NITROUS OXIDE EMISSION AND NITROGEN UPTAKE AFFECTED BY SOIL AMENDMENT AND NEMATICIDE IN RAINFED RICE SOILS AT CENTRAL JAVA

Emisi Dinitrogen Oksida dan Serapan Nitrogen dari Pemberian Bahan Pembenah Tanah dan Nematisida pada Tanah Sawah Tadah Hujan di Jawa Tengah

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ABSTRACT

Rice cultivation is one of the antropogenic sources of nitrous oxide (N_2O) emission that is produced by microbiological nitrification-denitrification processes. Incorporating soil amendment in rainfed rice soil attempted to increase soil productivity, while nematicide application aimed to maintain root growth system. Incorporating soil amendment and nematicide application are predicted to suppress N_2O production in lowland rice. The objective of this research was to study the interaction of soil organic amendment and nematicide on N_2O emission and nitrogen uptake from rainfed lowland rice soils. A field experiment was conducted in rainfed lowland rice soils during 2010/2011 wet season (direct seeded rice) and 2011 dry season (transplanted rice). The 3 x 3 factorial trial was arranged in a randomized completely block design with three replications. The first factor was soil amendment consisted of without rice straw, fresh rice straw and composted rice straw. The second factor was nematicide application consisted of without nematicide, neemcake and carbofuran. Variables measured were N_2O flux, rice grain yield and nitrogen uptake. Incorporation of fresh and composted rice straws reduced N_2O flux about 49.2% and 59.9% in transplanted rice, and 32.9% and 28.2% in direct seeded rice, respectively. The neemcake application reduced N_2O emission about 44-50%, while carbofuran application decreased N_2O emission by 23-35%. Neemcake has a good potential as nitrification inhibitor of N_2O emission, so the neem trees have a prospect to be cultivated intensively. The reduction of N_2O emission was effective in direct seeded rice system with the application of neemcake and fresh rice straw, however, in transplanted rice system it was effective with neemcake and composted rice straw applications.

[***Keywords*****:** Nitrous oxide emission, nitrogen uptake, rainfed lowland, soil amendment, nematicide]

ABSTRAK

Budi daya padi sawah merupakan salah satu sumber antropogenik emisi dinitrogen oksida (N_2O) yang dihasilkan dalam proses nitrifikasi dan denitrifikasi. Pembenaman bahan pembenah tanah ke dalam tanah sawah tadah hujan bertujuan untuk meningkatkan produktivitas tanah, sedangkan pemberian nematisida untuk mempertahankan pertumbuhan akar. Pembenaman bahan pembenah tanah dan pemberian nematisida diduga dapat menekan pembentukan N_2O di lahan sawah. Tujuan penelitian ini adalah untuk mengetahui pengaruh pemberian bahan pembenah tanah dan nematisida terhadap emisi N_2O dan serapan nitrogen pada tanaman padi sawah tadah hujan. Percobaan dilaksanakan di lahan sawah tadah hujan pada musim hujan 2010/2011 (padi gogorancah) dan musim kemarau 2011 (padi walik jerami). Percobaan faktorial 3 x 3 disusun dalam rancangan acak kelompok dengan tiga ulangan. Perlakuan faktor pertama adalah bahan pembenah tanah yang terdiri atas tanpa jerami padi, jerami segar, dan jerami melapuk. Perlakuan faktor kedua adalah pemberian nematisida yang terdiri atas tanpa nematisida, tepung mimba, dan karbofuran. Peubah yang diukur meliputi fluks dinitrogen oksida, hasil gabah, dan serapan nitrogen. Pembenaman jerami segar dan melapuk menurunkan fluks N_2O masing-masing 49,2% dan 59,9% pada padi walik jerami, dan 32,9% dan 28,2% pada padi gogorancah. Pemberian tepung mimba menurunkan emisi N_2O sebesar 44-50%, sedangkan pemberian karbofuran mengurangi emisi N_2O 23-35%. Tepung mimba potensial sebagai bahan penghambat nitrifikasi untuk menurunkan emisi N_2O sehingga tanaman mimba mempunyai prospek untuk dibudidayakan secara intensif. Penurunan emisi N_2O efektif pada padi gogorancah dengan pemberian tepung mimba dan jerami segar, namun pada padi walik jerami yang efektif adalah pemberian tepung mimba dan jerami melapuk.

[***Kata kunci*****:** emisi dinitrogen oksida, serapan nitrogen, sawah tadah hujan, pembenah tanah, nematisida]

INTRODUCTION

In Central Java, Indonesia, rainfed rice field covers about 30% of the one million ha of rice areas. The typical rainfed cropping system in Indonesia is a dry direct seeded rice in early wet season followed by transplanted rice with minimum tillage in late wet season. The average yield of direct seeded rice (DSR) is 3.5-6.5 Mg ha^{-1}, while that of transplanted rice (TPR) is 1.2-3.0 Mg ha^{-1} (Boling *et al*. 2004). The low and unstable rainfed rice yield can be attributed to water stress, nutrient deficiency, pest infestation including nematode, or a combination of these factors. Incorporation of soil amendment such as crop residues and manure is an attempt to improve soil and crop productivity, while application of nematicide is to maintain better root growth of rainfed rice.

