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Emissions of Methane and Nitrous Oxide from Rainfed Rice Field Treated with Different Rice Planting Systems and Nematicide Applications at Central Java, Indonesia

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ABSTRACT

Rice field is issued as a source of greenhouses gases (GHGs) emissions especially methane (CH_4) and nitrous oxide (N_2O). Rice cultural approach could mitigate GHGs emissions i.e. through rice planting systems and nematicide application. The field experiment was conducted in rainfed rice field at Pati District, Central Java to determine effect of planting systems and nematicide application on emissions of methane and nitrous oxide from rainfed rice field. The six treatments were arranged in a randomized block design with three replicates, namely transplanted rice (TR) without applying nematicide, TR + neem cake, TR + carbofuran, direct seeded rice (DSR) without applying nematicide, DSR + neem cake, DSR + carbofuran. Parameters observed were methane flux, nitrous oxide flux, organic C content in rhizosphere, soil pH, soil redox potential surrounding rhizosphere of Ciherang variety. Methane emission under transplanted rice system was generally higher than direct seeded rice system. The treatment of DSR + neem cake resulted lowest methane emission (71 kg CH_4 ha^{-1} $season^{-1}$). The TR system emitted N_2O lower significantly than the DSR system. Application of nematicide inhibitor materials decreased more effectively N_2O emission. The DSR system increased significantly grain yield and N uptake, while application of nematicide materials didn't increase grain yield but increased significantly N uptake.

Keywords: Crop establishment, methane, nitrous oxide, nematicide, rainfed rice field

INTRODUCTION

The challenges of rainfed lowland optimization in Indonesia are generally lack of water availability, pest and disease infestation, and low soil fertility. Rice planting system is one of strategies to overcome lack of water availability such as transplanting system or direct seeding system. The appropriate rice planting system in rainfed lowland will improve rice productivity.

Paddy soils are issued as source and sink of GHGs especially methane (CH_4) and nitrous oxide (N_2O) in agricultural sector. The release of methane and nitrous oxide to atmosphere contributes the anthropogenic greenhouse effects as much as 25 and 6%, respectively. Methane (CH_4) absorbs infrared radiation much more intensively than CO_2 (Kumar *et al*. 2010). Biogenic methane is produced exclusively by a group of strict anaerobes methanogens during methanogenesis (Kumar *et al.* 2010), while nitrous oxide is products of microbiological processes of nitrification and denitrification in soils. According to Whalen (2005), estimated total annual CH_4 emission from anthropogenic and natural sources was about 600 Tg CH_4 yr^{-1} and sinks of CH_4 were estimated to be 580 Tg yr^{-1} due to OH^- oxidation and via microbial oxidation in soils. At present, N_2O concentration is calculated approximately 4 Tg N yr^{-1}, while annual methane emission from paddy soils ranges 20-100 Tg CH_4-C yr^{-1} (Reay *et al.* 2009).

Methane source in paddy soils comes from soil organic matter, rice stubble decays, and fresh organic matter. Besides that, root exudates of rice plant are significant source of methane from paddy soils. Rice roots generally release amino acids, organic acids, and carbohydrate as root exudates. Root exudation pattern and carbohydrate release from rice roots depend on variability of rice cultivars (Wassmann *et al.* 1993). The magnitude of methane production depends on morphological and physiological rice variety, soil type, and soil properties. Low methane production occurs in soils which have low pH, silty textural class, high kaolinitic clay content, low cations exchange capacity, salinity, and high redox potential which inhibit activity of anaerobic methanogenic bacteria (Bachelet and Neue 1993).

Denitrification processes causes nitrogen losses from fertilizer as much as 25%. Nitrate reduction to NO, N_2O and N_2 in denitrification processes is controlled by soil factors, i.e. oxygen, moisture content, nitrate concentration, pH, temperature, organic carbon (Peoples *et al.* 1995). Application of N fertilizer on soil rich organic carbon enhances N_2O release. Carbon availability regulates processes of nitrification and denitrification to produce and release N_2O in soils (Khalil and Inubushi 2007).

