriculture, Universitas Sebelas Maret (UNS) with altitude 170 m asl from April to June 2016. Treatment factors that were examined consisted of azolla (0 and 10 tons/ha), biochar (0 and 2 tons/ha), and rice varieties (Cisadane, Memberamo, Ciherang, IR64). The results of this research showed that there was no interaction between azolla, biochar and varieties. Nevertheless, azolla treatment with dose of 10 tons/ha increased soil NH_4^+ content (41 days after planting, DAP) by 13.4% but tend to decrease at 70 and 90 DAP. Biochar treatment with dose of 2 ton/ha increases NO_3^- soil content (70 DAP) by 1.7% but decreases total N soil by 5.8% (41 DAP) and 4.7% (90 DAP). Different rice varieties generated different soil NH_4^+ content (41 DAP) and rice root volume. Cisadane variety can increase soil NH_4^+ content (41 DAP) by 52.08% and root volume by 51.80% (90 DAP) compared with Ciherang variety. Organic rice field management with azolla and biochar affects the availability of N in the soil and increase N absorption efficiency through its role in increasing rice root volume.

1. Introduction

Rice is a staple food and economic resource for Indonesian and becomes strategic value in achieving National Food Security. According to Indonesian Central Bureau of Statistics (BPS) [1], rice production decreased by 0.43 million tons or 0.61%. This decline is caused by the lack of nutrient management system, particularly the management of N, P, K nutrients which are unbalanced in intensified paddy field [2].

Nitrogen is one of the most important nutrients, as it improves grain quality and yield by increasing the number of tillers, leaf area development, grain formation, grain filling and protein synthesis [3]. In general, nitrogen in the soil is mobile and dynamic, it can easily change from one form to another form such as from NH_4^+ to NO_3^-, NO, N_2O and N_2 [4] leads to low absorption efficiency and total absorption of nitrogen in rice crops.

The use of organic substances such as azolla and biochar may provide nitrogen for rice crops [5] and improve environmental conditions as it increases soil CEC [6]. Azolla is one of the most suitable sources of nitrogen developed in paddy fields, since it is able to reduce nitrogen from the atmosphere to ammonia [7], in the amount of 100-170 kg N ha^{-1} per year [8]. The high content of nitrogen produced by azolla biomass must be balanced with maximum management to optimized nitrogen utilization, for example by using biochar and high yielding varieties.

Nitrogen availability in the soil is influenced by several factors such as the addition of nitrogen fertilizer, nutrient absorption and nitrogen cycle occurring in the soil. Because of the complexity of the nitrogen transformation, it is necessary to investigate the dynamics of nitrogen on paddy fields. This study aims to examine the effect of azolla, biochar and varieties on the dynamics of NH_4^+, NO_3^- and total nitrogen soil in paddy soil.

2. Methods

This research was conducted in a screen house located in Jumantono Laboratory, Faculty of Agriculture, Universitas Sebelas Maret (UNS) with altitude 170 m asl from April to June 2016. The characteristics of soil used as planting medium are presented on Table 1. This soil is an organic soil originated from Kebonagung, Sidoharjo, Wonogiri Regency.

Table 1. Soil Chemical Properties before Treatment

Parameter	Value
Organic C	4.19%
NH_4^+	0.004 ppm
NO_3^-	0.02 ppm
Total N	0.84%
pH H_2O	6.58
K_2O	2.31 cmol(+)/kg
P_2O_5 (Olsen)	12.33 ppm
CEC	44.51 cmol(+)/kg

This research used 0 and 10 tons/ha azolla as green manure and 0 and 2 tons/ha biochar as well as four different rice varieties (Cisadane, Memberamo, Ciherang and IR64). Half the dose of azolla and the whole dose of biochar were applied before planting by being immersed. Five days later half the remaining dose of azolla was applied by being spread on the surface. After azolla fully grown, 60% of azolla was embedded into the soil relate to the second weeding activities of azolla. Meanwhile, the rest of azolla (40%) was allowed to continue to grow until the rice crop was harvested.

