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Leaching Behaviour of Nitrogen in Forage Rice Cultivation that Applied with Animal Manure

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ABSTRACT

Increased use of N fertilizer may substantially increase of nitrate nitrogen (NO_3-N) leaching, which potentially pollutes groundwater. Leaching behaviour of nitrogen (N) was observed in the paddy field of forage rice cultivation. Two kinds of animal manure, cattle manure (CM) and poultry manure (PM) at 5 levels of N application (0, 70, 140, 210, 280 kg N ha^{-1}) as the organic N sources, and without any chemical fertilizers. "Tachisuzuka" forage rice variety was conducted in the experimental plot. Porous ceramic cups were installed in triplicate of each treatment at 45 cm depth to collect the percolation water samples during the cultivation rice periods. The concentration of total N, NH_4-N, NO_2-N and NO_3-N of water (surface and percolation) and soil sample solution were analysed using a Hach DR/2800 spectrophotometer. Result showed that NO_3-N leaching was higher than NH_4-N in the percolation water during the cultivation of forage rice periods. The highest NO_3-N leaching was found in 280 kg N ha^{-1} (6.3 mg L^{-1}), that it was indicated on the polluted levels. The highest of biomass production was in N280 (16.22 t ha^{-1}) and nearly similar result in N140, N210 and N280. It was concluded that the best application of N-fertilizer in 140 kg N ha^{-1} because it greatly enhanced N-fertilizer efficiency, and decreased steadily of NO_3-N concentration leaching in the environment of the groundwater.

Keywords: Ammonium (NH_4-N), Forage rice, N behavior, Nitrate (NO_3-N), N leaching

INTRODUCTION

In Japan, increasing numbers of farmers produce forage rice, which not only improves the country's self sufficiency with respect to feed but also contributes to the rural economy. Cultivation of forage crop in excess paddy fields is considered a promising way to enhance feed supply (Sakai *et al*. 2003; Kato 2008; Matsushita *et al*. 2011). New rice cultivars for whole crop silage (WCS) use have been released by the Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan (Sakai *et al*. 2003; Ookawa *et al*. 2010). As a result of subsidies from the Japanese government, the area for WCS rice cultivation has been increasing, reaching 26,000 ha in 2013 (MAFF 2013; Asada *et al*. 2013).

In forage rice as whole crop silage production, the whole plant is important; for example, high productivity of the whole plant including leaves, culms and grain is more important than grain weight compared to the varieties of rice for food (Sakai *et al*. 2003). Forage rice crop has advantages both in the effective use of the paddy fields and in the increase in self-supply rate of forage. (Kato 2008; Sakai *et al*. 2008; Matsushita *et al*. 2011).

Forage rice, which are a series of new varieties of rice that have been developed for use as whole crop silage for livestock feed, requires and tolerates higher nitrogen loading than as staple food varieties of rice (Zhuo and Hosomi 2008). Since nitrogen is the major essential nutrient, the N supplying capacity of paddy soils has a great impact on rice yield. Intensive rice cultivation usually relies on large amounts of nitrogenous fertilizers. In the past, N has been applied more to satisfy the rice demands and the efforts to improve rice yield (Kamiji and Sakuratani 2011). In contrast, some portions of N fertilizer are easily lost through various processes, such as leaching and denitrification. The increased use of N fertilizer may substantially increase nitrate-N (NO_3-N) leaching, which potentially pollutes groundwater. High nitrate concentrations are harmful to humans (Keeney 1982), and a high price is paid for aquatic environmental pollution caused by nitrogen application (Zhu *et al*. 2000).

The nitrogen losses or removals are N leaching through the soil by percolation water. Quantification of nitrate losses is important for devising measures to ensure sustainability of soil fertility and ground water resources and for the development of crop nutrient management. The nitrate concentration in the percolation water would be similar to the concentration in the ground water, if no nitrate decomposition takes places between the boundary of the root zone and the aquifer. Thus, attention should be focused on N losses in paddy fields because this may cause serious environmental problems. And it is well known that nitrogen content decreases in the paddy field. However, there are very few data available on the growth dynamic and environment of forage rice crop because of its short history, although the cultural practice of the whole crop rice is similar to that of normal rice.

