Alternate wetting and drying combined farmyard manure for reducing greenhouse gas while improving rice yield

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Abstract. Water and organic amendments are the most important factors controlling methane (CH₄) emissions from paddy fields. Alternate wetting and drying (AWD) in rice cultivation improve water productivity (WP), minimize methane emission, but might increase nitrous oxide emissions (N₂O). The effects of combined water management and organic manure application on methane and nitrous oxide emission, rice yield are not well documented. The objective of this experiment was to determine rice cultivation technology that can improve productivity and reduce GHG emissions on rice field. The Inpari 32 rice cultivar was used in this study. Closed chamber methods were used for measuring emissions of greenhouse gases. Our results showed that, in comparison with continuous flooding, the AWD significantly reduced total global warming potential (GWP) by 13–17%. The AWD technique increased grain yields by 6-7% compared with those of CF. The AWD technique reduced CH₄ (14–18%) and increased water productivity by 7–12% compared to CF system, along an 18–23% reduction in GHG intensity (GHGI). In conclusion, AWD technique and soil amendment with farmyard manure could be effectively used in greenhouse gas mitigation strategies for reducing GHG emission, GWP, and GHGI without sacrificing rice yield.

1. Introduction

The challenge of agriculture to fulfill food needs is even more remarkable because of an increase in population and the threat of climate change. Drought will become more critical as a result of climate change's implications on water resources for agriculture. In crop cultivation and food security, water availability is a limiting factor [1]. Water scarcity would affect roughly 2 million hectares of dry land and 13 million hectares of irrigated land by 2025 [2]. Carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), on the other hand, are the most significant contributions to greenhouse gas emissions from agriculture [3]. The three gases are converted to equivalent CO₂ (CO₂-e), which indicates how much each gas contributes to the greenhouse effect compared to CO₂ [4].

Paddy field is the primary source of methane gas up to 15% (25-170 million tons per year). Methane gas is naturally formed from the decomposition of organic matter through complex biochemical reactions by methanogenic microbes (Archaea), under anaerobic (flooded) conditions, still the amounts reaching the atmosphere depends on abiotic factors, including temperature, pH, nutrients, and groundwater table [5]. Rice plant has an essential function in the CH₄ emission from rice fields. Around 90% of CH₄, released from rice fields into the atmosphere is emitted through plants, by diffusion and ebullition. Air space in the aerenchyma tissue found in well-developed leaves, stems, and roots causes gas exchange in continuous flooding conditions to proceed rapidly. Aerenchyma acts...
as chimneys for the release of CH₂ into the atmosphere [6]. Therefore, it is needed to reduce GHG emissions, especially CH₂, by water management option.

Water is a significant requirement in rice cultivation, but not all rice growth stages require abundant water. Water management techniques have been implemented in several countries, including China, India, and Japan, to reduce CH₂ emissions [7]. Mid-season drainage reduces CH₂ emissions by 69.5% in paddy fields in Japan [8]. Meanwhile, draining land twice in central Thailand can reduce emissions by 35% [9]. The alternate wetting and drying technique (AWD) is an efficient water management technique that applied in irrigated land. AWD technique in rice cultivation can decrease CH₂ emissions [10], while also saving water [11], and reducing arsenic concentrations in grain [12]. The reduction of CH₂ emissions by AWD technique was 11-97%, but there was decreasing in yield of 13-33% [13]. The GHG mitigation is intended to reduce emissions, but also must be able to maintain or even increase yields so that farmers are interested. The objective of this study was to determine rice cultivation technology that can improve production and reduce GHG emissions on rice field.

2. Methodology

This research was carried out in the Experimental Field of the Indonesian Agricultural Environment Research Institute, Pati-Central Java (6 ° 46’39.7 ”S and 111 ° 11’53.0” E), during March-June 2020. The soil was classified as an Aeric Endoaquepts with low fertility. The experimental design was arranged in factorial (Randomized Completely Block Design). The factor I was Water management (Continuous Flooding / CF & and AWD 15 cm), while factor II was organic application (farm yard manure 3000 kg / ha and without organic matter). The rice cultivar used Inpari 32. Seedlings were planted when the age reached 18 days old with plant spacing 20 cm x 20 cm on each plot size of 30 m². Inorganic fertilizers were applied at 120kg N, 45kg P₂O₅, 60kg K₂O/ha, and broadcasted in three splits (active tillering, maximum tillering and primordial initiation stages) for all treatments.