The rice root-knot nematode is considered as one of constraints in optimizing rice production in rainfed rice fields (Dangal *et al.* 2009). Nematode infestation could reduce grain yield in range of 17-80% (Upadhyay *et al.* 2014). Application of nematicide in rice field aims to prevent nematode infestation and influences on greenhouse gas production. Effect of nematicide application on GHGs emission from rice field is still limited and further studied.

Pesticide materials as nitrification inhibitors could influence microbial activity including methanogen bacteria, nitrification bacteria, and denitrification bacteria in rice fields. Pesticide application in soils decrease NO_3^- and N_2O losses from denitrification process (Chen *et al.* 2008). According to Sahrawat (2004), carbamate pesticides such as carbofuran (2,3-dihidro-2,2-dimetil-7-benzofuranil metilcarbamate) could be used as nitrification inhibitor and to prevent plant pests. 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, nimbin (Vijayalakshmi *et al.* 1995) which can 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 N_2O emission.

The difference of rice planting systems will contribute surely on production and emission of greenhouse gases (GHGs) from lowland rice. The field study was required to determine methane and nitrous oxide emissions from rainfed rice field with different planting system and nematicide application.

MATERIALS AND METHODS

Site Description

The field experiment was conducted in rainfed rice areas at Pati District, Central Java Province during 2011 dry season. The experiment was located on 111°10'E and 6°45'S, 15 m above sea level, 17 km from north coastal of Central Java, and Oldeman climate type of E2-E3. The soils at experimental site was classified as Vertic Endoaquepts which was included in textural class of sandy loam (15% clay, 43% silt for topsoil; 23% clay, 40% silt for subsoil). The topsoils (0-20 cm depth) was moderately acid (pH-H_2O 5.6), low total N (0.3 mg g^{-1}), low organic C (3.2 mg g^{-1}), low extractable P by Bray 1 (5.06 ppm P), low cations exchange capacity (6.96 cmol(+) kg^{-1}), low exchangeable cations (0.12 cmol(+) K kg^{-1}; 0.24 cmol(+) Na kg^{-1}; 3.05 cmol(+) Ca kg^{-1}; dan 0.61 cmol(+) Mg kg^{-1}).

Experimental Design and Crop Establishment

The experiment was arranged using a randomized block design with three replicates and six treatments. The treatments were transplanted rice (TR) without applying nematicide (T_1), TR + neem cake (T_2), TR + carbofuran (T_3), direct seeded rice (DSR) without applying nematicide (T_4), DSR + neem cake (T_5), DSR + carbofuran (T_6). Rate of nematicide materials was 20 kg ha^{-1} for neem cake and carbofuran, respectively.

For transplanting system, two weeks old seedling of local variety of Ciherang were transplanted from seedbed in each plot of 4 m ×5 m with spacing of 20 cm × 20 cm. For direct seeded system, rice seed of Ciherang variety was seeded using dibble in each plot with spacing similar to transplanting system. Soil was plowed and levelled a week before planting. The nitrogen fertilizer of 120 kg N ha^{-1} was applied on three splits, namely 1/3N before planting, 1/3N at 45 days after germination (DAG), 1/3N at 60 DAG. The phosphorus fertilizer of 45 kg P_2O_5 ha^{-1} was applied before planting. The potassium fertilizer of 60 kg K_2O ha^{-1} was applied twice, namely 1/2K before planting and 1/2K at 60 DAG. The nematicide materials were applied three times together with N fertilizer application. Intensive plants nursery was done including weeding and pest controls.

Parameter Observation

Parameters observed were flux of methane and nitrous oxide, soil organic C content, grain yield, pH, and redox potential in rhizosphere. Soil sample for analyzing organic C content was taken together gas sampling time. Gas sample was taken at early growth phase, active tillering, maximum tillering, booting, and maturity phase. Redox potential and pH was measured together with gas sampling. Grain yield of 14% moisture content was measured from area harvest of 2 m × 3 m.

