Managing fertilizers and water treatments on rice production and N$_2$O emission

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Abstract. Addressing issues about climate change and higher food demand requires improve management practices. Fertilizer and water input are the critical resources to ensure high yield and low impact to environment in paddy field. The aim of this study was to determine whether higher grain yield and lower nitrous oxide (N$_2$O) emission can be achieved by managing fertilizer and water input. A field experiment was conducted during rice paddy season under conventional practice (CP) that comprised of farmer practice and continuous flooded. In contrast to CP, balanced fertilizer application and intermittent irrigation was applied for another treatment that namely technology introduction (TI). Results showed that the average of seasonal N$_2$O in the TI treatment decreased by 54% compared with the CP treatment. Aerobic–anaerobic increased in N$_2$O emissions. Lower N$_2$O emission at higher rate of N fertilization. Those findings indicated that enhancing rice production and mitigating GHG emission under application of balanced fertilizer and proper water management from paddy field can contribute to sustainable agriculture.

1 Introduction

More than 75% of the rice supply comes from irrigated lowlands rice field [1]. For producing rice, a continuous flooding (CF) is used for the rice irrigation under the traditional system. Producing every kg of rice traditionally need 1900–5000L of water [2]. However, flooded rice fields trigger methane (CH$_4$) production. One of mitigation options for reducing CH$_4$ emission from paddy fields is anaerobic–aerobic irrigation, but it considerably increases nitrous oxide (N$_2$O) emission relative to constant aerobic and anaerobic conditions [3]. Greenhouse gas emission (GHG) from agricultural sector in developing Asian countries is higher than in the developed Asian countries, i.e., China, India, Indonesia and Thailand [4]. Paddy fields emit one of powerful GHG emissions; namely N$_2$O and it has global warming potential 298 times higher than CO$_2$ at the 100-year time horizon [5]. Moreover, increases in the atmospheric concentration of nitrous oxide (N$_2$O) contribute directly to the destruction of the stratospheric ozone layer [6]. The N$_2$O emissions from paddy fields represent a substantial source of atmospheric N$_2$O, although in small quantity compared with those from upland systems [7]. The N$_2$O emission from agricultural sector contributes 60% of global anthropogenic N$_2$O emission [8]. The N$_2$O enhanced by 17% from 1990 to 2005 and are projected to increase by 35–60% up to 2030 [9]. Application of whether organic or inorganic N fertilizer to soils produce N$_2$O, as this gas is a by-product of the transformation of N compounds added to the soil [8]. The N$_2$O from soil are mainly produced by microbial activity, through nitrification and denitrification. The efficiency of N fertilizer is only approximately 30% [10]. Thus excessive use of N has led to a serious issue in intensive agricultural
production in generating a cascade of environmental issues i.e., soil degradation, lake eutrophication, groundwater pollution, and the emission of ammonia and greenhouse gases [11]. Irrigation and N fertilizer management are key inputs for optimizing grain yield but it largely affects N₂O emissions [12]. The individual effect of each approach on N₂O emission has been well documented by previous studies [13], [14], [15]. Emerging agricultural concepts is needed to address these challenges while maintaining crop yield has become a priority particularly for rice production. However, systematic studies on their combination effect on rice production are lacking. Therefore, the objective of this study is to determine whether higher grain yield and lower nitrous oxide (N₂O) emission can be achieved by managing fertilizer and water input.

2 Materials and Methods

2.1 Site description

The experimental field was located at the farmer’s field in Jaken, in the Pati Regency, Central Java, Indonesia. The area of experimental fields is included as rainfed lowland rice area. According to meteorological data that was collected from IAERI weather station, the mean annual air temperature was 37.9°C, and the mean air temperature during January to April 2018 was 38.1°C. The annual rainfall in 2018 was 1141 mm, and the rainfall during January to April 2018 was 687.5 mm.

2.2 Experimental design, culture practices and gas sampling

The experiment was conducted at 2 site of farmers’ field and arranged by a randomized block design. The experiment was comprised of conventional practice (CP) as a control and technology introduction (TI) with 3 replications. The CP applied farmer practice for fertilizer applications and continuous flooded (CF), while TI applied balanced fertilizer application and alternate wetting and drying (AWD). The application of fertilizers of CP and TI can be seen at Table 1.

| Fertilizer | Site A | Site B |
|------------|--------|--------|
|            | CP     | TI     | CP     | TI     |
| N          | 302    | 153    | 134    | 160    |
| P          | 63     | 27     | 30     | 34     |
| K          | 127    | 40     | 55     | 64     |
| Organic    | 3000   | 3000   |

Piezometers with 4 cm in diameter and 100 cm in length were installed in the field to measure the depletion of soil water in the field. Each of the plot was installed 3 pieces of piezometer. Water irrigation was well controlled every day under CF and AWD. Although the criteria for AWD differed between site A and B. AWD could not reach 15 cm below soil surface at Site A (Figure 1). The crops were established by transplanting. Plants were harvested when they completely matured. The harvested area of each plot was approximately 3 x 3 m for determination of yield per unit area.
Fig. 1 Seasonal variations in daily average surface water level for two management practices during rice growing season

The N\textsubscript{2}O fluxes were measured by closed chamber method during the rice-growing period. Each experimental plot had removable chambers for gas collection, which measured 40 cm x 20 cm x 30 cm for N\textsubscript{2}O sampling. Gas samples were collected once a week. However, when the plots of TI were drainage, the gas sampling was collected every day. Five gas samples from each chamber of N\textsubscript{2}O were collected with interval time at 10, 20, 30, 40 and 50 minutes. Gas samples were collected using a 20-mL syringe and transferred into 10 ml of vacuum vial then brought directly to the laboratory. The CH\textsubscript{4} and N\textsubscript{2}O concentrations were directly analyzed with a gas chromatograph (GC), which was equipped with electron capture detector (ECD) for N\textsubscript{2}O analysis.