In paddy field, the main source of N in rice is nitrate-N (NO_3-N), and ammonium-N (NH_4-N). NO_3-N is a mobile form of N, is very soluble and leaches easily when excess water percolates through the soil. And also, one of the most important forms of inorganic nitrogen needed for the growth of rice plants is NH_4-N. And it is known that the soil layers of rice paddies have the capacity to absorb NH_4-N. High NH_4-N concentration in soil during irrigation periods may result in lodging of rice plant due to root rot, and may lead to the leaching of high NO_3-N when rainfall occurs during non irrigation period. This has been corroborated by the fact that rice plants develop system for utilizing NH_4-N based on their physiological responded to such growth environments (Zhuo *et al*. 2011; Wang *et al*. 1993).

Organic wastes, especially animal manures, have long been used as sources of nutrient for crops. In recent years, there has been increasing interest in organic farming as an environmentally friendly alternative to conventional agriculture, and it has long been touted as the practice of choice around the world (Wang *et al*. 1995). The cultivation of forage rice consumes animal manure, which is overproduced in Japan. The main sources of NO_3-N (nitrate ions) and NO_2-N (nitrite ions) in the groundwater and surface waters are considered to be nitrogenous compound from agriculture and livestock farming (Kumazawa 2002).

Objectives of this study were to observe behaviour of nitrogen in the surface and the percolation water through the soil layers in the paddy field of forage rice cultivation, and to establish a proper fertilizer management practice that would minimize environmental pollution.

MATERIALS AND METHODS

Experimental Design

The experiment was conducted at the experimental paddy field plot using the soil which was classified as Andisol. Forage rice cultivation was carried out from June to October, 2012. Five treatment plots were constructed by inserting a plastic frame into the hard subsoil layer in the paddy field to prevent water from leaching laterally within the plow layer. The height of the frame was 20 cm above the ground level to ensure that flood water was retained within the plots. “Tachisuzuka” forage rice variety was transplanting into the experimental plot on June, 2012. Two kinds of animal manure namely fermented cattle manure (CM) and dry poultry manure (PM) (Table 1) at 5 levels available N (0, 70, 140, 210, 280 kg N ha^{-1}) (Table 2) were applied and without any chemical fertilizers. Each plot was sized 10 m^2.

Table 1. Chemical characteristics of the manures.

Characteristic	Cattle Manure	Poultry Manure
Total- N (%)	1.68	3.38
Total-P (%)	1.82	5.10
Total-C (%)	41.10	29.35
K_2O (%)	2.62	4.07
CaO (%)	0.79	19.17
MgO (%)	0.79	1.24
NO_3-N (mg 100 g^{-1})	0.63	8.75
NH_4-N (mg 100 g^{-1})	41.51	298.04
T-Inorg N (mg 100 g^{-1})	42.14	306.79
C/N ratio	24.47	8.69
Water content (%)	62.71	19.06

Table 2. Amount of N-applied derived from animal manure in each treatment.

Treatment	N (kg ha^{-1})	Animal manure (g m^{-2})	
		Cattle Manure (CM)	Poultry Manure (PM)
N0	0	0	0
N70	70	2000	270
N140	140	2000	630
N210	210	2000	1000
N280	280	2000	1360

N-PM = 2.75%, N-CM= 0.61%, effective N is different among kinds of manure, CM = 15%, PM =70%.

Sampling Method

Surface and Percolation Water Samples. The surface water samples from the paddy field plots were collected for determining of the NH_4-N concentration at 0 to 30 days after transplanting (the beginning start cultivation) in each treatment plot. The percolation water samples was collected by the porous ceramic cups (height 70 mm, outer diameter 18mm, and inner diameter 13 mm) which were installed and inserted through holes, were created using bore into the soil in depth of 45 cm below soil surface with three replicates in each treatment in 7, 14, 21, 28, 35 and 50 days after transplanting. Percolation water was only considered as the downward movement of water through layers of soil below the ground surface. The percolation water sample in the porous ceramic cup was taken and pumped off several times by hand pump and water sample was collected using a 50-ml polypropylene conical tube, which in suction tubes. The concentrations of total N, NH_4-N, NO_2-N and NO_3-N of water (surface and percolation) were analysed using a Hach DR/2800 spectrophotometer. The Persulfate Digestion Method, Salicylate Method, USEPA diazotization method and Cadmium Reduction Method were used in those samples of total N, NH_4-N, NO_2-N and NO_3-N, respectively.