Gas sample was taken using closed chamber with size of 40 cm × 40 cm × 60 or 120 cm depend on plant height in the field. Closed chamber from polycarbonate was equipped with thermometer and septum on upper of chamber. Gas sample was taken in the morning (07.00-09.00 am) with time interval of ten minutes interval after laying chamber (10th, 20th, 30th, 40th minutes). Gas sample was taken using polypropylene syringe 10 mL volume. Every gas sampling, temperature inside chamber must be recorded. Gas sample was analyzed using gas chromatography that was equipped *flame ionization detector (FID)* and porapak N column (80/100 mesh, 0,3 cm × 2 m) to determine CH_4 concentration, or *electron capture detector (ECD)* and porapak Q column to determine N_2O concentration. Flux of methane and nitrous oxide was computed using formula from Lantin *et al*. (1995) as follow:

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

E : GHGs flux (mg m^{-2} minute^{-1})
dc/dt : GHGs rate per time (µL L^{-1} minute^{-1})
Vch : Chamber volume (m^3)
Ach : Chamber area (m^2)
Wm : Weight of GHGs compound (16 10^3 mg)
Vm : Volume of GHGs compound (22.41 10^{-3} m^3)
T : Average temperature inside the chamber during gas sampling (°C)

Data was analyzed using analysis of variance to determine treatment effect, and least significant difference test at 5% level to compare among treatment means.

RESULTS AND DISCUSSION

The difference of planting system in rainfed rice field generally influenced flux pattern of greenhouse gases such as methane and nitrous oxide (Figure 1). The methane (CH_4) flux decreased in rice crops planted with transplanting system, while direct seeding system increased methane flux. Peak of methane flux was occurred at 40 days after germination (DAG) on transplanting system and 55 DAG on direct seeding system. At 55 DAG, the highest methane flux was occurred on direct seeding system, however, low flux was occurred on transplanting system. The methane flux generally decreased at maturity stage of rice growth (95 DAG). Dubey (2005) reported that methane flux declined after flowering stage of rice crop due to the decrease of photosynthetic rate after developing rice grains and the decrease of available assimilate supply.

Peak of nitrous oxide flux under transplanting system was occurred at 55 days after germination (DAG), while direct seeding system was occurred at early crop growth (25 DAG). The N_2O flux was relatively low at crop generative growth (grain filling and maturity stages) (Figure 2). The lower N_2O flux was gained by applying nematicide materials than without nematicide.

The high fluxes of methane and nitrous oxide were affected by water conditions in rice field. The high methane flux was occurred due to soil submergence, however, the aerobic soil caused high nitrous oxide flux and low methane flux. Redox potential in soil generally was negative, except in direct seeding system was positive at early growth.

