Effect of flooding duration on nitrous oxide emission from organic and conventional rice cultivation system in Central Java, Indonesia

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Abstract. Majority paddy fields in Indonesia are cultivated under conventional management practices. Recently, organic farming has been developed due to a high demand of more healthy food and soil fertility improvement of farmer field. A greenhouse experiment was conducted to investigate N2O emission from organic (O) and conventional rice field (K) collected from Sragen (S, soils with clay texture) and Magelang (M, soils with coarse texture) region. The soils were treated with different duration of flooding, i.e., no flooding (P0), flooding 2 weeks (P2), and flooding 4 weeks (P4). The result showed that there were no significant differences on N2O emission among the treatments in this study. However, N2O emission (kg N ha⁻¹) was emitted more significant in organic than in conventional management practice in both regions. N2O emission (kg N ha⁻¹) showed the highest value (0.39 – 1.21) when soil was flooded during 2 weeks. Interestingly, N2O emissions from both regions showed the same trend, neglected their different soil texture.

1. Introduction
Global warming is one of the main concerns over worldwide because its directly impact on human life. Global warming occurs due to the increasing of average surface temperature and oceans, mainly due to the emissions of greenhouse gases (GHG) such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and chlorofluorocarbons (CFCs). Especially after the Industrial Revolution, emissions of GHG have increased dramatically due to increasing industrial and transportation activities associated with the use of fossil energy sources and land use changes.

Based on the data issued by Intergovernmental Panel on Climate Change [1], total anthropogenic GHG emissions have continued increase over 1970 to 2010 with larger absolute increases between 2000 and 2010. Anthropogenic GHG emissions in 2010 have reached 49±4.5 Gt CO₂-eq/yr. Majority, GHG emissions generated by anthropogenic activities include land use and land use change in agricultural and forest systems, industrial development, and urban expansion. Particularly in the agricultural soil, the emissions of CO₂, CH₄, and N₂O depends on the biophysical processes and the incorporation or decomposition of organic residues in the soil. Soil aerobic conditions produce CO₂, while anaerobic conditions produce CH₄, and nitrification and denitrification processes of mineral-N result in N₂O emission.

Rice is produced from approximately 8.1 million ha of land in Indonesia in 2013, which is needed by the fourth rank of biggest population in the world after China, India, and United State. Sustainable management of that land for rice production is very crucial to meet national rice demand. Rice field is one of the potential source of GHG emissions to the atmosphere. The magnitude of GHG emitted the
atmosphere is significantly related to soil managements practiced by farmers. An effective management of rice field should be implemented to minimize the GHG emission while the fields still have high productivity.

$N_2O$ gas accounts for 6–8 % of the current global warming with a global warming potential (GWP) 298 times more than CO$_2$[1]. This $N_2O$ gas also plays a significant role in ozone (O$_3$) depletion [2]. Rice cultivation is considered to be one of the important source of $N_2O$ emission [3]. In Indonesia, straw incorporation and application of dairy manure are the most common organic fertilizer applied by farmers. Recently, organic farming is developing due to the awareness of farmers to maintain soil fertility in their fields.

Most of paddy fields in Indonesia are cultivated under conventional management practices which giving high chemical fertilizer. Farmers accustomed to use high chemical fertilizer to their field since the government implemented the green revolution on 1970s which focus on increasing the rice yield. Numerous field experiments have been dedicated to measure N2O emissions from paddy fields which included chemical fertilizer in their treatments, such us [4] studied high amount of N chemical fertilizer stimulated $N_2O$ emission, supported by [5] that urea application significantly increased $N_2O$ emission. Most of the result showed that $N_2O$ emission increase in the conventional paddy field due to chemical fertilizer application, especially using of N fertilizer.

However, the cycling of flooding then drainage of standing water in paddy field promotes $N_2O$ emission [6], due to provide suitable environment for nitrifier and denitrifier produce $N_2O$. That changed in water condition dominates $N_2O$ emissions [7]. As we knew, water management is recognized as one of the most important factors affecting $N_2O$ emissions from paddy fields. Understanding how to manage water irrigation in the paddy field might suppress $N_2O$ emission to the atmosphere. This study was conducted to identify the impact of flooding and drained condition on $N_2O$ emission from soils cultivated under organic and conventional management practices.