Soil Samples. Soil samples were taken at 45 cm depth of soil in three replicates of each treatment before transplanting and after harvesting. A-2.5g of fresh weight soil samples was dissolved in 50 ml 2M KCl solution. The extracts were shaking for an hour time, and then centrifuged for 5 minute. The supernatant of samples were filtered through a glass microfiber filters (Whatman GF/C 47mm Ø circles, UK). The concentration of total N, NH_4-N, NO_2-N and NO_3-N of soil solution were analysed using a Hach DR/2800 spectrophotometer.

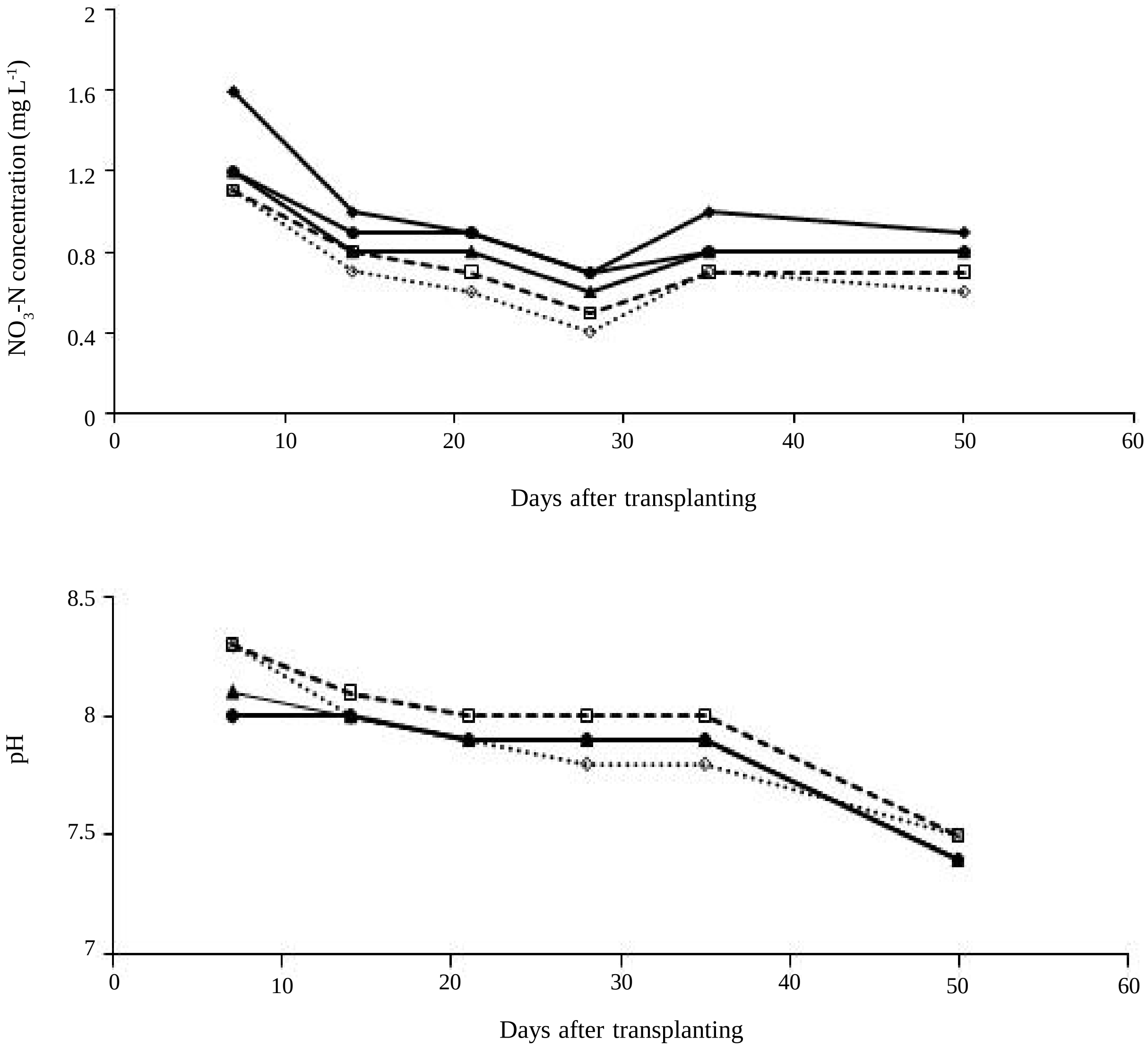

Figure 1. The NO_3-N concentration and the pH in the percolation water during the cultivation of forage rice. N0 (····◇····), N7 (--□--), N14 (—▲—), N21 (—●—), and N28 (—◆—).

RESULTS AND DISCUSSION

Nitrate (NO_3-N) Concentration and pH in the Percolation Water

As shown in Figure 1, the NO_3-N concentrations in the percolation water during the cultivation periods of forage rice increased as follow with increasing of N application, while the pH water decreased.

Increasing of the NO_3-N concentration in the percolation water was assumed due to increasing of N levels of animal manure application in the rice field. Highest concentration was found on the 280 kg N ha^{-1} application. The highest of NO_3-N leaching concentration was detected on 1.6 mg L^{-1} at the beginning cultivation rice. This result showed that the higher N fertilizer application could increase the NO_3-N leaching loss through the soil layers. However, the NO_3-N concentrations in the leachate had decreased during the cultivation rice periods.

It was reported that the higher of the percolation water, the higher is the leaching of nitrogen. Application of N fertilizer at higher doses caused higher N leaching losses (Sahu and Samant 2006). Higher application rates of N fertilizer combined with floodwater of rice field on high fertility soils seemed to have greater potential for NO_3-N leaching (Agrawal *et al*. 1999). On the farming practices and land use types may interfere with NO_3-N pollution via root zone, but not necessarily be the sole factor guiding spatial pattern of NO_3-N pollution in groundwater. Liu *et al*. (2005) reported that the levels of pollution are clean (0-3 mg L^{-1}), lightly polluted (3-6 mg L^{-1}), polluted (6-10 mg L^{-1}) and severely polluted ($\geq$ 10 mg L^{-1}). In this study, the highest of nitrate leaching was found in 280 kg N ha^{-1} application and the total NO_3-N cumulative in leachate water was 6.3 mg L^{-1} (Figure 1 and 3). That result was indicated on the polluted levels and potential of pollution by environment.