The alternate wet-dry soil condition under rainfed rice system influences the magnitude of nitrous oxide (N_2O) emission. Rice cultivation is a source of atmospheric methane (CH_4) and nitrous oxide (N_2O) and as a potential sink for carbon. The N_2O is produced in soil either from nitrification process under aerobic condition or from denitrification process under anaerobic condition (Majumdar 2003). The N_2O in soil is produced by microbial nitrification process during oxidation of ammonia to nitrate and nitrate reduction. Nitrifier bacteria (*Nitrosomonas* and *Nitrobacter*) which are chemoautotrophic bacteria play a role in nitrification-denitrification processes and N losses from rice field (Minami and Fukushi 1984). Under reductive soil condition, anaerobic facultative bacteria of denitrifier change nitrate to N_2O and N_2 (Klemedtson *et al.* 1988). The microbial processes that regulate N_2O emission from rice cultivation are controlled by soil ammonium (NH_4^+) and nitrate (NO_3^-), and moisture availability (Jetten 2008). Nitrate is quite unstable in flooded soils which will be lost as N_2O and N_2 via denitrification in some days after flooding (Ladha *et al.* 1997). Denitrification produces N_2O in anaerobic soil conditions, however, it could also take place with existence of oxygen. Some denitrification bacteria use O_2 and NO_2^- simultaneously as electron acceptor (Klemedtson *et al.* 1988).

The N_2O emission was accounted for about 30% of the total national green house gas (GHG) emission from agriculture in 2005 (80,179 Gg CO_2-eq), which was lower than CH_4 emission contribution (67%) (Ministry of Environment 2010). The agricultural soils contribute N_2O as much as 0.2-2.1 Tg N_2O worldwide (Hansen and Bakken 1993). The atmospheric N_2O concentration is reported to increase with the rate of 0.25% per year (Snyder *et al.* 2009). The lifetime of N_2O in atmosphere is relatively longer than that of methane gas, and its global warming potential is 250-310 times higher than that of CO_2 (Abao *et al*. 2000).

Application of soil organic amendments to annual crops generally increases denitrifier activity and N_2O emission (Meijide *et al.* 2009). Rice straw is one of organic amendments that is excessively available in rainfed rice ecosystems. Incorporation of rice straw into the soil returns most of the nutrient and helps to conserve soil nutrient reserves in the long term. About 40% of N taken up by rice remains in vegetative plant parts at crop maturity (Dobermann and Fairhurst 2002).

Rice straw management in rainfed rice field could affect pattern and magnitude of N_2O emission (Xiong *et al.* 2007). According to Meijide *et al.* (2009), higher emission of N_2O from manure or crop residues is attributed to more anoxic conditions produced by the stimulation of denitrification and to the supply of readily available C, a substrat for denitrification, so that it favors for generating N_2O.

Pesticidal materials could function as nitrification inhibitors that are often used to increase N fertilizer use efficiency (Rao 1994) and decrease NO_3^- and N_2O losses from denitrification process (Chen *et al.* 2008). According to Kusmaraswamy *et al. in* Sahrawat (2004), carbamate pesticides such as carbofuran (2,3-dihydro-2,2-dimethyl-7-benzophuranil methylcarbamate) could be used as nitrification inhibitor and controlling plant pests. The commercial carbofuran is used as nematicide in food crops to maintain root growth. Some natural materials such as neem tree (*Azadirachta indica* A Juss) seed and its extract have been used as a biological nematicide for food crops and as a nitrification inhibitor. Neem seeds contain the active fractions such as azadirachtin, meliantriol, salannin and nimbin (Vijayalakshmi *et al*. 1995) which potentially reduce N_2O generation (Thind *et al*. 2010). The azadirachtin in neem seeds and carbofuran can be expected to have a similar effect on suppressing N_2O emission. Neem seed could be regarded as a cheap nematicide and more friendly to the environment than carbofuran that could contaminate rice ecosystem.

Neem trees are found easily in Java and Bali (Ambarwati 2007) and can grow in many locations with various soil types such as clay soil, saline soil, flooded soil and unfertile soil. Neems in India are used for medicine, botanical studies, mass propagation techniques, food preservation, pollution prevention, poultry and cattle feed, fertilizer, soil conservation, pharmacology, etc. (Puri 1999).

Rice crops absorb nitrogen in the forms of ammonium (NH_4^+) and nitrate (NO_3^-). N uptake is controlled by availabilities of NH_4^+ and NO_3^- in soil, N loss from soil-crop system including N_2O in denitrification process and root ability to absorb N (Yamakawa *et al.* 2004).

Information on the effect of soil organic amendment and nematicide application on N_2O emission in rainfed rice field is relatively limited. The objective of this research was to determine the effects of soil amendment and nematicide application on N_2O emission and N uptake from rainfed rice field.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted in intensive rainfed rice areas in Jakenan Subdistrict of Pati District, Central Java during 2010/2011 wet season (November 2010 to March 2011) and 2011 dry season (March to June 2011). The experimental site was located at altitude of 15 m above sea level, 17 km south of north coast of Central Java (111°10’ E and 6°45’ S). The average annual rainfall at the site was lower than 1,500 mm (Boling *et al.* 2004). The average daily maximum temperature was 31.7°C and the average minimum temperature was 23.5°C. Solar radiation was low (13 MJ m^{-2} d^{-1}) from December to February and high (18 MJ m^{-2} d^{-1}) from August to October. The soil was classified as Vertic Endoaquepts with pH-H_2O of 5.6 and contained low total N (0.3 mg g^{-1}) and low organic C (3.2 mg g^{-1}).