2. Materials and Methods

Three different water managements (P0: without flooding, P2: 2 weeks flooding, and P4: 4 weeks flooding) were combined with soil getting from organic (O) and conventional (K) rice paddy cultivations in Sragen (S) and Magelang (M) region. Each combination treatment had 3 replications. Then they were arranged by a completely randomized design. Soil was collected by zigzag method on 0-20 cm depth in each field. Then, soil was mixed and air drying. After dried, soil was sieved ø 0.5 mm then entered into the pipe (80 cm height, diameter 12 cm) about 3 kg. Those soil was treated then conducted the gas investigation. Tap water was entered to the pipe until 5 cm flooding. Gas sampling was carried out on 0, 7, 14, 21, and 28 days after flooding at 15, 30, and 45 minutes interval with syringe and then kept into 12 ml vacuum bottle covered by aluminum foil. Gas samples were analyzed by gas chromatography. Emission of $N_2O$ was calculated with the following equation provided by [8].

$$E = \frac{dc}{dt} \times \frac{Vch}{Ach} \times \frac{mW}{mV} \times \frac{273.2}{273.2 + T}$$

Note:

E : emission of $N_2O$ (ug/m$^2$/day)

dc/dt : concentration difference of $N_2O$ per time (ppb/minute)

Vch : chamber volume (m$^3$)

Ach : chamber area (m$^2$)

mW : molecular weight of $N_2O$ (g)

mV : molecular volume of $N_2O$ ( 22,41 l)

T : chamber temperature (°C)
Statistical analysis performed using Genstat 11.1. All of statistical differences in N2O gas emission among the treatments were determined using Tukey’s test following the analysis of variance (ANOVA) for the two treatments.

3. Results and Discussion
The average of N\textsubscript{2}O flux from the soil appears to increase or decrease in both Sragen and Magelang soils (Figures 1 and 2). Treatment of KP0 and OP0 showed the average N\textsubscript{2}O flux was more stable, compared to other treatments. It appears that in the non-inundation treatment, the amount of N\textsubscript{2}O emitted per week was more stable. Meanwhile, the amount of N\textsubscript{2}O emitted in the 2-week and 4-week flooding treatments was more variable by time. Flooding causes an anaerobic condition in the soil so that the existing NO\textsubscript{3} may be turned into N\textsubscript{2}O.

![Figure 1](image1.png)

**Figure 1.** Seasonal Variation of N\textsubscript{2}O Flux in Magelang

![Figure 2](image2.png)

**Figure 2.** Seasonal Variation of N\textsubscript{2}O Flux in Sragen

Figure 3 showed that the highest total N\textsubscript{2}O emission in Magelang during incubation period was found in OP2 treatment (3.60 mg N m\textsuperscript{2} day\textsuperscript{-1}), while the lowest N\textsubscript{2}O emission was found in treatment of KP0 and OP0.
Meanwhile, the figure 4 showed that the highest N$_2$O emissions are obtained in the treatment of KP4. The amount of N$_2$O emitted from treatment of OP2 was not significantly different from that of KP4. The lowest emission was shown in the treatment of KP0, OP0 and KP2. However, those three treatments showed insignificantly different results. Thus, it can be stated that a 2-week flooding treatment may lead to an increase in the total amount of N$_2$O emitted into the air compared with non-flooding treatment and continuous flooding treatment for 4 weeks. Alternate anaerobic and aerobic cycling considerably increased N$_2$O emission relative to constant aerobic and anaerobic conditions and the net N$_2$O emission increased with the duration of the anaerobic and aerobic periods from 7–7 days to 14–14 days [9]. The N$_2$O emission rate peaked when waterlogged soil columns were drained to become well-aerated (waterfilled pore space = 63%) [10] and a very small amount of N$_2$O was emitted during the waterlogging period [4].

N$_2$O emissions from both regions showed the same trend, neglected their different soil texture. N$_2$O emission (mg N m$^{-2}$ day$^{-1}$) was emitted more significant in organic than in conventional management practice in both Magelang and Sragen (Figure 5 and 6).
Figure 5. Total N$_2$O Emission from Organic and Conventional Rice Fields in Magelang

Figure 6. Total N$_2$O Emission from Conventional and Organic Rice Field in Sragen

4. Conclusion
There were no significant difference on N$_2$O emission among the treatments in this study. However, N$_2$O emission (kg N ha$^{-1}$) was emitted more significant in organic than in conventional management practice in both regions. N$_2$O emission (kg N ha$^{-1}$) showed the highest value (0.39 – 1.21) when soil was flooded during 2 weeks. N$_2$O emissions from both regions showed the same trend, neglected their different soil texture.

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