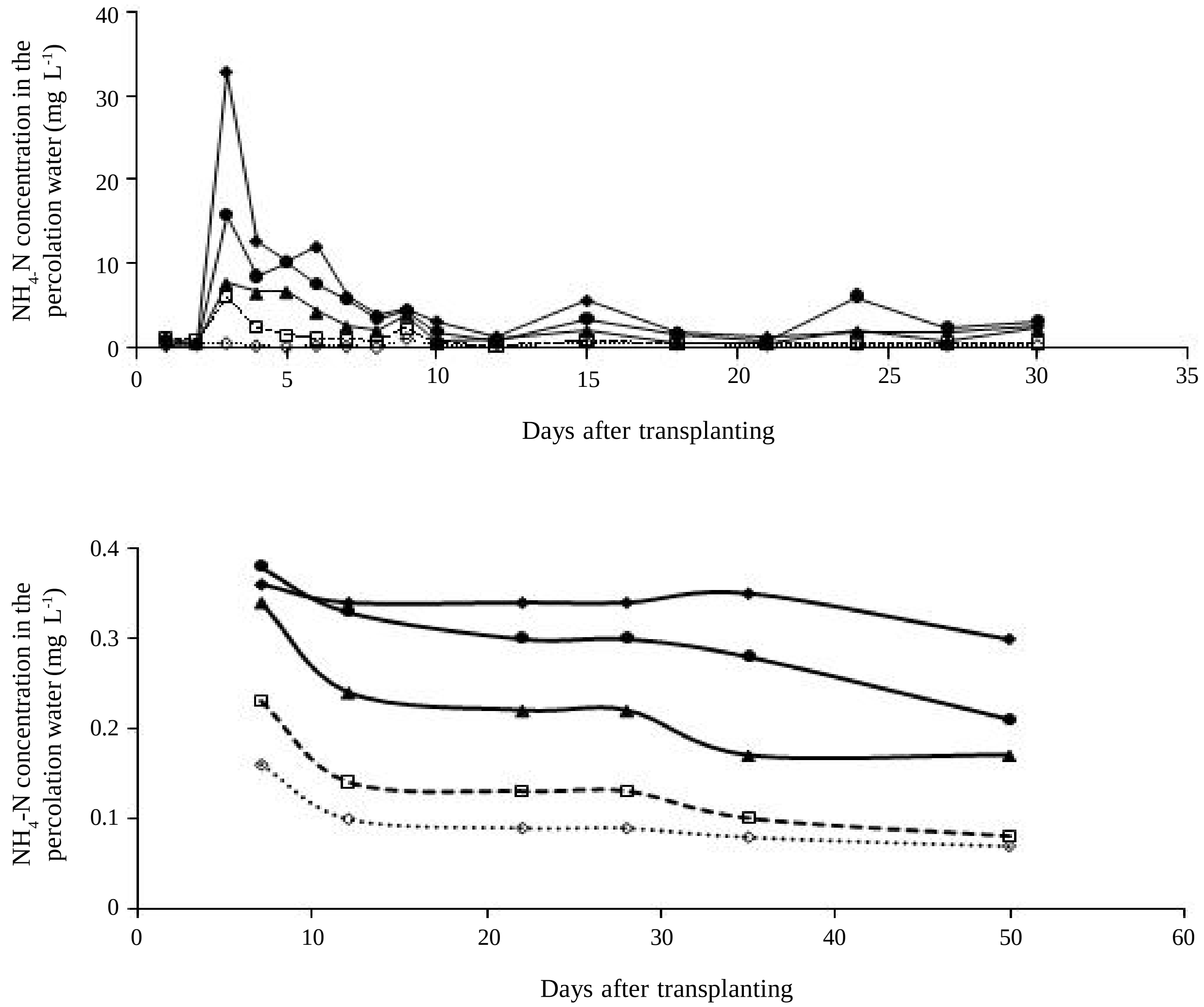

Figure 2. The NH_4-N concentration both of in the surface and percolation water during the cultivation of forage rice. N=0 (····◇····), N=7 (---□---), N=14 (—▲—), N=21 (—●—), N=28 (—✦—)

Ammonium (NH_4-N) Concentration in the Surface and Percolation Water

Generally NH_4-N adsorption in the soil can affect the N uptake by rice plant. It is reported that the percentage of adsorbed NH_4-N in soil ranges from 85 to 95% in paddy fields (Okajima & Imai, 1973; Toriyama & Ishida, 1987). Leaching loss of N occurs in the form of NO_3-N and NH_4-N form rice fields and the extent of loss by nitrate is more than 90% (Sahu and Samant 2006).

The leaching of NH_4-N in the percolation water was lower than the leaching of NO_3-N. Concentration and distribution of NH_4-N both of in the surface and percolation water during the cultivation periods were showed in the Figure 2. The NH_4-N concentration in the surface water was higher at the beginning of cultivation days; and then was occurred decreasing concentration throughout the cultivation periods. The highest concentration was found in the 280 kg N ha^{-1} application.

In the percolation water, the NH_4-N concentration was also higher in the 280 kg N ha^{-1} application. Increasing of level N application was significantly higher and could increase to the NH_4-N concentration leaching in the percolation water; however among of the concentration was very low (0.38 mg L^{-1}).

It is considered that the NH_4-N concentration leaching much lower than NO_3-N (Figure 1 and 2); it was caused for the growing up rice need the NH_4-N a lot. One of the most important forms inorganic nitrogen (NH_4-N) of needed for the growth of rice plants, and it is known that the soil layers of rice field have the capacity to absorb NH_4-N. This result has been corroborated by the fact that rice plants develop system for utilizing NH_4-N based on their physiological responses to such growth environments.