Experimental Design

The factorial trial of 3 x 3 was arranged in randomized complete block design with three replications. The first factor was soil organic amendment (without soil amendment, fresh rice straw 5 t ha^{-1} and composted rice straw 5 t ha^{-1}). The second factor was nematicide (without nematicide, neemcake 20 kg ha^{-1} and carbofuran 20 kg ha^{-1}). Organic amendments of rice straw were incorporated during soil tillage, while nematicides were applied three times coincided with N fertilizer application.

Under direct seeded system in 2010/2011 wet season, rice seeds were planted using dibble in plots of 4 m x 5 m with spacing of 20 cm x 20 cm. Under transplanted system in 2011 dry season, the two-week rice seedlings of Ciherang variety were transplanted from seedbed. The direct seeded rice was planted on November 19, 2010 and harvested on March 8, 2011, while transplanted rice was transplanted on March 18, 2011 and harvested on June 10, 2011.

After incorporating organic amendment, land was incubated for two weeks before transplanting. Nematicide materials were grinded, sieved and then applied together with N fertilizer. Recommended inorganic fertilizers were applied at the rates of 120 kg N, 45 kg P_2O_5 and 60 kg K_2O per hectare in the forms of urea, SP 36 and KCl, respectively. The N-urea fertilizer was applied in three splits, namely 1/3 before planting, 1/3 at 40 days after germination (DAG) and 1/3 at 55 DAG. SP36 fertilizer was applied before planting and KCl was applied in two splits, namely 1/2 before planting and 1/2 at 55 DAG. The content of N, P and K in rice straw was considered in calculation of inorganic fertilizer requirement. The crop was monitored and controlled intensively for pests, diseases and weeds.

Data Collection

Variables observed were N_2O, NO_3^- and NH_4^+ contents in soil, N uptake and rice grain yield. N uptake was calculated from multiplication of N concentration in biomass and biomass weight (grain and straw). Nitrous oxide flux was measured at several crop growth stages, namely active tillering, maximum tillering, panicle initiation, heading and maturity stage. The gas sample was taken using closed chambers from plexiglass material with size of 40 cm (length) x 20 cm (width) x 20 cm (height). The chambers were laid in soil surface between rice hills.

The gas samples were taken in four time intervals of 10, 20, 30 and 40 minutes during early morning (07.00-09.00 a.m.) using 10 ml polypropilen syringes. The syringes were coated with aluminum foil to reduce sunny radiation during gas sampling. At gas sampling, air temperature and chamber headspace were also measured. The gas sample was analyzed using a gas chromatography equipped with electron capture detector (ECD) and Porapak Q column to determine N_2O flux (Jain *et al.* 2000). The Shimadzu 14A chromatography gas that has been calibrated with high precision (detector 150°C, colomn 100°C, injector 150°C) was used to measure N_2O flux. Nitrous oxide flux was computed following the equation from Lantin *et al.* (1995).

$$E = \frac{dc}{dt} \cdot \frac{Vch}{Ach} \cdot \frac{Wm}{Vm} \cdot \frac{273.2}{273.2 + T}$$

E = N_2O flux ($\mu g\ m^{-2}\ minute^{-1}$)
dc/dt = N_2O rate per time (mole ppb $minute^{-1}$)

Vch = chamber volume (m^3)
Ach = chamber area (m^2)
Wm = weight of N_2O compound (44.02×10^3 mg)
Vm = volume of N_2O compound at 1 bar pressure (22.41×10^{-3} m^3)
T = average temperature inside the chamber during gas sampling (°C)

Data Analysis

Data were analyzed using analysis of variance to determine treatment effects and least significant difference (LSD) test at the 5% level to evaluate the differences between means.

RESULTS AND DISCUSSION

Dynamics of N_2O Flux

In direct seeded rice crop, N_2O fluxes were high at early rice growth (active tillering) stage and declined until heading or maturity stage (Fig. 1). The high N_2O flux at early growth stage related with aerobic soil condition due to low rainfall in September-October 2010 (Fig. 2), but became saturated at 30 DAG. Nitrous oxide produced at early rice growth stage might be an intermediate product of nitrification and denitrification. Adequate rainfall in dry soil increases N_2O emission due to increased N input from rain into organic N pool in the soil (Johnson *et al.* 2007). Decomposition rate of organic matter in aerobic soils generally takes place faster that reduces available carbon and increases electron acceptor requirement during intensive mineralization and reduction of NO_3^- to N_2O (Gold and Oviatt 2005).

Application of nitrification inhibitor reduced N_2O flux from rainfed rice field with direct seeded rice cropping. The N_2O flux in plot with neemcake was lower than those with carbofuran and without nematicide. The highest N_2O flux was found in plot without nematicide followed by plots treated with carbofuran and with neemcake. Nitrous oxide fluxes under direct seeded rice at active tillering, maximum tillering, panicle initiation, heading and maturity growth stages were 0.84-4.12, 0.05-0.50, 0.07-0.19, 0.04-0.22, and 0.03-0.51 µg N_2O m^{-2} $minute^{-1}$, respectively.