The water management treatments were started 10 days after transplanting /DAT. Water table depth was maintained at 2–5 cm for the first 10 DAT for the seedlings to recover and to suppress weeds. In CF, standing water of 2–5 cm water depth was kept from 10 DAT to 7 days before harvesting. In the AWD treatments, the timing of irrigation was based on the water depth in the field water tube installed in each plot, and the irrigation schedule may vary among replicates. The tubes were installed in the field to depths of 15 cm for AWD. When the water disappeared in the tubes, the plot was irrigated to a depth of around 5 cm above the soil surface. Measured parameters were CH₄ and N₂O (with closed chamber method), climate data, irrigation water volume, grain yield (2 m x 3 m). The measurement of CH₂ and N₂O fluxes was carried out weekly with a manually closed chamber. The CH₂ and N₂O measurement time intervals were 0, 10, 20, 30 minutes. The CH₂ and N₂O gas were analyzed using GC Shimadzu 14A and to calculate the GHG flux from paddy fields, the following formula was used [14].

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

Which :

\[
E = CH₄ \text{ or } N₂O \text{ flux (mg/m²/day)}
\]

\[
dc/dt = \text{the concentration change over time of } CH₄ \text{ or } N₂O \text{ (ppm/minute)}
\]

\[
Vch = \text{chamber volume (m}^3\text{)}
\]

\[
Ach = \text{chamber area (m}^2\text{)}
\]

\[
mW = \text{molecular weight of } CH₄ \text{ or } N₂O \text{ (g)}
\]

\[
mV = \text{molecular volume of } CH₄ \text{ or } N₂O \text{ (22.41 l)}
\]
$T = \text{the mean of temperature inside the chamber (°C)}$

The global warming potential (GWP) was calculated from the CH$_4$ and N$_2$O emissions from the rice field during growing season. The GWP is expressed by CO$_2$-e emissions, and the conversion of CH$_4$ and N$_2$O emissions to GWP are 34 for CH$_4$ and 298 for N$_2$O as below [15].

$$\text{GWP} = (34 \times \text{CH}_4) + (298 \times \text{N}_2\text{O})$$

Where, GWP is the combined global warming potential (kg CO$_2$-equivalents). The yield-scaled GWP is calculated as follow [16].

$$\text{Yield scaled GWP} = \text{GWP} / \text{rice yield}$$

Where, yield-scaled GWP is represented in kg CO$_2$-equivalents per kg of rice yield. The data of CH$_4$ and N$_2$O fluxes, plant parameters and results were statistically analysed using ANOVA and continued with the Duncan Multiple Range Test to determine the significant difference among treatments.

3. Results and Discussions

3.1. Climate Condition and Water Level Depth

The daily precipitation and daily maximum and minimum air temperature during the rice growing (from 1 April to 26 June, 2020) are described in Figure 1. Total rainfall around 520 mm was distributed in 30 rainy days. Water management was applied to re-flood the field, whenever the soil water level fell to a predetermined threshold level of about 15 cm below the soil surface (Figure 2). There were 2 AWD cycles during rice growing season, so the reduction of CH$_4$ flux was relatively lower than CF. In the CF treatment, irrigation water was managed daily to keep 2 cm height from soil surface for 0 to 10 DAT and then 5 cm depth until one week before harvesting.

![Figure 1. The rainfall condition and air temperature during rice growing season](image-url)
3.2 GHG Emission and Global Warming Potential (GWP)

Different irrigation methods significantly affected CH$_4$ cumulative emission (Table 1). The CF without organic amendment gave highest CH$_4$ emission compared to other treatments. Methane is emitted from paddy soils that derived from decaying process of organic materials [17]. The organic materials are naturally derived from three sources: (1) old soil organic matter, (2) organic carbon including root exudates and dead root, and (3) dead plant, such as rice straw [18]. There was no significant effect among treatments on N$_2$O emission (Table 1).