Total N Leaching in the Percolation Water

The cumulative of total N leaching in the percolation water was showed in the Figure 3. Increasing of the N levels application increased the accumulative of total N in the percolation water. The cumulative value (95.87 mg L^{-1}) was highest in the 280 kg N ha^{-1} application.

The data showed that there was a significant difference between treatments. Therefore, the total N leaching increased with increasing of the N levels application. Thus, higher levels of N-leached would affect higher the level of pollution on the environment. Considering of both crop yield and environmental effect, the best management practices need to be determined. To reduce environmental impact of N-fertilizer, the total amount of application needs to be reduced. One possible way is to increase the efficiency of N fertilizer (Zhu *et al*. 2000).

Total N, NH_4-N, NO_3-N, NO_2-N Concentration in the Underground Soil Layers

Percolation process as a mass movement of water vertically, bringing the dissolved elements, including nitrogen, from the top layer to layer underneath which is an aerobic layer, and known as leaching process (Suprapti *et al*. 2010). The N available for plant uptake and leaching out of the root zone depends on the transport and transformations of different N. The total N, NO_3-N, NO_2-N, NH_4-N

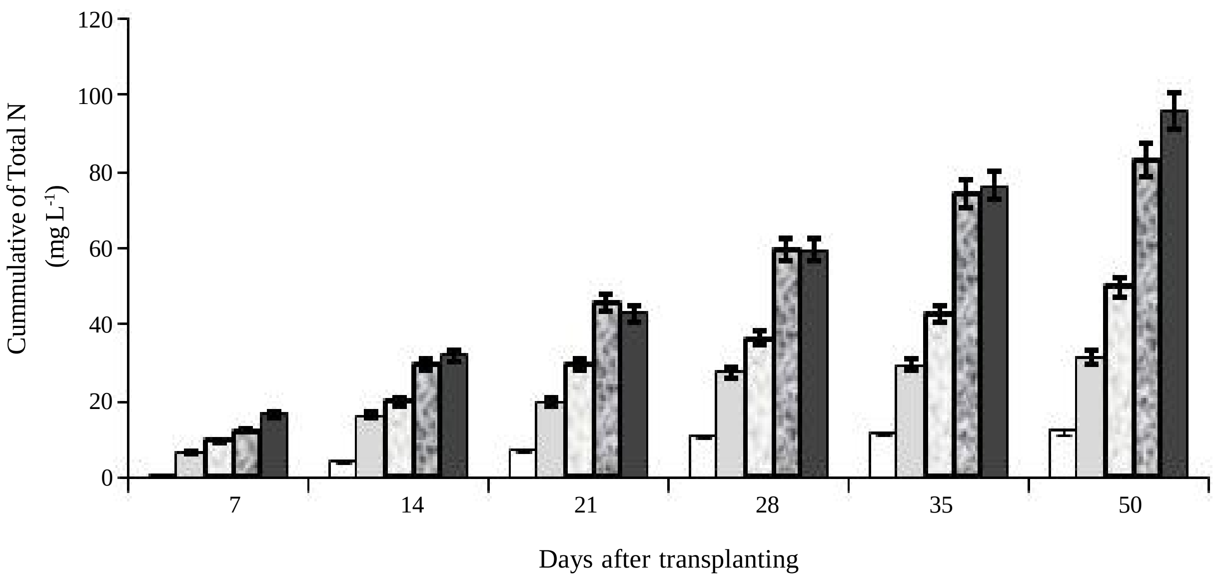

Figure 3. The cumulative of total N leaching in the percolation water during the cultivation of forage rice. N0 (□), N7 (□), N14 (□), N21 (□), and N28 (■).