The highest N_2O flux from rainfed rice field occurred at 60 DAG (after panicle initiation stage) in transplanted rice (Fig. 3). The N_2O increased at early growth stage from active tillering to maximum tillering, and reached the peak at panicle initiation stage. The N_2O flux declined at crop reproductive growth stage from heading to maturity stage or harvesting time. In transplanted rice crop, N_2O fluxes at active tillering, maximum tillering, panicle initiation, heading and maturity growth stages were 0.08-1.10, 0.10-0.66, 0.20

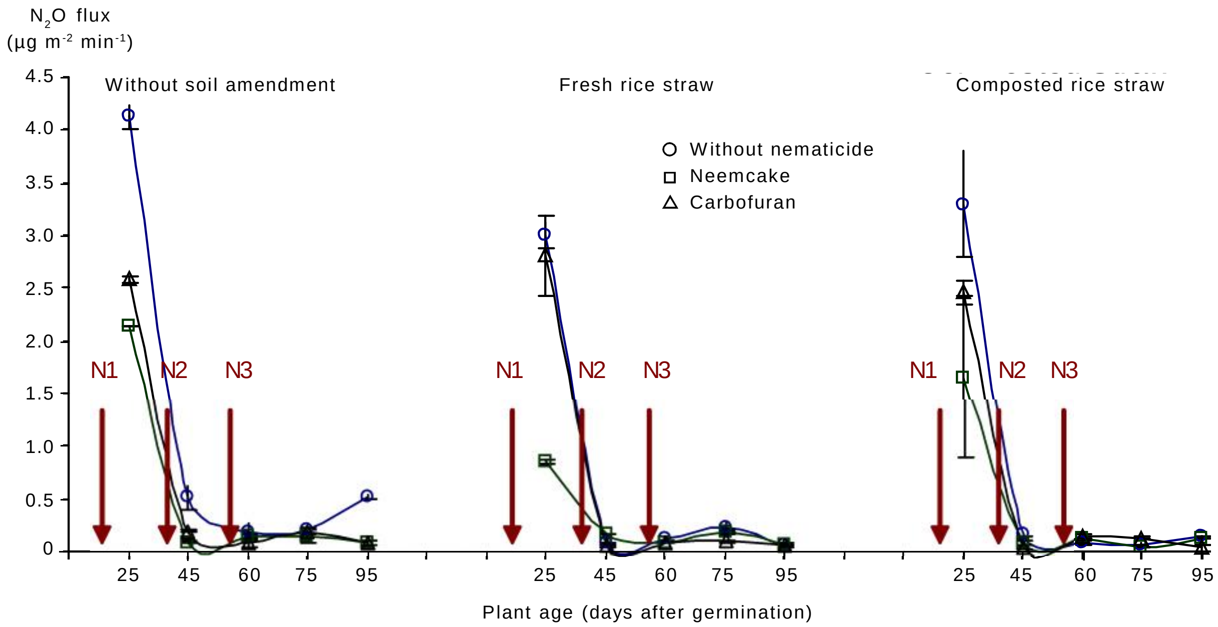


Fig. 1. Dynamics of nitrous oxide fluxes in direct seeded rice crop applied with soil amendments (fresh and composted rice straw) and nematicide, Jakenan, Pati, Central Java, 2010/2011 wet season (November 2010 to March 2011); N1 = first N application, N2 = second N application, N3 = third N application.

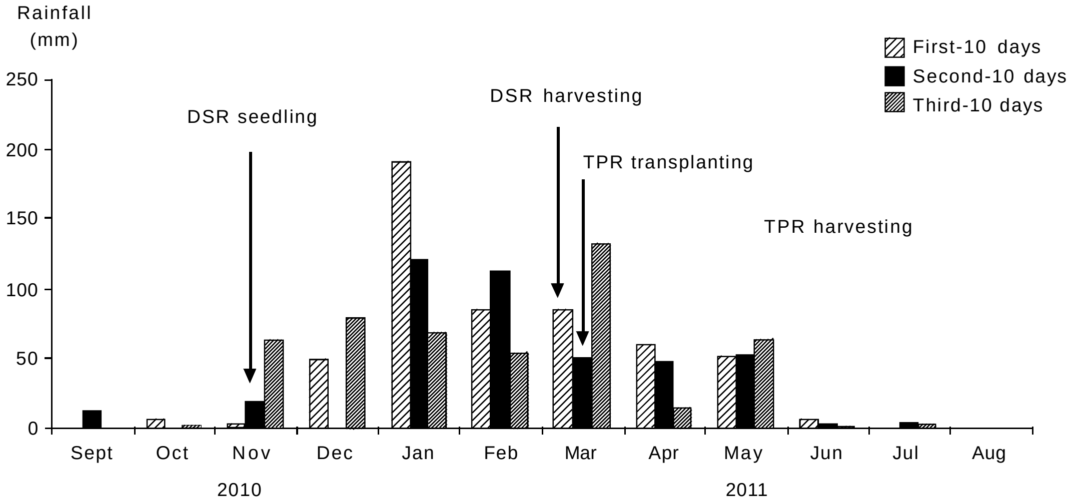


Fig. 2. Rainfall distribution at Jakenan Experimental Station, Pati, Central Java, from September 2010 to August 2011; DSR = direct seeded rice, TPR = transplanted rice.