This experiment used completely randomized block design (CRBD) and the data were analyzed by using ANOVA with F test at the level of 95% and then followed by DMR test at the level of 95% as well as correlation test. Various parameters were measured including NH_4^+ and NO_3^- soil (determining ammonium method with KCl 1 N), total nitrogen soil (Kjedahl) and root volume of paddy.

3. Results and Discussion

3.1 Effect of Azolla on N-NH_4^+, N-NO_3^-, Total N Soil and Rice Root Volume

The application of azolla with dose of 10 tons/ha increased ($p<0.01$) soil NH_4^+ content by 13.4% (41 days after planting, DAP) and rice root volume (41, 70 and 90 DAP; Table 2). It is in line with Mujiyo et al. [5] in which the use of azolla fertilizer increased NH_4^+ content in the soil, since Azolla fertilizers mineralized and transformed into simple components such as NH_4^+ and NO_3^-. Root volume on 41, 70, and 90 DAP also increased by 6.3, 8.3 and 13.3%, respectively (Table 2), compare to those without azolla application. According to Fosu-Mensah et al. [9] azolla increased the whole growth of rice plants as indicated by plant height, total dry weight, and grain yield.

Elements derived from the high N content of azolla will be released into the soil after azolla decomposition [10], followed by increasing total N of soil [11]. Nevertheless, in this research NO_3^- and total nitrogen soil was not affected ($p>0.05$) by azolla application. It is assumed that NH_4^+ released by azolla has not been nitrified to NO_3^- and NO_2^- but only increases NH_4^+ content. Furthermore, the increase in NH_4^+ did not increase the total Nitrogen of soil since total nitrogen consists of organic and inorganic N, by which amount of organic N in the soil is more than 90% [11]. According to Suntoro et al. [12] azolla as a green manure has not been able to increase the total N of soil, because azolla must be decomposed first to provide nitrogen. This process occurs gradually and takes quite a long time to completely decomposed.

Table 2. Effect of Azolla Application on NH_4^+ Soil Content (41 DAP) and Root Volume (41, 70, 90 DAP)

Dose of Azolla (tons/ha)	NH_4^+ Soil Content (ppm)	Root Volume (cm^3) 41 DAP	70 DAP	90 DAP
0	0.575^a	0.426^a	2.457^a	8.054^a
10	0.652^b	0.453^b	2.660^b	9.126^b

The number followed by the same letter in the same column shows no significant difference in the DMRT test of 5%

3.2 Effect of Biochar on N-NH_4^+, N-NO_3^-, Total N Soil and Rice Root Volume

The application of biochar with dose of 2 tons/ha enhanced ($p<0.05$) soil NO_3^- content by 1.7% (70 DAP) and total soil nitrogen (41 and 90 DAP; Table 3). The small magnitude in the increase of NO_3^- content was due to the first season of application biochar has a low adsorption capacity compared with long-standing biochar, as has been explained by Cheng et al. [13]. Based on several studies, Clough et al. [14] summerized that biochar is able to absorb NO_3^- longer in the soil, so it is not washed away and can be absorbed by plants. Furthermore, Dempster et al. [15] explained that biochar application increased water holding capacity led to reduce nutrients leaching in the soil, including NO_3^-. However, application of 2 tons/ha of biochar treatment generated lower total nitrogen content than without biochar treatment (Table 3). It is assumed that application of biochar in the soil can improve the physical and chemical properties of the soil, thus, supports the plant roots to absorb nitrogen. In line with this research, Santoso [16] explained that N total in the soil decreased due to absorption by the rice plants.

