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N_2O-N emissions from organic and conventional paddy fields from Central Java, Indonesia

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Abstract

To evaluate the effect of farming system on gaseous emission of N from soil, the measurements of nitrous oxide (N_2O) were taken in organic and conventional paddy fields in tropics. Eleven soil samples from organic and neighboring conventional sites in Central Java, Indonesia were incubated at two different moisture contents expressed as water filled pores (WFPS), namely 75% WFPS and 100% WFPS. Emission of N_2O-N at 75% WFPS was significantly higher in conventional management than in organic management. At 100% WFPS, the N_2O-N emission was also higher in conventional than in organic farming system. Although it was not significantly different, it has significantly and positively correlations with SOC, total N and initial mineral N content. Due to the swelling ability of the high clay which is contained in soil samples, less N_2O-N emission in 75% WFPS than in 100% WFPS was observed in the present study. The range of N_2O-N emission at 75% WFPS was 0.01 – 0.03 kg N_2O-N/ha in organic farming and 0.005 – 0.16 kg N_2O-N/ha in conventional farming; for organic farming at 100% WFPS, the N_2O-N emission was 0.04 – 61 kg N_2O-N/ha and in conventional farming was 0.08 – 74 kg N_2O-N/ha. This study concludes that organic farming in paddy fields might have more promising potential to mitigate N_2O-N emission than conventional farming in paddy fields.

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Keywords: N_2O-N emission; organic paddy fields; conventional paddy fields

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1. Introduction

Rice production is the major tropical food production, particularly in Asia. For Indonesian people, rice is the main source of carbohydrate in the daily menu. The demand for rice increases along with the increase of population. It encourages the Indonesian government to pursue self-sufficiency in rice to reduce food insecurity. The effort to increase rice production is done by intensification and extensification.

Intensification has been done by applying chemical fertilizers and pesticides increasingly. However, since 1990's farmers has already begun to suffer from the decline of soil fertility, and the dependence of chemical fertilizer (inorganic) has been increasing. In the middle of the soil fertility declining, organic farming system arises. Organic agriculture is an environment-friendly way of farming; the main characteristic of organic farming is the use of local varieties followed by fertilization with organic fertilizers, and pests control are also with natural pesticides.

Due to the unique nature of rice production with typically flooded soils and high nitrogen input, the release of N_2O from soils through denitrification increases and contributes to global warming. According to [1], N_2O has strong infrared absorption capacity and traps the radiation from the earth's surface. It is estimated that N2O has approximately infrared absorption capacity 300 times more than CO2 on a mass basis. Moreover, in the upper stratosphere, N_2O is oxidized to NO by the action of UV light, and NO destroys the ozone layer which protects living things against the sun's UV-radiation [2]. Nitrogen fertilization increased the N_2O emissions from both continuous flooding and mid-season drainage treatments [3,4], as it was emitted mainly through rice plants in the presence of floodwater, while through soil surface in the absence of floodwater [5]. The application of mineral N increases substrate availability for nitrification and denitirification [6], provides more available N for soil microbes, and will lead to higher N_2O efflux [7].

[8] promoted organic agriculture as a partial means for agriculture mitigation of CH_4 and N_2O emission. Nevertheless, few studies exist about N_2O emission which occurs in organic and conventional farming system in paddy fields at tropical areas. The main objective of this study is to compare the N_2O emission from organic vs conventional farming system in humid tropics, thus to examine whether organic agriculture management has potential for mitigating the of N_2O emission.

2. Material and methods

2.1. Site description

Eleven soil samples under organic farming (O1-O11) and eleven conventional (C1-C11) were taken in Godean and Imogiri sub-districts of Daerah Istimewa Yogyakarta (DIY) Province, Sawangan and Salaman sub-districts of Magelang District, and Sukorejo and Jetis sub-districts of Sragen district; last two districts are located in Central Java Province.