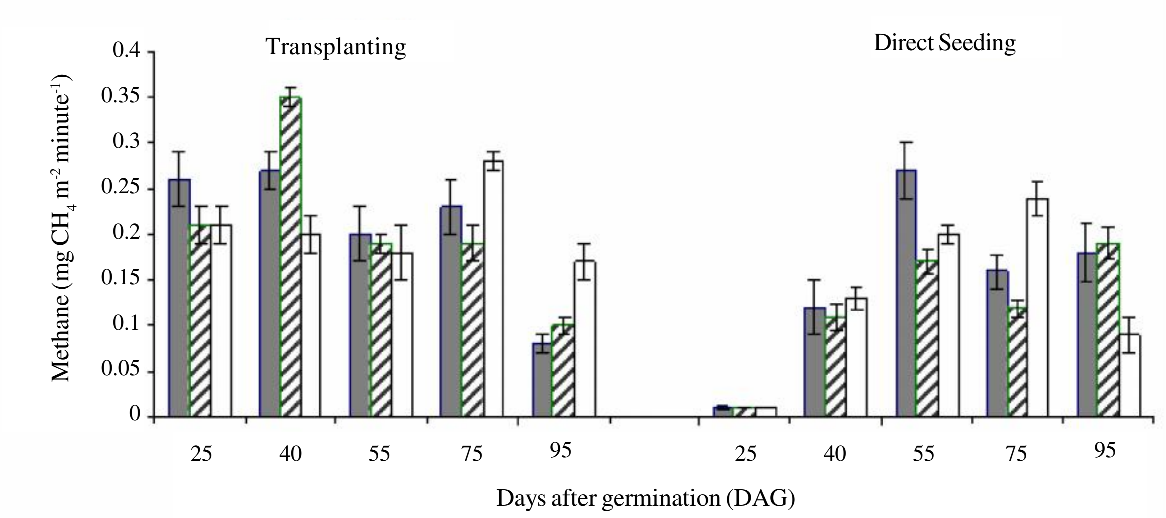

Figure 1. Methane fluxes on some growth stages of rainfed lowland rice crop. ■: Without nematicide, ▨: Neem cake, □: Carbofuran.

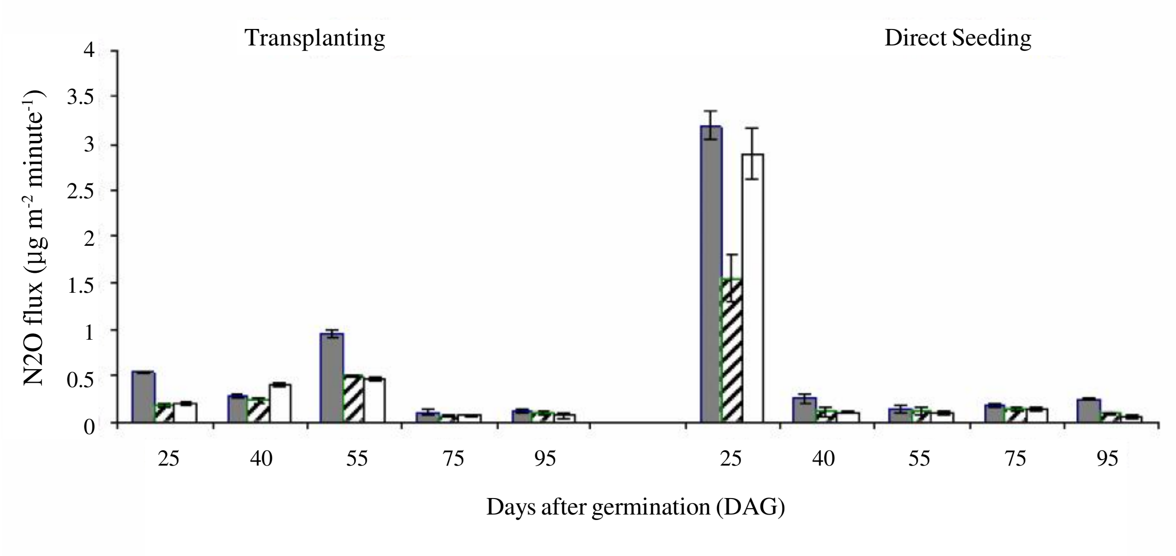

Figure 2. Nitrous oxide fluxes on some growth stages of rainfed lowland rice crop. ■: Without nematicide, ▨: Neem cake, □: Carbofuran.

Relationship between redox potential and greenhouse gas (CH_4 and N_2O) fluxes are presented in Figure 3. Methane production correlated negatively and significant (p = 0.008) with redox potential. This means reductive soil condition favors activity anaerobic microbe such as methanogenic bacteria in generating methane. Methane generation in rice field occurs on redox potential range of -100 till -200 mV (Dubey 2005). Nitrous oxide production correlated positively and significant (p = 0.0001) with redox potential. This means that oxygen availability in soil enhances rate of nitrification process so that more nitrous oxide as byproduct of nitrification are released to atmosphere. The positive value at 25 DAG showed that aeration at early growth favored microbial nitrous oxide production.