Table 3. Effect of Biochar Application on NO_3^- Soil Content (70 DAP) and Total N Soil Content (41 and 90 DAP)

Dose of Biochar (ton/ha)	NO_3^- Soil Content (ppm)	Total N Soil Content (%) 41 DAP	90 DAP
0	0.0058^a	0.580^a	1.034^a
2	0.0059^b	0.548^b	0.988^b

The number followed by the same letter in the same column shows no significant difference in the DMRT test of 5%

3.3 Effect of Different Rice Varieties on N-NH_4^+, N-NO_3^-, Total N Soil and Rice Root Volume

The application of different rice varieties resulted in different ($p<0.01$) rice root volume (41, 70 and 90 DAP). Table 4 shows that two varieties (Cisadane and Memberamo) generated the higher root volume than other varieties. The largest increase of rice root volume was found for Memberamo compared to Ciherang variety on 41 and 70 DAP by 80.0% and 52.0%, respectively. While on 90 DAP, the largest increase was found in Cisadane variety 51.8% compared to Ciherang variety. This result indicates that the use of different rice varieties can provide a varied growth response. According to Adisarwanti [17] the growth response of rice plants varies depending on genetic factors and growing environmental conditions. The use of different varieties also increased NH_4^+ soil content (41 DAP) with the highest increase in Cisadane variety which is 52.08% compared with Ciherang variety and 14.77% compared with Memberamo variety and 35.94% compared to IR64 variety.

Table 4. Effect of Varieties Application on NH_4^+ Soil Content (41 DAP) and Root Volume (41, 70, 90 DAP)

Rice Varieties	NH_4^+ Soil Content (ppm)	Root Volume (cm^3)		
		41 DAP	70 DAP	90 DAP
Cisadane	0.730^c	0.730^c	2.826^c	10.217^c
Memberamo	0.636^b	0.636^d	2.904^c	8.898^b
Ciherang	0.480^a	0.480^a	1.909^a	6.732^a
IR64	0.537^a	0.537^b	2.231^b	7.521^a

The number followed by the same letter in the same column shows no significant difference in the DMRT test of 5%

Nitrogen availability is indispensable for the root growth and development, and the preferred form of Nitrogen for rice plants is NH_4^+ [18]. A good plant's root growth affects the availability of nutrients in the soil including NH_4^+. Santoso [16] explains that the reaction between root plant and soil will affect the environmental conditions of the rhizosphere by releasing CO_2, H^+, HCO_3^- and other organic compounds, which affect the availability of nutrients. Furthermore, Mantelin and Touraine [19] explain that the condition of rhizosphere is influenced by root activity that becomes habitat for soil microorganisms because of organic nutrients availability are beneficial to microorganisms' growth. The microbial colonization that occurs will affect the biology of roots and plants.

3.4 Effect of Azolla, Biochar and Different Rice Varieties on the Dynamics of N-NH_4^+, N-NO_3^- and Total N Soil

Azolla treatment with dose of 10 tons/ha significantly affect the dynamics of N-NH_4^+ in the soil (Fig. 1), whereas 2 tons/ha biochar treatment significantly affected the dynamics of N-NO_3^- (Fig. 2) and total N soil (Fig. 3). The decrease in NH_4^+ soil content from 41 DAP to 90 DAP (Fig. 1) was caused by an increase in the rice root volume (Fig. 4), and supported by the close relationship between the decrease in NH_4^+ soil content and the increase of rice root volume (Fig. 5). This result is in line with Sipahutar and Kasno [20] that the decrease of NH_4^+ content in the soil is caused by faster absorption of NH_4^+ ions by plants and partly lost or transformed into a form which is not available to plants.