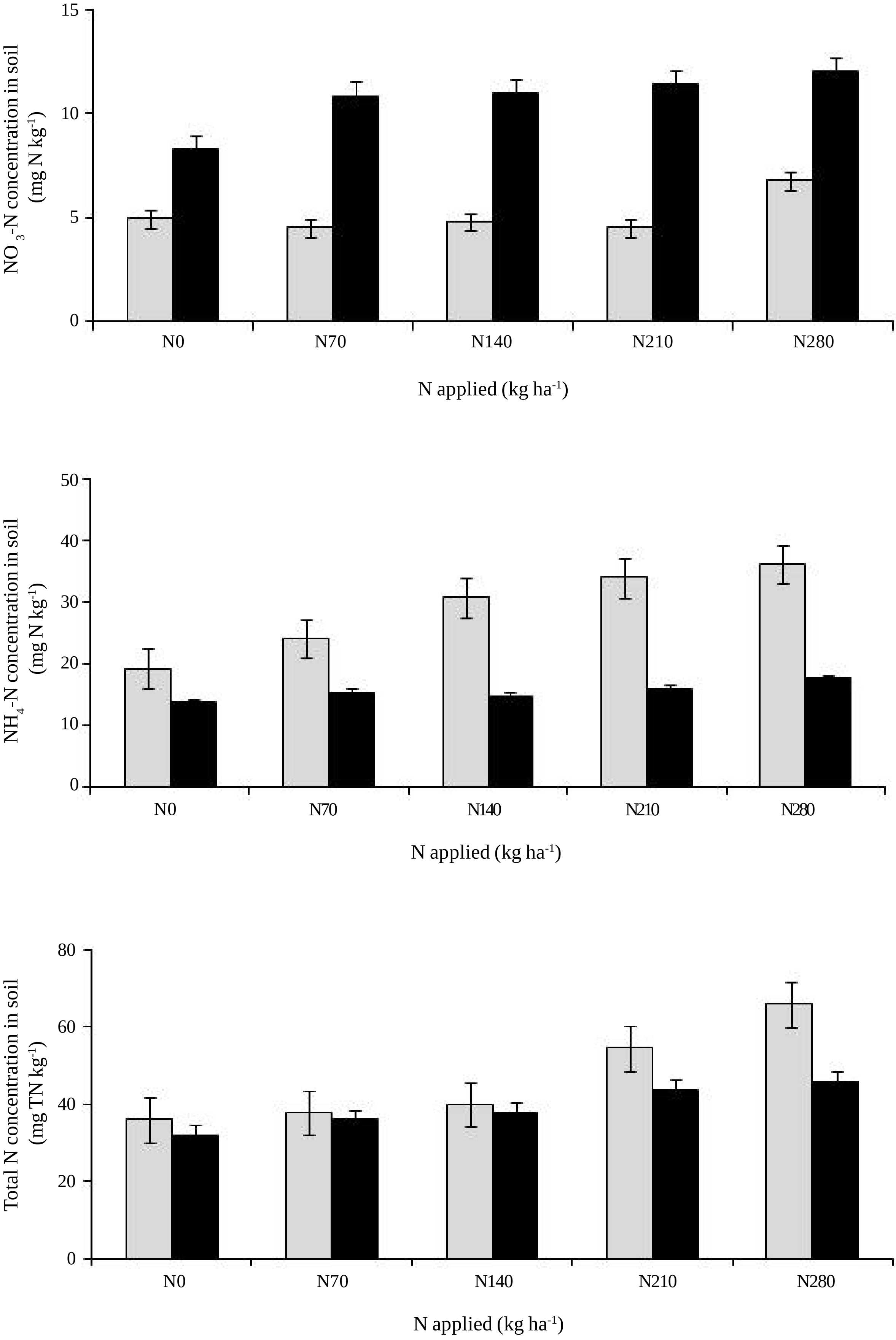

Figure 4. The NO_3-N, NH_4-N, and total N concentrations remained in the soil of the rice field. AN (□) and HS (■)