Figure 4 shows that organic carbon in soil surrounding of rice roots generally increased with increasing growth stages of rice crop. Under direct seeding system, average of soil organic C content increased until generative growth stage (75 DAG) and decreased at maturity growth stage. The increase of organic C availability at vegetative growth stages will stimulate activity of methanogenic bacteria in producing methane. The vegetative growth of rice crop produce root exudates actively that will be used by those bacteria as energy sources and substrate to generate methane. According to Kumar *et al.* (2010), there was a positive correlation between dissolved methane content and total organic carbon. Availability of organic matter in soil which is used microbe for substrat and energy source to produce methane in anaerobic conditions (Qin Y *et al*. 2010). Root exudates contain carbon in range of 2-20% from photosynthetic results (Clarkson 1985). Based on Dubey (2005) study, more than 50% of total methane emission from rice field was due to root exudates. The magnitude of soil organic C in

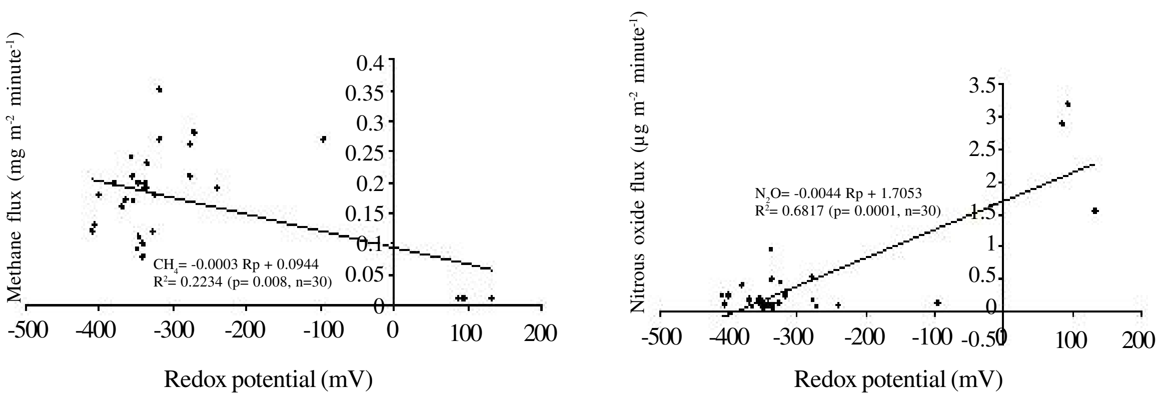

Figure 3. Relationship between redox potential change and greenhouse gases fluxes in surrounding rhizosphere of Ciherang variety.

rice rhizosphere correlated positively and significant with methane emission which was shown in simple regresion $CH_4 = 0.0119 + 0.27$ C-org ($R^2 = 0.3926$, $p = 0.0001$, $n = 30$) (Figure 5).

Under transplanting system, root exudates of rice crop at vegetative growth stage contained high carbon relatively. Carbon released in root exudates is used as energy source by bacteria that involved in nitrogen transformation, so that it is predicted that it caused high nitrous oxide release that occurred at vegetative and generative growth stages.

Submergence and drainage of rice field will affects acidity change in soil and dynamic of microbe activity that is involved in releasing greenhouse gas. Figure 6 shows that soil reaction on various growth stages of rice crop ranged generally 5-6. Soil tend more acid with growth time of Ciherang variety. The decrease of soil pH at reproductive growth stage was followed by the decline of methane and nitrous oxide emissions.