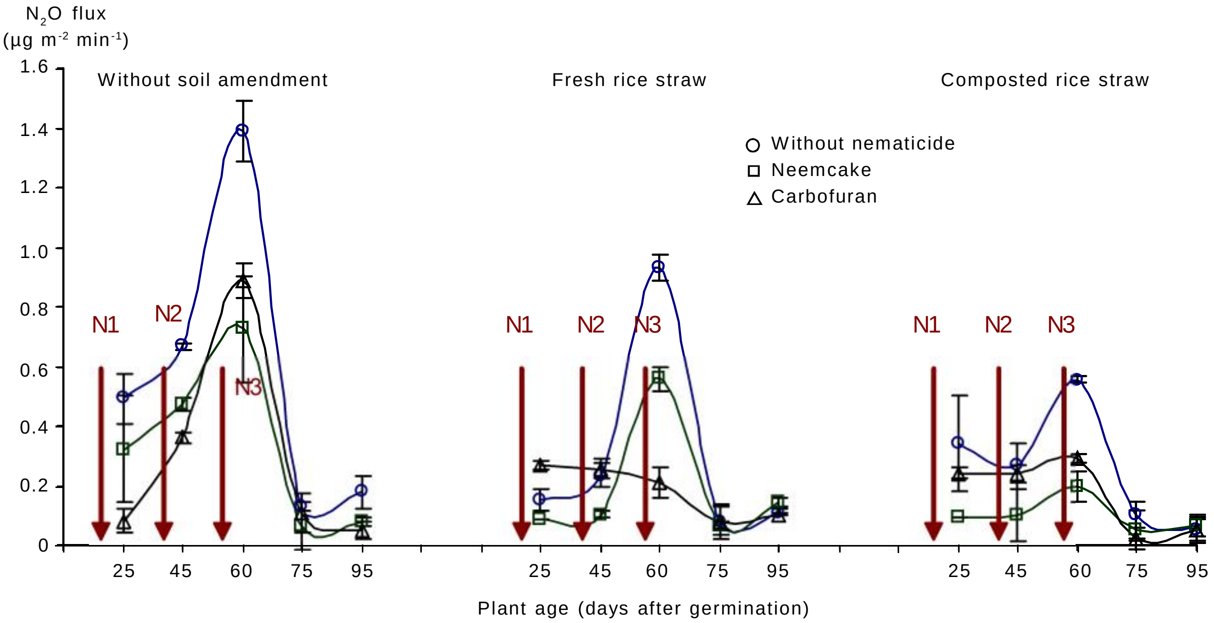


Fig. 3. Dinamics nitrous oxide fluxes at some growth stages of transplanted rice crop treated with soil amendments (fresh and composted rice straw) and nematicides, Jakenan, Pati, Central Java, 2011 dry season; N1 = first N application, N2 = second N application, N3 = third N application.

-1.38, 0.02-0.14, and 0.10-0.63 µg N_2O m^{-2} $minute^{-1}$, respectively. The highest N_2O flux was found on plots without soil amendment and without nematicide, and it was significantly different from applying rice straw combined with nematicide (Fig. 3).

The highest N_2O flux at panicle initation growth stage of transplanted rice seemed attributed to optimal root exudation. Rice roots produce more exudates at early generative growth or panicle initiation stage (Yoshida 1978). Translocation of photosynthate from leaves to roots is optimal at panicle initiation stage and it is translocated partly into rice grains at reproductive growth stage (Yoshida 1978). Root exudates are required by microbes in their metabolism as energy source or substrates in their activities, including denitrifier in anaerobic soil condition.

Root exudate is organic matter which consists of carbohydrate, organic acids and amino acids that are fermented to acetic acid or CO_2 and H^+. Some root exudates are used by certain microbes as electron acceptor (Holzapfel-Pschron *et al.* 1986).

Soil Nitrate Content in Rice Rizhosphere

Potential N_2O emissions from rice field increase if available N for microbial transformation is enhanced through inorganic N fertilization, legume cropping, incorporation of organic fertilizer and plant residues into soil, and mineralization of soil biomass and other soil organic matter. The flooded rice field is ideal habitat for anaerobic facultative bacteria such as denitrifier in releasing N_2O and fixing N_2 that can function well in soil with low oxygen availability (Rao 1994).

Nitrogen availability in soil affected the generation and release of N_2O. The high N_2O fluxes seem to be influenced by nitrate content in rice rizhosphere. Nitrate content was high at panicle initiation stage, namely 45 days after transplanting in transplanted rice or 60 DAG in direct seeded rice (Fig. 4). In direct seeded rice, nitrate content in soil at 25 DAG was higher than that at 45 DAG, so that it contributed to the high N_2O flux at early rice growth stage (Fig. 1). Soil nitrate content is one of key factors that influences denitrification process and N_2O emission from agricultural soils (Xiong *et al*. 2007). Nitrate is a mobile anion that easily leached into soil reductive layer and used by denitrification bacteria as electron acceptor in producing N_2O gas (Unger *et al*. 2009).

Nitrous Oxide Emission from Rainfed Rice Soils

Incorporation of rice straw into the soil influenced significantly N_2O emission from rainfed rice field ($p < 0.0001$). Application of nematicides reduced significantly N_2O emission ($p < 0.0001$), however, its interaction with soil amendment treatment was only significantly different in direct seeded rice crop ($p < 0.001$). Nitrous oxide emission in direct seeded rice was higher than that in transplanted rice. The N_2O emissions from transplanted rice ranged from 57 to 320 g ha^{-1} $season^{-1}$, whereas from direct seeded rice it ranged from 124 to 485 g ha^{-1} $season^{-1}$ (Table 1). The low water availablity in early growth stage of direct seeded rice produced a high N_2O compared with that of transplanted rice.

