N₂O emission and grain yield of rice from organic and conventional farming in the paddy field

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Abstract. Rice cultivation is a significant contributor to N₂O. Organic agriculture, which is entirely dependent on the source of nitrogen from organic matter can become an alternative to mitigate the high N₂O emission. This research aimed to observe the N₂O emission from the organic and conventional rice fields. Two sites of rice fields were selected for this study, i.e. Sawangan, Magelang and Godean, Yogyakarta, Indonesia. Three plots of organic rice field and three plots of conventional rice field were selected as study sites. Gas samples were collected four times during the plant growth, i.e before transplanting, 2 weeks after transplanting, maximum vegetative stages and 2 weeks before harvesting. Godean site shows the emission of 138 µg N₂O/m²/hour for organic field and 336 µg N₂O/m²/hour for the conventional field. Sawangan site shows the emission of 348 µg N₂O/m²/hour for organic field and 444 µg N₂O/m²/hour for the conventional field. The results showed organic farming able to reduce the emission of N₂O up to 20% on average. Rice growth and grain yield proved that organic rice showed a higher result compared to conventional rice. This study implied that organic rice farming might be promising land management to mitigate N₂O emission and produce a higher yield.

1. Introduction

Climate change is one of the most concerning problems of a human being today. The global average temperature has risen by 0.6 to 0.9 degrees Celsius due to anthropogenic activities that contributed to greenhouse gas emissions into the atmosphere. Agriculture with inundated rice fields is considered to be one of the main sources of N₂O emissions. Agriculture is a sector that is estimated to contribute 75% of global N₂O emissions [1]. Thus reducing soil N₂O flux is a substantial mitigation opportunity for agriculture to reduce its contribution to greenhouse gas emissions [2]. Soil oxidation during rice cultivation such as mid-season drainage effectively reduces CH₄ emissions but results in higher N₂O emissions [3]. The practice of a combination of drainage from the middle season and the use of green manure can be carried out without changing clean greenhouse gas emissions while sustaining grain yields in organic rice fields [4].

Organic rice cultivation has recently become a popular farming system among farmers due to higher rice prices, healthier rice and less environmental damage. Inorganic planting systems, fertilizers, and pesticides are used to come from organic materials [5]. FAO support for organic agriculture as a solution to reduce CH₄ and N₂O emissions [4]. A potentially important contribution from sourcing from organically managed agriculture is the careful management of nutrients and the reduction of N₂O emissions from the soil [6]. Mineral fertilizers, which currently cause direct N₂O emissions in the range of 10% of agricultural GHG emissions, are completely avoided in organic
farming systems. Some research shows that organic farming can mitigate N$_2$O emissions. Organic agriculture, which relies on nitrogen sources from organic matter, can be an alternative to mitigate high N$_2$O emissions from rice fields. The lower release of N from soil organic matter may decline the potential for N$_2$O emissions based on the IPCC method, but when organic matter input is higher and N turnover rates are bigger the opposite effect may occur [7]. This research was done to clarify the amount of agricultural N$_2$O gas emission, rice growth, and grain yield in organic and conventional rice farming in tropical areas in Indonesia.

2. Materials and methods

2.1. Study sites
Two sites of rice fields were selected for this study, i.e. Sawangan, Magelang (-7.531187, 110.287091) and Godean, Yogyakarta (-7.767686, 110.297135), Indonesia. From each site, three plots of organic rice fields and three plots of conventional rice fields were selected as study sites.

2.2. Soil properties analysis
Soil samples were taken from the rice field four times during the plant growth, i.e before transplanting, 2 weeks after transplanting, 8 weeks after transplanting and 2 weeks before harvesting. Analysis of soil sample were done at the Laboratory of Soil Science Department, Faculty of Agriculture, Universitas Gadjah Mada, Indonesia. Soil properties analysis followed the procedure developed by [8]. An Air-dried soil sample was used for the soil properties analysis. The soil properties observed were pH H$_2$O (1:5) (w:v) using pH meter, redox potential (Eh) using Oxidation Reduction Potential (ORP meter), soil available NH$_4^+$ using KCl 2 M extraction method.