Pairs of organic and conventional farming sites were chosen as close as possible to each other to avoid differences in soil type. Data on paddy field management such as physical condition of the field, paddy cultivation, and yields were collected during interviews with farmers.

The paddy field management in each sub-district is relatively the same, either in organic or in conventional farming system. It is due to the fact that in one district it has several farmer groups which have similar way to manage their fields. The differences are the term when they start to cultivate organically and the area of their field. For organic farming in Godean sub-district (O1 and O3), they applied 2000-3000 kg/ha compost from cow dung and green manure before planting, but only O2 practiced 8000 kg/ha compost and rotten eggs. In Imogiri sub district, organic farmers (O4-O5) spread 4000 kg/ha compost and 2 L/ha of liquid bio-fertilizer. Sawangan's organic farmers (O7-O8) spread 3000 kg/ha compost and 8200 kg/ha/year compost of goat dung for O6. In Sragen district, the organic farmers (O9) practiced 3000 kg/ha compost. A one-year organic farming system in Salaman sub-district, the farmers practiced 7000 kg/ha compost in their paddy fields. Special case for O11, the farmers applied 1500 kg/ha organic fertilizer at the beginning of planting, but at the age of 3 weeks after planting, they applied 97 kg/ha urea.

Most conventional farmers in all district applied mineral fertilizer for their sample, like Phonska (15-15-15-10) in average of 500-700 kg/ha, twice in one season planting, and some others farmer spread 900-1000 kg/ha NPK Kujang (15-15-15) once in one season planting.

2.2. Soil sampling and general soil analysis

Soil sampling for organic and conventional farming fields was conducted in July 2012. Three plots per location were selected as field replications; samples of topsoil (0-20 cm depth) were taken in a zigzag pattern and composited for each individual field. Soil samples were air dried, cleared from stones and other impurities, grinded and sieved through 2 mm sieve.

General soil analyses that have been conducted are soil texture with pipette method which was classified according to USDA soil texture class, pH KCl, SOC with Walkley and Black method, total N by CNS macro analyzer, mineral N (NH_4^+ and NO_3^-) at the beginning and the end of experiment which was measured by autoanalyser.

Initial water content was measured to calculate the amount of water needed to attain two different moisture contents expressed as water filled pores (WFPS), namely 75% WFPS and 100% WFPS for incubation. Each location had different amounts of initial mineral nitrogen (both NH_4^+-N and NO_3^--N). These initial data allowed us to adjust mineral N of all soil samples to the highest amount; in this case the highest initial values for NH_4^+-N and NO_3^--N were 68 mg N/kg (as found in C9) and 26.8 mg N/kg (as found in O8) respectively. They have the same initial mineral N at the beginning of the denitrification process.

2.3. N_2O-N emission

A pre-incubation was carried out at 55% WFPS, to stimulate the soil organisms activity after sieving and air drying of soil samples. The additional mineral N was mixed with the water needed to attain 55% WFPS. Due to the muddy soil condition on the paddy field, it was hard to measure the real bulk density in the field, thus in this experiment we assumed that the bulk density was 1.20 g/cm3. Soil was repacked into a PVC column with 4.5 cm in diameter and soil surface was levelled at 3 cm below the top of columns. The pre-incubation was done for 5 days in the dark room with controlled temperature (± 20°C).

After the pre-incubation, the incubation was started by adjusting the water content until 75% WFPS and 100% WFPS. Incubation was carried out in triplicate. The tubes were placed inside the jars, which were closed air tight and incubated in the darkness at 20 °C. A gas sample (1 ml) was taken per day from the headspace with an airtight syringe through a septum in the lid. N_2O-N concentration was measured immediately with a gas chromatograph with electron capture detector (GC-ECD). The measurement settings were as follows: nitrogen as carrier gas, 200 °C injector temperature, 30 °C oven temperature and 310 °C detector temperature. The next step was to open the jars for 10 minutes to allow aeration, meanwhile the moisture content was checked and water was added if needed. The incubation stopped when the cumulative N_2O-N emission reached a constant value, which in this experiment was on the seventh day.