The decrease of soil acidity in rhizosphere increased fluxes of methane and nitrous oxide from rice field. The soil pH correlated positively with neither methane flux nor nitrous oxide flux (Figure 7). The high methane flux was affected by the increase of soil pH value. Microbial activity in forming methane or producing nitrous oxide is generally low in soil with high acidity. According to Wang *et al.* (1993), optimum generation of methane and nitrous oxide was occurred on neutral pH range, so that the increase of soil acidity could inhibit generation of CH_4 and N_2O.

Based on statistical analysis of variance, planting system and application of nematicide under rainfed lowland ecosystem affected significantly on methane emission ($p < 0.0001$) and nitrous oxide

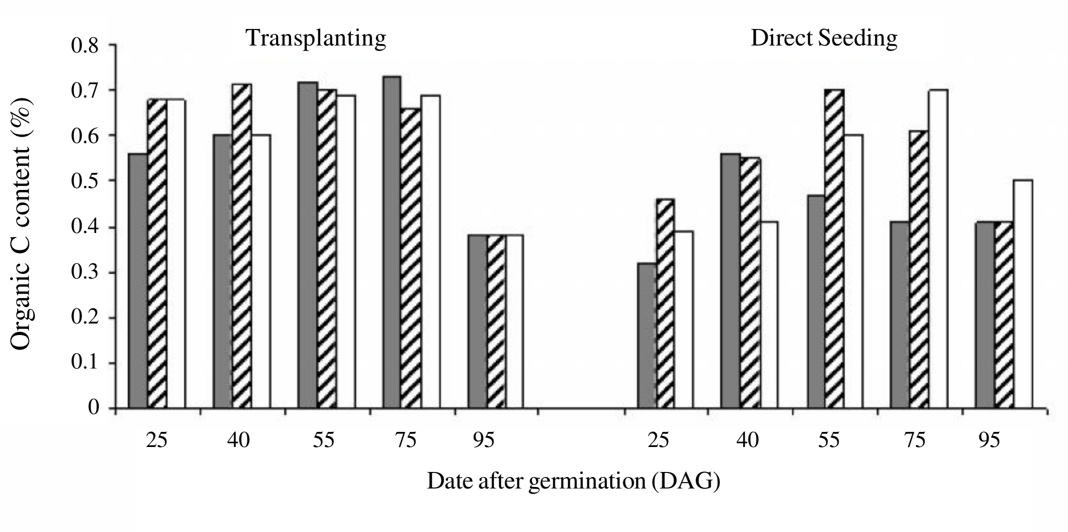

Figure 4. Soil organic C content in surrounding of Ciherang variety rhizosphere. ■: Without nematicide, ▨: Neem cake, □: Carbofuran.

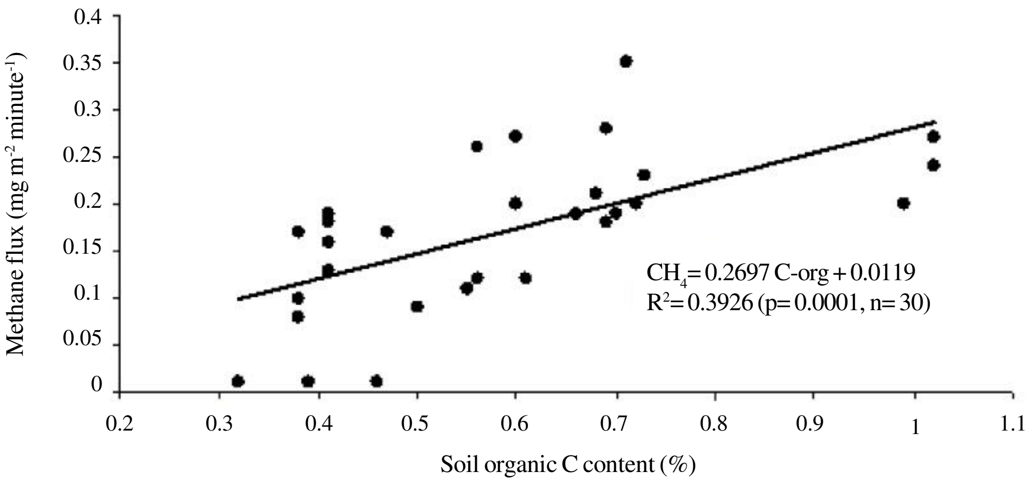

Figure 5. Relationship between organic carbon content in soil and methane flux in rice field.