2.3. N$_2$O gas measurements
Gas samples were collected four times during the plant growth, i.e before transplanting, 2 weeks after transplanting, 8 weeks after transplanting and 2 weeks before harvesting. The N$_2$O gas was collected using a closed chamber method equipped with a thermometer in the mid-morning time, and the gas was taken by gas-tight glass syringe. Nitrous oxide gas flux analysis of the gas samples were measured using Gas Chromatography Agilent 7820A GC System with ECD Detector. Gas samples were then injected into the GC machine, which was calibrated before using N$_2$O standard gas. The air sample analysis can be converted to greenhouse gas flux with the formula as follow [9]:

F = $\frac{dc/dt \times V_{ch}/A_{ch} \times mW/mV \times 273.2/(273.2+T)}{273.2}$ ……………………………………… (1)

Note. F: flux of N$_2$O gas (mg/m$^2$/minute), dc/dt: concentration difference of N$_2$O (ppm/minute), Vch: Chamber volume (m$^3$), A: Chamber Area (m$^2$), mW: molecular weight of N$_2$O (g), mV: molecular volume of N$_2$O (22.41 l), T: average temperature at sampling

2.4. Rice growth and grain yield observation
Plant height and several tillers of the organic and conventional field were observed in 2 weeks after transplanting, 8 weeks after transplanting, and 2 weeks before harvesting. Grain yield was observed at harvesting.

3. Results and discussion

3.1. Soil Properties
Figure 1 indicated that soil pH in organic and conventional ranged from 7.0–7.3. There was no tendency to change soil pH during the growth of the rice plant. Figure 1 showed that there was a change in the value of soil redox potential during the growth of the rice plant. The highest soil redox potential was found in the before transplanting stage, and the lowest soil redox potential was found in
2 weeks after the transplanting stage in both organic and conventional rice farming. Soil redox potential in organic paddy field showed a lower value of redox potential than in conventional paddy field at before transplanting, 2 weeks after transplanting, 8 weeks after transplanting and 2 weeks before harvesting growth stage of Godean and at 2 weeks after transplanting, 8 weeks after transplanting and 2 weeks before harvesting stage of Sawangan.

Figure 1. Soil pH (A and B) and soil redox potential (soil Eh) (C and D) in organic and conventional rice farming during rice growth. Note. G: Godean, S: Sawangan, O: organic, C: conventional, BT: before transplanting, 2AT: two weeks after transplanting, 8AT: 8 weeks after transplanting, 2BH: two weeks before harvest. Data presented are the mean of soil analysis results collected from each three organic rice fields and conventional rice fields.

Figure 2 showed that there was a change in the value of soil available NH$_4^+$ and NO$_3^-$ during the growth of the rice plant. The amount of soil available NH$_4^+$ and NO$_3^-$ was higher in the organic paddy field than the conventional paddy field. However, the amount of soil available NH$_4^+$ and NO$_3^-$ tended to decrease from the BT stage to the 2BH stage in organic rice farming in both sites. Soil available NH$_4^+$ and NO$_3^-$ in conventional rice farming tend to decrease in Sawangan site, however, soil available NH$_4^+$ and NO$_3^-$ was an increase at the 2BH stage in Godean site.

Figure 3 showed that the amount of N$_2$O emission in organic and conventional paddy fields greatly varied during the stage of paddy growth. The amount of N$_2$O ranged from 77.1 to 214.6 µg.m$^{-2}$.hour$^{-1}$ and 100 to 536.4 µg.m$^{-2}$.hour$^{-1}$ in organic and conventional paddy fields sampled from Godean, respectively. The amount of N$_2$O emission ranged from 144.4 to 578.2 µg.m$^{-2}$.hour$^{-1}$ and 188.0 to 786.0 µg.m$^{-2}$.hour$^{-1}$ in organic and conventional rice fields sampled from Sawangan. Godean site shows average emission of 138 µg.m$^{-2}$.hour$^{-1}$ for organic field and 336 µg.m$^{-2}$.hour$^{-1}$ for conventional field. Sawangan site shows average emission of 348 µg.m$^{-2}$.hour$^{-1}$ for the organic field and 444 µg.m$^{-2}$.hour$^{-1}$ for the conventional field. This amount of N$_2$O emission was more or less comparable with the amount of N$_2$O emission reported by [10].
Figure 2. Soil available NH$_4^+$ (A and B) and soil available NO$_3^-$ (C and D) in organic and conventional rice farming during rice growth. Note. G: Godean, S: Sawangan, O: organic, C: conventional, BT: before transplanting, 2AT: two weeks after transplanting, 8AT: 8 weeks after transplanting, 2BH: two weeks before harvest. Data presented are mean of soil analysis result collected from each three organic rice field and conventional rice field.