2.4. Statistical analysis

The effect of management practices on N_2O-N was determined by splitting comparing the means between organic and conventional. The independent t-test was used to check the significant effects of management practices by comparing the means within fields; this test was only used for data that are normally distributed. Kolmogorov-Smirnov test was performed to check the normality of the data. Levene's test was used to check the assumption of variances equality. For data which were not normally distributed, the non-parametric Mann-Whitney U test was used to check the significant differences. All significances were evaluated at $P<0.05$, however for Pearson correlation, both 0.05 and 0.01 levels of significance were tested. The statistical analyses were performed using SPSS version 20.0.

3. Result

Fig. 1 summarizes the effect of farming system on N_2O-N emission at 75% WFPS. The N_2O-N accumulation increases with the increasing time of incubation. A significant difference between all organic and conventional farming fields ($P<0.05$) was observed; a more detailed statistical analysis per site was performed and it shows that site 7 had significantly higher N_2O-N emission in conventional management than in organic (433% increase). Although a consistent trend of higher N_2O-N emission in conventional than in organic fields was observed in mostly all sites, some exceptions (site 1 and 2) were observed where N_2O-N emission in organic farming system was slightly higher than in conventional farming. Compared with all paired fields, site 11 had the highest N_2O-N emission accumulation in conventional management (0.06 µg N_2O-N/g soil).

Analogous to N_2O-N emission at 75% WFPS, the N_2O-N emission at 100% WFPS was also higher in conventional farming system compared with organic ones (Fig. 2.). Nevertheless, on site 6, N_2O-N emission was significantly higher by almost 600% in organic field than in conventional field. In general, by comparing organic fields and conventional fields, there were no statistically significant differences. Due to the large standard deviations, it should be noted that the scale of y-axis differs between site 1 – 5 and site 6 – 11; the last sites have higher scale, due to much higher accumulation of N_2O-N emission. The highest N_2O-N emission accumulation was 27 µg N_2O-N/g soil (C10).