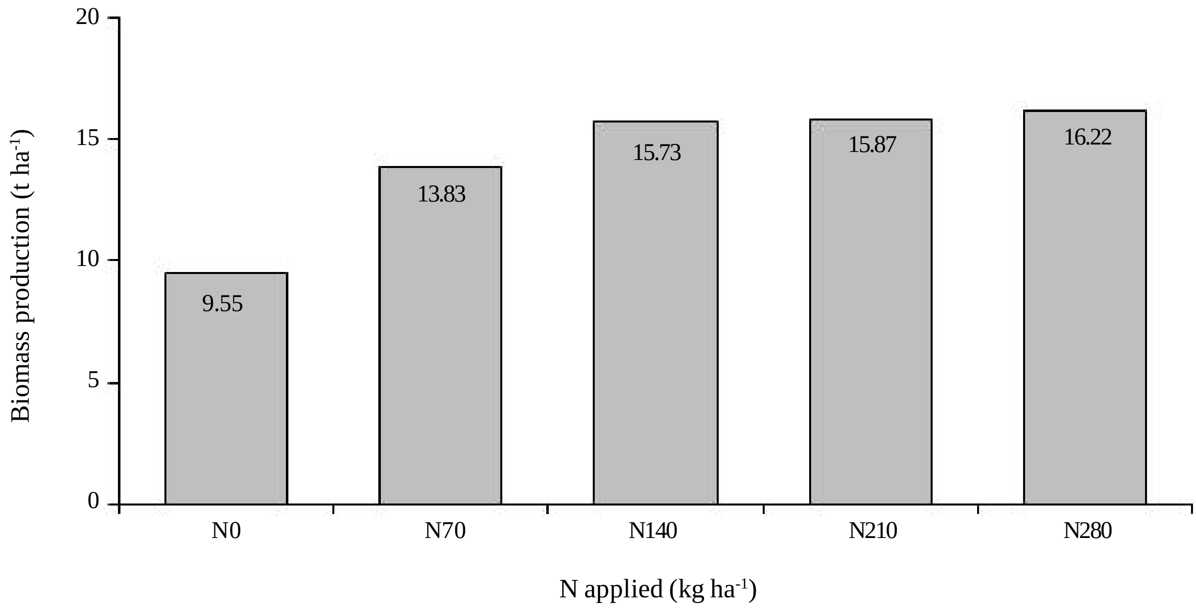

Figure 5. Biomass production of forage rice under different level of N application.

concentration in the HS. While, the NO_2-N concentration at the AN was higher rather than the concentration in the HS, but the concentration was very low (ignore). The NH_4-N concentration at the AN was higher than the concentration in the HS. As the result showed that increasing of N levels application caused higher NO_3-N and NH_4-N leaching, but the concentration of NH_4-N leaching was low (can see at the HS concentration, Figure 4).

Higher concentration of NO_3-N leaching could indicate higher of NO_3-N pollution in the ground water rice field. The NO_3-N pollution has negative effect on the environment. Thus, it was necessary to manage efficiency N-fertilizer for maintaining of environmental impact in the groundwater and improving the soil fertility for the high yield of the forage production.

Biomass Production of Forage Rice

Figure 5 shows the biomass production by plant as effect of increasing N levels of available from 0 to 280 kg N ha^{-1} application derived from animal manure in forage rice cultivation. Increasing the level of N application significant difference increased of the biomass production. The highest of production was found in 280 kg N ha^{-1} (16.22 Mg ha^{-1}). Based on the biomass production was occurred increasing in the following treatment N0>N70>N140>N210> N280. However, the increase of biomass production was nearly similar result in N140, N210 and N280.

From biomass production (Figure 5), it suggested to use of the N-fertilizer in 140 kg N ha^{-1}. These doses of N-fertilizer increased N-fertilizer efficiency, and NO_3-N concentration leaching in the groundwater began to decrease steadily.

CONCLUSIONS

It concluded that the increasing of available of N application (0 - 280 kg N ha^{-1}) derived from cattle manure (CM) and poultry manure (PM) significantly increased the concentration of NO_3-N, NH_4-N, and total N in the percolation water, and remained of underground soil in the forage rice field. The NO_3-N leaching was higher than NH_4-N in the percolation water during the cultivation of forage rice periods. The highest of NO_3-N and total N leaching were found in 280 kg N ha^{-1} (6.3 mg L^{-1} and 95.87 mg L^{-1}), respectively, that it was indicated on the polluted levels. The highest of biomass production was found in N280 (16.22 Mg ha^{-1}) and nearly similar result in N140, N210 and N280. It concluded that the best of application of N-fertilizer was 140 kg N ha^{-1} because it greatly enhanced N-fertilizer efficiency, and decreased steadily of NO_3-N concentration leaching in the environment of the groundwater

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