The highest cumulative N$_2$O emission was observed with CF with organic amendment (1.48 kg ha$^{-1}$) and the lowest was CF without organic amendment (1.16 kg ha$^{-1}$). Many studies have shown that fertilizer application have a significant impact on GHG emissions from agricultural soils. N$_2$O emissions from inorganic fertilizers (such as NPK or urea) were significantly higher than those from organic amendment [19].

Furthermore, there was no significant influence on N$_2$O emissions between inorganic and organic fertilizers [20]. The GWP was influenced by water management, significantly. The highest GWP was from CF without organic amendment treatment (13,216 kg CO$_2$-e ha$^{-1}$). The GHGI was also stronger depended on water management than organic amendment.

Table 1. CH$_4$, N$_2$O emission, and GWP during the experimental period

| Treatments | CH$_4$ emission (kg ha$^{-1}$) | N$_2$O emission (kg CO$_2$-e ha$^{-1}$) | GWP (kg CO$_2$-e ha$^{-1}$) | GHGI (t CO$_2$-e t$^{-1}$) |
|------------|-------------------------------|---------------------------------|---------------------------|-------------------------|
| W$_0$O$_0$ | 375.72$^a$                    | 1.48$^a$                       | 13,216$^a$                | 2.66$^{ab}$             |
| W$_1$O$_0$ | 313.45$^b$                    | 1.41$^a$                       | 11,078$^b$                | 2.04$^c$               |
| W$_0$O$_1$ | 378.40$^a$                    | 1.16$^a$                       | 13,212$^a$                | 2.79$^a$               |
| W$_1$O$_1$ | 328.58$^{ab}$                 | 1.40$^a$                       | 11,589$^{ab}$             | 2.31$^{bc}$            |

Different letters in the same column represent significant difference at P<0.05

3.3 Grain Yield and Water Productivity

Grain yield was greatly influenced by water regimes (Table 2). The AWD significantly stimulated to rice yield. The AWD technique gave the highest grain yield by 5.38 t ha$^{-1}$ in combination with organic amendment (W$_1$O$_0$). Intermittent drainage has the advantage of improving oxidative soil conditions by stimulating root activity, increases soil carrying capacity and ultimately reducing excess water that causes anaerobic conditions and will also
helps brings oxygen into the soils thus making aerobic condition and also reducing the formation of methane. Mid-season drainage enhances nitrogen uptake as well as soil oxidative conditions [21].

By using AWD irrigation method, there was saving water in the rice growing season. The rainfall was relatively high during this experiment, while saving water input (include irrigation and rainfall) of $W_0O_0$ and $W_1O_1$ by 2% and 3% of the irrigation water, respectively. The highest total water productivity was achieved by $W_0O_0$ treatment and then followed by $W_1O_1$ treatment (Table 2). The water productivity was estimated by the amount of rice yield divided to the total water consumption of rice growth. Water productivity ranged from 0.75 to 0.87 t m$^{-3}$ under the CF and AWD irrigation regimes, respectively. The AWD irrigation regime significantly enhanced water productivity by 7-12% relative to CF irrigation regime.

Table 2. Yield and water productivity from water management and organic amendment

| Treatments | Grain Yield (t ha$^{-1}$) | Water Productivity (t m$^{-3}$) |
|------------|----------------------------|----------------------------------|
| $W_0O_0$   | 4.97$^{ab}$                | 0.78$^b$                         |
| $W_1O_0$   | 5.38$^a$                   | 0.87$^a$                         |
| $W_0O_1$   | 4.72$^b$                   | 0.75$^b$                         |
| $W_1O_1$   | 5.00$^{ab}$                | 0.81$^{ab}$                      |

Different letters in the same column represent significant difference at P<0.05

According to these results, it is important to develop best water management methods to minimize the GHG emissions, and at the same time, without causing any significant impact on rice yield. Thus, implementation of an AWD irrigation method should be a perfect approach to increase rice yield, enhance water productivity, and decrease GHG emissions in the rice cultivation.

4. Conclusions
The AWD technique significantly reduced total global warming potential (GWP) by 13–17% compared to CF. The AWD technique rose grain yields by 6-7% compared with those of CF. The AWD technique reduced CH$_4$ (14–18%) and increased water productivity by 7–12% compared to CF treatment, along with 18–23% reduction in GHG intensity (GHGI).

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