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$_2$O 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.

| Parameter       | Value         |
|-----------------|---------------|
| Organic C       | 4.19%         |
| NH\(_4^+\)      | 0.004 ppm     |
| NO\(_3^-\)      | 0.02 ppm      |
| Total N         | 0.84%         |
| pH H\(_2\)O     | 6.58          |
| K\(_2\)O        | 2.31 cmol(+)/kg |
| P\(_2\)O\(_5\) (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, Cihang 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 Muijyo 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.

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] summarized 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.

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 Ciheraing 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 Ciheraing 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.

### 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 | 70 | 90 |
| 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%.

### 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%.
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  | 70  | 90  | 41  | 70  | 90  |
| 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](image_url)
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 \( \text{NH}_4^+ \) soil content and root volume

4. Conclusion
Application of azolla with dose of 10 tons/ha enhanced the soil \( \text{NH}_4^+ \) 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 \( \text{NO}_3^- \) 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 \( \text{NH}_4^+ \) soil content and roots volume. Cisadane variety generated higher \( \text{NH}_4^+ \) 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 increase \( \text{N} \) absorption efficiency through its role in increasing the root volume of rice crops.

Acknowledgement
This research was supported by INSENTIF RISET SINAS, The Ministry of Research, Technology and Higher Education, Republic of Indonesia, 2016. We also would like to thank “TIM PENELITIAN PADI 2016” (Rizka and Krista) for their participation on paper preparation.

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