Figure 3. N$_2$O emission of organic and conventional rice farming. (Note: G: Godean, S: Sawangan, O: organic, C: conventional, BT: before transplanting, 2AT: two weeks after transplanting, 8AT: 8 weeks after transplanting, 2BH: two weeks before harvest. Data presented are mean of soil analysis result collected from each three organic rice field and conventional rice field.)
3.2. Growth parameter
Table 1 showed that there was no difference in the plant height of rice in organic and conventional rice farming in the Godean site. The plant height of rice in organic rice farming was slightly higher than conventional rice farming in Sawangan site. Several tillers and grain weight of rice in conventional farming.

Table 1. Plant height and number of tillers at 8 weeks after transplanting, and grain weight at harvest of rice in organic and conventional rice farming in Godean and Sawangan sites.

| Site     | Management | Plant Height (cm) | Number of tillers | Grain weight (g) |
|----------|------------|------------------|-------------------|-----------------|
| Godean   | Organic    | 90               | 14                | 30.6            |
|          | Conventional | 93              | 17                | 23.0            |
| Sawangan | Organic    | 106              | 15                | 39.4            |
|          | Conventional | 94              | 18                | 30.0            |

Note: Data presented are mean of plant analysis result collected from each of three organic rice fields and conventional rice field.

4. Discussion

4.1. Soil properties of organic and conventional paddy field
Flooding also reduces the soil redox potential, increases the pH of acid soils, and decreases the pH of alkaline [11]. We also did not observe a remarkable change in soil pH after flooding during the rice growth. This may be because the soil pH of this research is close to 7. Our result showed that soil redox potentials decreased with the duration of the week after planting, but increased slightly at the 2 weeks before harvest. This redox potential is a reference to the soil oxidation status. The decrease of redox potential will be greater if soils are saturated for a longer period than for short period [12]. At a pH of 7, redox potentials at >414 mV imply oxic soil conditions, redox potentials at 414–120 mV imply mid oxic soil conditions, and redox potentials at <120 mV imply anoxic soil conditions [13]. Considering those values, the situation of the soils in Sawangan and Godean are considered in the midoxic condition in the rice transplanting stage and turn into an anoxic situation during the plant growth. At a pH of 7, redox potentials at 300 - 100 mV indicates $\text{Fe}^{2+}$ formation, redox potential at 0-150 mV indicates a beginning of $\text{S}^{2-}$ formation, and redox potential at -150–220 mV indicate $\text{CH}_4$ formation [14].

The value of redox potential in this research showed the maximum value of 90.2 and 116.3 mV at a conventional and organic paddy field at Sawangan, and the maximum value of 282.1 and 114 mV at a conventional and organic paddy field at Godean. The minimum value of -145 mV and -134 mV in organic and conventional paddy fields in Godean, respectively. While, the value of redox potential showed the minimum value of -126 mV and -90 mV in organic and conventional paddy field in Sawangan, respectively. Under these condition, it seems that $\text{CH}_4$ has not yet been formed. However, our estimation of this redox potential was done at surface soil. A lower redox potential values may be observed in deeper soil layer. The decrease of redox potential is greater in deeper soil layer than surface layer [12].

The redox potential value in the organic paddy field was always lower than the conventional paddy field in Sawangan, however, the redox potential value in the organic paddy field was lower than the conventional paddy field only before transplanting and 2 weeks after transplanting in Godean. The addition of organic matter considerably and consistently enhances CO$_2$ emissions and decreases redox potentials [15]. Lower soil redox potential value is not only related to prolonged soil saturation but also an increase of demanding oxygen by addition of decomposable carbonaceous rich substances such as organic matter [16].