3 Results and discussions

The N\textsubscript{2}O emissions from paddy soils under CP and TI are given in Figure 2. The range of N\textsubscript{2}O emissions under CP and TI treatments at Site A were around 0.19 to 0.22 and 0.14 to 0.3 kg ha\textsuperscript{-1} season\textsuperscript{-1}, respectively. The mean of N\textsubscript{2}O emission during rice growing season under CP and TI treatments were 0.21 and 0.23 kg ha\textsuperscript{-1} season\textsuperscript{-1}, respectively. There were very large variations in N\textsubscript{2}O emissions from rice plots among triplicates. No significantly different between the treatments on N\textsubscript{2}O emissions. This likely because there was no significantly different on water treatments between CP and TI. Under AWD increased in N\textsubscript{2}O emissions. This suggests that the aerobic–anaerobic cycling triggers interchangeable nitrification of ammonia and denitrification of nitrate, enhancing the total N\textsubscript{2}O emissions [16]. Therefore, the above results suggested that intermittent irrigation of rice paddies significantly stimulated N\textsubscript{2}O emission. Soil water content had strong effects on the N\textsubscript{2}O emissions. The application of N fertilizer on CP was higher than TI, but N\textsubscript{2}O emission on CP was lower than TI. The lower N\textsubscript{2}O emission is likely because decreasing denitrification potential in rice soils. The similar finding was found that nitrogen fertilizer application did not significantly increase seasonal and annual N\textsubscript{2}O emissions [13]. The integrated application of N fertilizer and straw reduced 50% N\textsubscript{2}O emissions [17]. The application of N fertilizers improved plant physiology and the plants’ N uptake [18]. The comparison revealed a significantly positive correlation between grain yield and reduction in N\textsubscript{2}O emission from CP.
Seasonal variations existed in N$_2$O emissions under different water and N management combinations at Site B (Figure 3). N$_2$O emissions were primarily induced by field drying and fertilization. The CP resulted higher N$_2$O emissions throughout 3 replications. The range of N$_2$O emissions from CP and TI were approximately around 1.43 to 1.69 kg ha$^{-1}$ season$^{-1}$ and 0.44 to 0.92 kg ha$^{-1}$ season$^{-1}$, respectively. Significantly higher on the average of N$_2$O emission was found at CP treatment compare to TI. The application of N fertiliser increased substrate availability for nitrification and denitrification and provides more available N for soil microbes, and will lead to higher N$_2$O emission [19]. The TI could reduce N$_2$O emission around 54% than the CP. TI plots applied organic fertilizer. Application of organic fertilizer resulted lower water filled pores (WFPS) than in conventional fields. Organic fertilizer under flooding-drying water regimes was significantly lower N$_2$O emission than conventional rice field [20]. While rice field added with chemical fertilizer emitted more N$_2$O emission than in rice field with organic fertilizer addition [21]. N$_2$O emissions were increased by the application of nitrogen fertilizers due to nitrification and denitrification processes.

Yield and yield components in all parameter measured between CP and TI were not different (Table 2). Among the yield components, no large different between the treatments that caused yield one treatment higher or lower than another. Providing enough water for rice growth would promote percentage of filled grain as long as nutrient supply is sufficient and climate is favourable for rice plant growth [22]. Rice production increased with the nitrogen fertilizer application. TI resulted higher yield compare to CP at Site B. This is likely because the process of wetting and drying change soil structure. It affects the biological processes that lead to C and N transformations and the biogenic gases production [23]. Aerobic and anaerobic condition influence root activity, photosynthesis and respiration of rice plants.
Table 2. Yield and yield components on conventional practice (CP) as a control and technology introduction (TI) during rice growing season

| Site | Treatment | Panicle number per m² | % filled grain | 1000 weight grain (g) | Yield (ton ha⁻¹) |
|------|-----------|-----------------------|---------------|----------------------|-----------------|
| A    | CP        | 207                   | 67            | 27                   | 6.58            |
|      | TI        | 330                   | 77            | 27                   | 6.12            |
| B    | CP        | 256                   | 68            | 27                   | 6.26            |
|      | TI        | 329                   | 62            | 28                   | 6.39            |

4 Conclusions
Irrigation regimes and N fertilization strategies are two of the most important factors for increasing grain yield and mitigating N₂O emission. Aerobic–anaerobic cycling triggers N₂O emissions. Enhancing rice production and mitigating N₂O emission under application of balanced fertilizer and proper water management from paddy field have been done to contribute for sustainable agriculture. Lower N₂O emission at higher rate of N fertilization might be caused by the decreasing denitrification potential in rice fields, but further study is needed to explore the specific mechanism.

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6 References
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