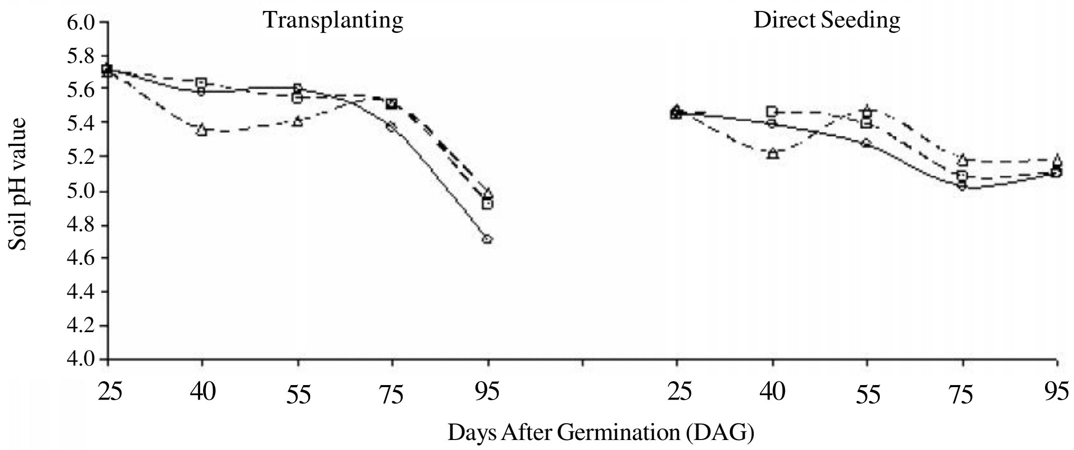

Figure 6. Soil pH change in surrounding rhizosphere of Ciherang variety.

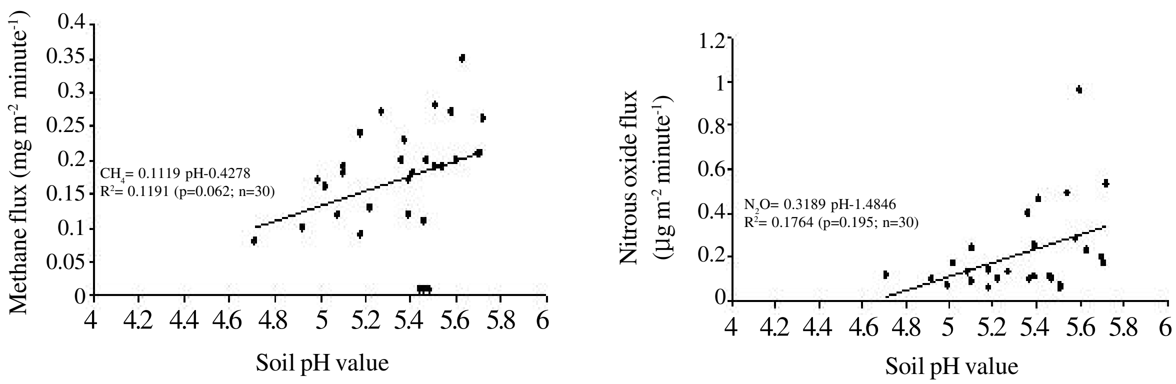

Figure 7. Relationship between soil pH and greenhouse gas fluxes in rainfed rice field.

emission ($p < 0.0001$), respectively. Methane emission under transplanting system was generally higher than under direct seeding system. Transplanting system emitted significantly nitrous oxide lower than direct seeding system (Table 1). Transplanting system reduced N_2O emission in ranging of 29.5 – 46.9% compared with direct seeding system.