Rice straw application decreased significantly N_2O flux relative to without rice straw application because lignin content in rice straw can inhibit N_2O generation in nitrification and denitrification processes (Dobermann and Fairhurts 2002). The average N_2O flux emissions from plots without rice straw and those treated with fresh or composted rice straw were 242, 123 and 97 g N_2O ha^{-1} $season^{-1}$ in transplanted rice, and 316, 212, 227 g N_2O ha^{-1} $season^{-1}$ in direct seeded rice, respectively (Table 1). Applications of fresh or composted rice straw reduced N_2O fluxes as much as 49.2% and 59.9% in transplanted rice, and 32.9% and 28.2% in direct seeded rice, respectively. The composted rice straw application reduced N_2O emission higher than the fresh rice straw application in transplanted rice.

Interaction of rice straw and nematicide application reduced significantly N_2O emission. Rice straw application *in situ* into rice soils generally increased N fixation and reduced denitrification rate and N_2O formation (Vallejo *et al*. *in* Meijide *et al*. 2009). Application of rice straw reduced N_2O release from soil to atmosphere, meaning that it reduced N losses in N_2O form resulted from nitrification-denitrification

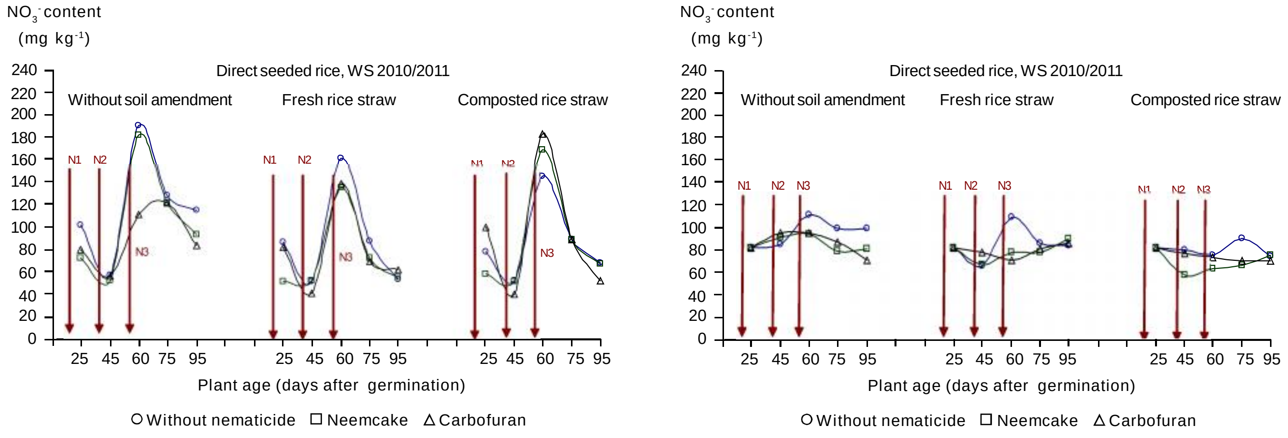


Fig. 4. Soil nitrate content in rainfed rice rhizosphere treated with soil amendment and nematicide on direct seeded rice and transplanted rice, Jakenan, Pati, Central Java, wet season 2010/2011 and dry season 2011; N1 = first N application, N2 = second N application, N3 = third N application.

Table 1. Effect of soil amendment incorporation and nematicide application on nitrous oxide (N_2O) emission from rainfed rice soils, Jakenan, Pati, Central Java, WS 2010/2011 wet season and DS 2011 dry season.

Nematicide application	N_2O emission (g ha^{-1} season^{-1})		
	Without soil amendment1)	Fresh rice straw1)	Composted rice straw1)
Direct seeded rice			
Without nematicide	485 ± 14a	273 ± 7a	237 ± 30a
Neemcake	210 ± 3b	124 ± 6b	166 ± 53a
Carbofuran	253 ± 26b	240 ± 27a	277 ± 5a
Average2)	316 ± 3 A	212 ± 26 B	227 ± 5 B
Transplanted rice			
Without nematicide	320 ± 20a	170 ± 20a	138 ± 19a
Neemcake	188 ± 36b	107 ± 39a	57 ± 8c
Carbofuran	218 ± 7b	93 ± 19a	97 ± 4b
Average2)	242 ± 18 A	123 ± 2 B	97 ± 9 B

1)Means in the same column followed by the same letter in each crop are not significantly different according to LSD test at 5% level.

2)Means in the same row followed by the same capital letter in each crop are not significantly different according to LSD test at 5% level.

processes and increased inorganic N fertilizer efficiency. However, the effect of rice straw incorporation into the soil was not consistent among cropping seasons. Rice straw is an indirect source of C-N compound as substrates for microbial metabolism such as sugar, pectin, lignin, sellulose, hemisellulose and protein and polyphenols can inhibit nitrification (Ponnamperuma 1977).

Inorganic N fertilizer application without rice straw in check treatment emitted N_2O higher than combination of inorganic N fertilizer and rice straw application (Table 1). It is attributed to the more rapid N transformation from NH_4^+ to NO_3^- from inorganic N fertilizer than from organic fertilizer. The response of vertic endoaquepts to inorganic N fertilizer application was high due to the low N content in soil (0.3 mg g^{-1}), so that it increased N_2O emission, although soil nitrate content in rhizosphere was higher than plots with combination of N fertilizer + rice straw (Fig. 3).