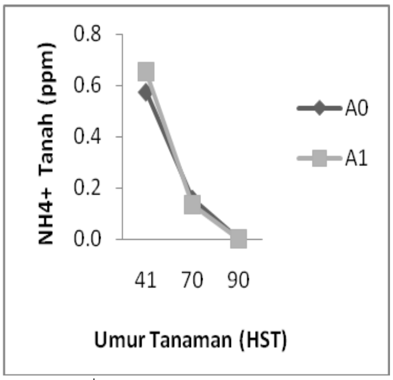

Figure 1. NH_4^+ soil content 41, 70 and 90 DAP

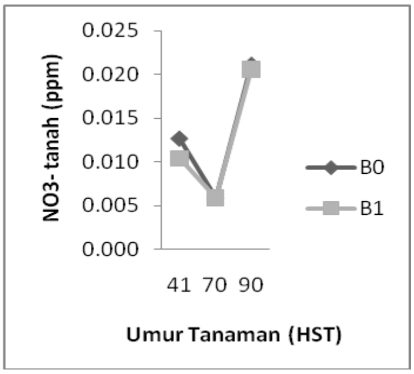

Figure 2. NO_3^- soil content 41, 70 and 90 DAP

The increase of NO_3^- soil content from 70 DAP to 90 DAP (Fig. 2) is inversely proportional to the NH_4^+ content (Fig. 1). This is in line with Purwanto [21] who observed that the decrease of NH_4^+ in soil increased NO_3^- concentration in the soil due to nitrification. The decreased of total N soil content at 70 DAP and increased at 90 DAP (Fig. 3) was influenced by the rapid process of mineralization and immobilization of nitrogen. The increasing of total N is due to inorganic N such as NO_3^- and NH_4^+ used by soil microorganisms for the decomposition process of crop residue which leads to increase N-organic soil [22].

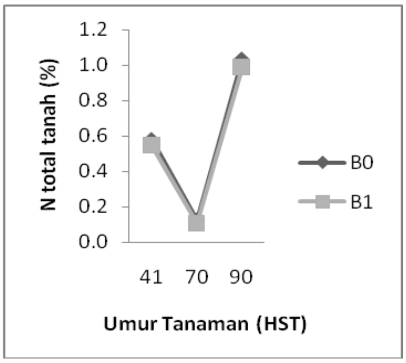

Figure 3. Total N soil content 41, 70 and 90 DAP

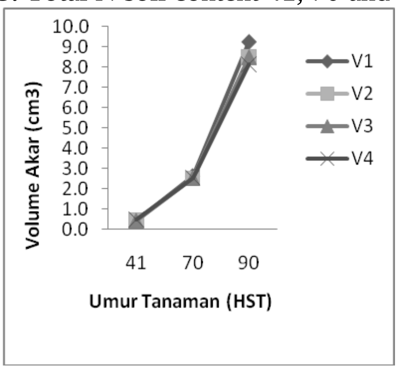

Figure 4. Rice root volume 41, 70 and 90 DAP

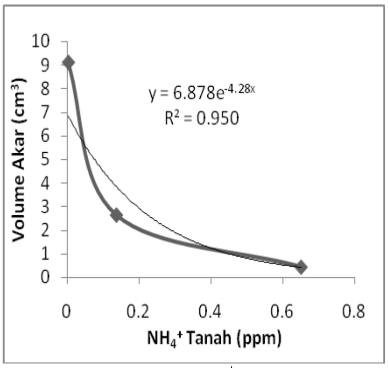

Figure 5. Correlation graph of NH_4^+ soil content and root volume

4. Conclusion

Application of azolla with dose of 10 tons/ha enhanced the soil NH_4^+ content at 41 DAP but tends to decrease at 70 and 90 DAP. Azolla increased rice root volume at 41, 70 and 90 DAP. Biochar with dose of 2 tons/ha increased NO_3^- soil content at 70 DAP but decrease N total of soil content at 41 DAP by and 90 DAP. The use of different varieties caused different NH_4^+ soil content and roots volume. Cisadane variety generated higher NH_4^+ soil content at 41 DAP and root volume at 90 DAP compared with Ciherang variety. Organic rice field management with azolla and biochar affect the availability of N in the soil and increased N absorption efficiency through its role in increasing the root volume of rice crops.

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