Nematicide application tend reduced methane emission in direct seeding system but did not reduce it in transplanting system. The direct seeding system reduced methane emission as much as 23.5 –

Table 1. Methane and nitrous oxide emission, grain yield, and N uptake of Ciherang variety during dry season of 2011.

Treatment	CH_4 emission (kg ha^{-1} season^{-1})	N_2O emission (g ha^{-1} season^{-1})	Grain yield at 14% mc (kg ha^{-1})	N uptake (kg N ha^{-1})
TS, without nematicide	115 a	210 c	4004 b	80 c
TS + neem cake application	122 a	117 e	4182 b	88 c
TS + carbofuran application	131 a	136 e	4190 b	86 c
DSS, without nematicide	88 b	332 a	5391 a	99 b
DSS + neem cake application	71 c	166 d	5055 a	108 a
DSS + carbofuran application	82 bc	256 b	5346 a	107 ab
Coefficient of variability (%)	8.56	3.65	4.48	4.74

Means in same column with same letter do not differ significantly at 0.05 according to least significant difference test
TS = transplanting system, DSS = direct seeding system, mc= moisture content

41.8%. Treatment of direct seeding system + neem cake application released lowest methane (71 kg CH_4 ha^{-1} $season^{-1}$) as shown in Table 1.

Nematicide application reduced nitrous oxide emission more effective than without nematicide. Application of neem cake reduced N_2O emission higher than carbofuran application into rainfed rice soils. Majumdar *et al.* (2000) reported that application neem cake together nitrogen fertilization was effective to inhibit nitrification and to decrease nitrous oxide emission from rice field in North India. The highest N_2O emission was occurred in treatment of direct seeding system without applying nematicide, however, N_2O flux was decreasing with applying nematicide.

Treatment of rice planting system and nematicide application affected significantly to grain yield ($p < 0.0001$) and nitrogen uptake ($p < 0.0001$). The direct seeding system could yield grains higher than transplanting system, while nematicide application did not affected grain yield significantly. The direct seeding system could increase grain yield in ranging of 17.3 – 25.7% (Table 1). The high grain yield in direct seeding system was predicted that rice roots penetrate deeper into topsoil so that they could absorb nutrients more effective in rhizosphere. This is shown by higher N uptake in direct seeding system than other one. The N uptake in direct seeding system increased as much as 18.5 – 19.2% (Table 1). According to Patil *et al.* (1998), rice crop planted with direct seeding system could extract nutrients efficiently. Under direct seeding system, root hairs of young roots develop well that may extract nutrient effectively. The root hairs are rarely available on young roots of rice crops that planted with transplanting system.

Application of nematicide material under direct seeded system affected higher nitrogen uptake than under transplanting system. Nitrogen uptake is the amount of N nutrient taken up by the rice plant at maturity. Direct seeded system is more efficient in nutrient use which is referred by a higher yield per unit of nutrient uptake. Based on the study by Samson and Wade (1998), the better root rice growth insurance effectively nutrient uptake to yield more rice grains.

CONCLUSIONS

The difference of rice planting systems affected significantly on emissions of methane and nitrous oxide from rice cropping. Rice culture with transplanting system emitted significantly higher methane and lower nitrous oxide than direct seeding system under rainfed lowland ecosystems.

Application of nematicide in difference of rice planting systems emitted significantly methane and nitrous oxide. Treatment of neem cake application in direct seeding system emitted lowest methane than others. Nematicide application in transplanting system decreased nitrous oxide emission more effective than without applying nematicide.

Direct seeding system increased significantly grain yield and nitrogen uptake as much as 17.3 – 25.7% and 18.5 – 19.2%, respectively compared with transplanting system. The N uptake increased significantly with applying nematicide in rainfed lowland rice soils.

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