The content of soil available $\text{NH}_4^+$ dan $\text{NO}_3^-$ cannot be explained based solely on the effect of soil properties such as redox potential or soil pH, because of the presence of rice plant. Available $\text{NH}_4^+$ dan
NO$_3^-$ are necessary for rice growth. The amount of NH$_4^+$ dan NO$_3^-$ is also influenced by adsorption by soil complex exchange, and the leaching, especially for NO$_3^-$ [17], which cannot be held by the soil exchange complex. Moreover, under alternate flooding and drying conditions practiced in this rice cultivation, dan NO$_3^-$ are easily denitrified and increased the rate of emission of N$_2$O [10]. The content of NH$_4^+$ dan NO$_3^-$ are higher in organic paddy field than conventional paddy field in both locations, Sawangan and Godean. This indicated that soil organic matter of organic paddy field produces more available nitrogen than conventional paddy field.

4.2. N$_2$O emission in the organic and conventional paddy field
Nitrous oxide (N$_2$O) is one of the greenhouse gases that causes ozone depletion in the stratosphere. As inorganic nitrogen fertilizers, soil organic matter can be a source of significant increases in N$_2$O in the atmosphere. Soil properties influence the response of N$_2$O emissions in the soil to the application of N fertilizer. Soil pH is found as the principal factor explaining inequalities in N$_2$O emission from agriculture [9], however, this report reviews N$_2$O emission on a regional scale. In this research, we found there is no change in the soil pH during the rice growth, which indicated that the soil pH does not influence the change of N$_2$O emission. The value of soil redox potential, available NH$_4^+$ and available NO$_3^-$ also changed during the period of paddy growth (Figure 1 and Figure 2). These data indicated that the environment of soils in organic was more reduced than in the conventional paddy field. The redox potential of the soil is found to influence N$_2$O accumulation as the production and consumption of N2O occur in narrow redox windows where the redox range levels are negatively correlated with the pH [18]. However, the soil environment varied from reduced to oxidized conditions during the paddy growth. Alternating soil condition from oxidized to reduced is more favorable for N$_2$O to form compared to continuous flooding [10]. Intermittent drainage decrease in CH$_4$ emission and an increase in N$_2$O emission compared with continuous flooding [19]. The value of N$_2$O emission in the organic paddy field was lower than the conventional paddy field in both sites, Godean and Sawangan at each week of sampling.

N$_2$O is released from the soil from the process of nitrification and denitrification, which means that N$_2$O can be formed under an anaerobic environment and reduced condition, however, both processes need NO$_3^-$ as a source of N$_2$O. The redox potential value of organic paddy soils was lower than the conventional paddy field. The value of redox potential ranged from −145 mV to +114 mV in organic paddy field and ranged from -134 mV to +282.1 in a conventional paddy field in Godean. The value of redox potential ranged from −126 mV to +116.3 mV in the organic paddy field and ranged from -91.7 mV to +90.2 mV in the conventional paddy field in Sawangan. N$_2$O emission was regulated within a narrow redox potential range of +120 to +250 mV, due to the balance of N$_2$O production and its further reduction to N2 [20]. N$_2$O emission was lesser in organic paddy field than in conventional field at each stage of rice growth except for 2 weeks after transplanting stage in Godean. We assumed that this lower emission of N$_2$O found in the organic paddy field may be related to a lower redox potential value in the organic paddy field.

4.3. Rice growth and yield
Rice growth and grain yield proved that organic rice showed a considerably higher result compared to conventional rice. This may be related to the amount of soil available NH$_4^+$ dan NO$_3^-$ were found higher in organic paddy field than conventional paddy field. This study implied that organic rice farming might be promising land management to mitigate N$_2$O emission and produce higher rice yield.

5. Conclusion
Organic farming able to reduce the emission of N$_2$O up to 20% on average. Rice growth and grain yield proved that organic rice farming showed a higher result compared to conventional rice farming. This study implied that organic rice farming might be promising land management to mitigate N$_2$O emission and produce higher rice yield.
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