The low N_2O emissions in plots with rice straw might be related with the reduction of denitrifier population and NH_4^+ availability from rice straw decomposition in anoxic condition. According to Kirk (2000), anaerobic organic matter decomposition produces simple organic acids + amino acids RCH_2NH_2COOH + NH_4^+. Beside that, nitrification inhibitor materials will inhibit the oxidation of NH_4^+ to NO_2^- and N_2O (Kirk and Kronzucker 2005).

Application of nematicide materials reduced N_2O emission significantly relative to applying nematicide. N_2O emission from neemcake treatment was lower than that from carbofuran treatment. Nitrous oxide emissions in treatments without nematicide, and those with neemcake and carbofuran were 209, 117 and 136 g N_2O ha^{-1} season^{-1} in transplanted rice, and 332, 167 and 257 g N_2O ha^{-1} season^{-1} in direct seeded rice, respectively. Applications of neemcake and carbofuran reduced N_2O emissions as much as 44.0% and 34.9% in transplanted rice, and 49.7% and 22.6% in direct seeded rice, respectively (Table 1).

Neem seed is more effective than carbofuran in reducing N_2O emission, especially if it is combined with composted rice straw. In this study, neem seeds contained 0.13% tannin that is a compound that could inhibits bacterial activities in nitrification and denitrification processes. Tannin is a polyphenolic organic compound that could be used by fungi of genus *Aspergillus* and *Penicillium*, so that it inhibits *Aspergillus* and other bacterial activities (Rao 1994). Although amino acids are more available in rhizosphere, polyphenolic compound will inhibit activity of some bacterial genera. Commonly found in rhizosphere, namely *Pseudomonas*, *Achromobacter*, *Arthrobacter*, *Azotobacter*, *Mycobacterium* and *Bacillus*. Among those genera, *Pseudomonas* and *Achromobacter* are the main ones involved in denitrification processes in rice field (Rao 1994).

The lowest N_2O emission was found in plot treated with composted rice straw + neemcake, namely 57 ± 8 g N_2O ha^{-1} season^{-1} in transplanted rice, and in plot treated with fresh rice straw + neemcake in direct seeded rice (124 ± 6 g N_2O ha^{-1} season^{-1}). The nitrous oxide emission in treatment of composted rice straw + neemcake was not significantly different from treatment of fresh rice straw + neemcake. Thus, application of rice straw + neemcake reduced effectively N_2O emission from rainfed rice field. In plots either without rice straw or with composted rice straw, application of neemcake produced the lowest N_2O emission followed by carbofuran application and without nematicide. In plot with fresh rice straw, carbofuran application emitted the lowest N_2O followed by neemcake application and without nematicide.

The highest N_2O emission was found in plot without nematicide + without rice straw, namely 320 ± 20 g N_2O ha^{-1} season^{-1} in transplanted system and 485 ± 14 g N_2O ha^{-1} season^{-1} in direct seeded system. The high N_2O fluxes were affected by N fertilizer transformation through nitrification and denitrification processes, so that the nitrate produced is used as substrate in generating and releasing N_2O gas to atmosphere. According to Meijide *et al.* (2009), application of N fertilizer into irrigated rice field or lowland rice system with high rainfall favors denitrifier that increases atmospheric N_2O emission.

Nitrogen Uptake in Rainfed Rice Crops

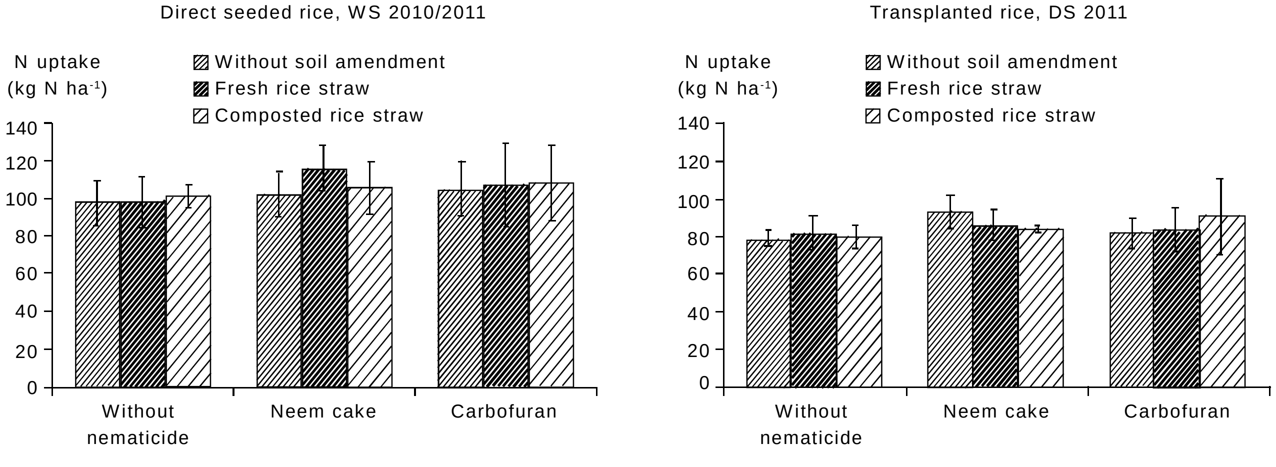
The high nitrogen absorbed by rice crop means that external supply of organic and inorganic nitrogen was efficiently used by rice crop such that N losses could be suppressed. Figure 5 shows that N uptake in direct seeded rice was relatively higher than that in transplanted rice because direct seeded rice yielded biomass higher than transplanted rice. Application of rice straw did not generally increase N uptake, however application of nematicide materials tended to increase N uptake in rainfed rice. In transplanted rice, the highest N uptake was found in plot without rice straw + neemcake (93 kg N ha^{-1}), whereas in direct seeded rice the highest N uptake (116 kg N ha^{-1}) occurred in plot with fresh rice straw.