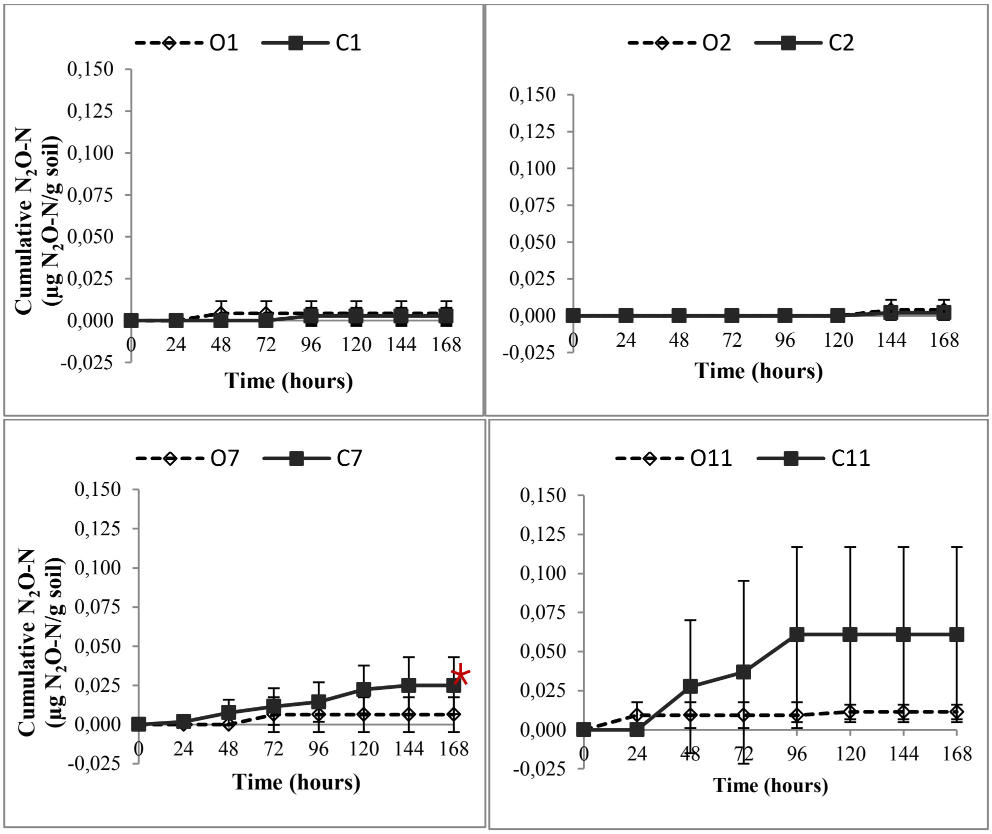

Fig. 1. Cumulative N_2O-N emission at 75% WFPS. All graphs have same scale on y-axis. Error bars indicate standard deviation. Bars followed by * are significant at $P<0.05$.

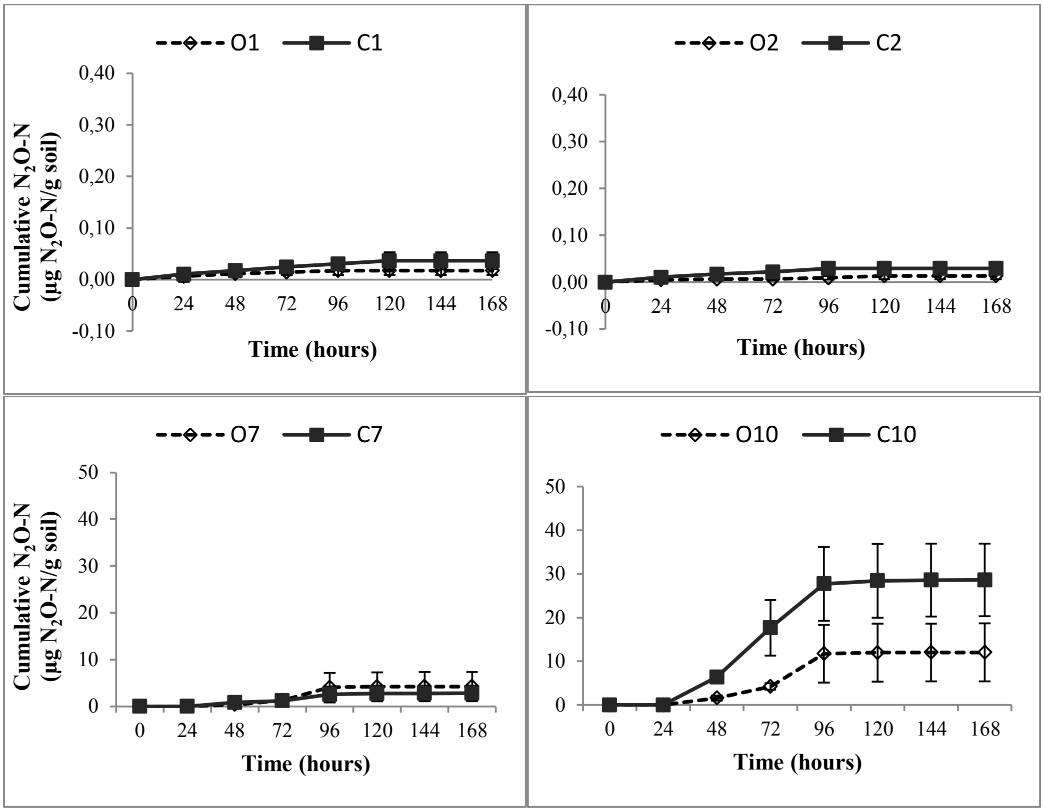

Fig. 2. Cumulative N_2O-N emissions at 100% WFPS. All graphs do not have same scale on y-axis. Error bars indicate standard deviation. Bars followed by * are significant at $P<0.05$.