Rice crop absorbs nitrogen in the forms of NH_4^+-N and NO_3^--N. NH_4^+ could be retained on surface of cations exchange complex that could prevent N losses through leaching. Ammonium ion is an important N source in reductive soil, whereas NO_3^- is adsorbed weakly on soil particle so that it is leached easily and diffused to reductive soil layer. Nematicide materials play a role in delaying or inhibiting oxidation of ammonium to nitrate, so that N is stable in NH_4^+ form readily available for plants (Ladha *et al.* 1997).

Application of nematicide generally increased N uptake because better root development might be optimal for nutrient absorbtion. Application of neemcake together with inorganic N fertilizer improved fertilizer application efficiency through increasing N uptake, but it did not increase grain yield (Table 1). According to Ladha *et al.* (1997), from the applied N fertilizer in rice soil, only 20% is deposited in grains, 12% in straw, 3% in roots, 24% retained by soil and 41% is lost through volatilization, nitrification-denitrification, run off and leaching. Application of nitrification inhibitor together with N fertilizer aimed to improve N uptake in critical growth stages (Kirk 2000).

Nitrogen uptake is influenced by the magnitude of N-NO_3^- and N-NH_4^+ in the soil. Exchangeable NH_4^+ in soil under direct seeded rice cropping was relatively higher than that under transplanted rice cropping (Fig. 6). Soil exchangeable NH_4^+ at maximum tillering was higher than that at maturity growth stage. Soil exchangeable NH_4^+ in transplanted rice ranged from 36 to 109 ppm N-NH_4^+ at 45 DAG and 18-74 ppm N-NH_4^+ at 95 DAG, whereas in direct seeded rice it ranged from 38 to 135 ppm N-NH_4^+ at 45 DAG and from 19 to 78 ppm N-NH_4^+ at 95 DAG, respectively.

Application of nematicides generally increased exchangeable NH_4^+ in rainfed rice soils (Fig. 6). Nematicide materials either neemcake or carbofuran were effective to control conversion of NH_4^+ to NO_2^- and NO_3^-. Nitrification inhibitor materials controlled N_2O emissions indirectly by preventing NO_3^- accumulation in soil, so that rice crop effectively absorbed N in NH_4^+ form.


Direct seeded rice, WS 2010/2011

Transplanted rice, DS 2011

Fig. 5. Nitrogen uptake in biomass of rainfed rice crops at harvesting time treated with soil amendment (fresh and composted rice straw) + nematicide application, Jakenan, Pati, Central Java, wet season 2010/2011 and DS 2011 dry season.

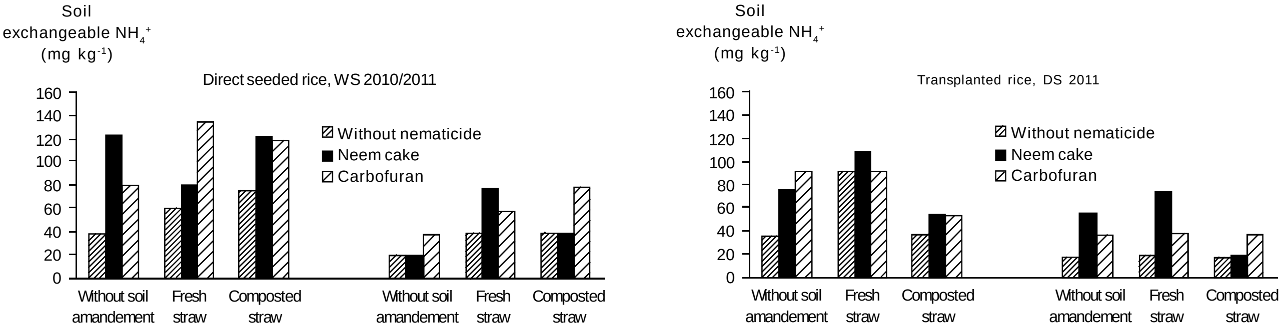


Fig. 6. Soil exchangeable NH_4^+ at 45 and 95 days after germination (DAG) of rainfed rice crops treated with soil amendment (fresh and composted rice straw) + nematicide application, Jakenan, Pati, Central Java, wet season 2010/2011 and 2011 dry season.

CONCLUSION

Rice straw incorporation into rainfed rice soils significantly reduced nitrous oxide emission from rice soils with a range of 28.2-32.9% in direct seeded rice and 49.2-59.9% in transplanted rice. Application of neemcake or carbofuran significantly reduced N_2O emissions from rainfed rice soils as much as 49.7% and 22.6 % in direct seeded rice and 44.0% and 34.9% in transplanted rice, recpectively.

Nitrogen uptake in direct seeded rice was relatively higher than that in transplanted rice and this lead to a higher biomass production in direct seeded rice. N uptake of rainfed rice crops was high when nematicide materials were applied.

Farmers should apply composted rice straw in rainfed rice field to reduce N losses in form of N_2O and to improve N fertilizer efficiency. Application of natural nematicides such as neemcake is effective as nitrification inhibitor.

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