4. Discussion

Emission of N_2O-N at 75% WFPS was significantly higher in conventional management than in organic management. It could be due to the fact that the synthetic N fertilizer inputs in conventional paddy fields was easily released, so that the mineralization process went faster to produce more emission in conventional fields. A constant cumulative of N_2O-N emission was observed at the end of measurement, which means there was no more emission after the seventh day.

At 100% WFPS, the N_2O-N emission in conventional tended to be higher than in organic farming system, although it was not significantly different. Nevertheless, in more detailed statistical analysis, N_2O-N emission in O6 was significantly higher than C6. This is probably related with the long term to organically manage the soil and this location has been managed organically for 25 years. The application of organic matter in submerged paddy soil for long term can cause rapid activity of microorganisms for nitrification-denitrification process and lead to higher N_2O-N flux. [9] explained that long-term soil amendment with organic substrates may efficiently increase soil carbon content. Analogous with the curve shape of N_2O-N emission at 75% WFPS, a constant cumulative N_2O-N emission was observed at the end of measurement. There was a very big variation of water status during the experiment of site 6-11. The water level in experiment of site 6-11 was strongly fluctuating, after flooding in one day, on the next day of experiment the water was suddenly gone. Intermittent water condition could cause higher N_2O-N emission as a result of denitrification of accumulated NO_3^--N on dry condition. At site 4, the N_2O-N emission in conventional field was strikingly increased for about 0.26 µg N_2O-N/g soil at 4th day of measurement.

Although some literature reported that there would be a high N_2O-N emission at lower moisture content [10, 11], less N_2O-N emission in 75% WFPS than in 100% WFPS was observed in the present study. This is probably due to the swelling ability of the high clay contained in soil samples. When water was added to the soil, the soil absorbed a lot of water and prompted a swelling process, which caused the WFPS in the experiment lower than 75% or 100%. This explains that a very low emission at WFPS 75% is because of less water content, and higher emission at 100% WFPS is due to the availability of O_2.

The range of N_2O-N emission at 75% WFPS was 0.01 – 0.03 kg N_2O-N/ha in organic farming and 0.005 – 0.16 kg N_2O-N/ha in conventional farming; for organic farming at 100% WFPS, the N_2O-N emission was 0.04 – 60.55 kg N_2O-N/ha and in conventional farming was 0.08 – 74.42 kg N_2O-N/ha. It is due to heavy texture class of soil samples, thus the mineralization process went slower than coarser texture soil. Mineralization of soil organic matter and biomass is further influenced by the interactions with soil texture. The greater physical protection of organic matter in fine-textured soils can lead to lower the mineralization rates compared with coarse-textured soils [13]. However, this range value was rough calculation, because in this experiment the soil samples were taken at the depth 20 cm from the soil surface; in field situation, the N_2O-N emission at deeper soil depth could be lower than this experiment.

The N_2O-N emission in most organic fields at both WFPS was lower than in conventional fields. [11] found that N_2O-N emission in organic rice field was significantly lower than conventional rice field under flooding-drying water regimes in Southeast China. This result was also revealed by [15] in Thailand, which the rice field added with chemical fertilizer emitted more N_2O-N emission than in rice field with organic fertilizer addition.

5. Conclusion

Organic management of paddy fields in Central Java, Indonesia, has a promising potential to mitigate the nitrous oxide emissions from agriculture. Compared with conventional, organic management emitted 23% less nitrous oxide. Different water content affected the nitrous oxide emission differently. Lower water content (75% WFPS) emitted less nitrous oxide than higher water content (100% WFPS), due to swelling effect of high clay content in soil sample. It caused oxygen availability in soil pores thus the condition to reach denitrification was not fulfilled.

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