Alternate wetting and drying system (AWD) combined with farmyard manure to increase rice yield and reduce methane emission and water use

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Abstract. Rice cultivation in flooded conditions is one of the methane emission sources. The objective of this study was to determine the effect of water management and farmyard manure application on grain yield, CH4 emissions, and water use efficiency. This study was conducted at the Indonesian Agricultural Environment Research Institute, Pati Central Java from November 2019 to March 2020. The treatments consisted of two factors, a) water management, namely 1) continuous flooding, at 5 cm (CF) and 2) Alternate Wetting-Drying, at 15 cm (AWD) system; and b) farmyard manure namely 1) farmyard manure application 2) without farmyard manure. The observed parameters were rainfall and air temperature, CH4 emissions, water level and milled dry grain. The measurement of CH4 gas emissions was conducted using a closed chamber method. The result of this study indicated that AWD management could increase grain yield by 3.3-8.5% and also reduce CH4 emissions by 12-14% compared to continuous flooding. AWD combined with organic fertilizer application produced the highest grain 7.27 tons ha⁻¹ and emitted the lowest CH4. The AWD management also saved 32-38% of water compared to the continuous flooding.

1. Introduction
Global food demand is increasing annually. The ways to suffice the demand and avoid food scarcity by keeping food security and ensuring food availability while climate change significantly impact natural resources. The land management strategies are needed to increase the rice yield and reduce the impact of climate change since the agricultural sector contributes to emitting greenhouse gases through methane emissions in rice cultivation. Rice cultivation emits methane, especially in flooding conditions.

Plant and soil ebullition are factors that cause a large number of CH₄ released from rice fields into the atmosphere. 35%-62% of methane is emitted through soil ebullition [1]. Methane is the result of anaerobic microbial decomposition of organic matter by methanogenic bacteria through methylotrophic, hydrogenotrophic, and acetoclastic routes [2]. Moreover, the aerenchyma vessels found in well-developed leaves, stems, and roots also cause gas exchange in anaerobic soil conditions [3]. In the long run and if not surmounted, it will cause global warming and impact climate change.

One of the obvious impacts of climate change is weather chaos that causes drought. In several areas, they have shorter periods of rain and less rainfall even in the coming rainy season so that drought has caused water scarcity whereas water is one of the primary needs for rice irrigation which is the largest water consumer in the agriculture sector [4]. An alternative way to reduce greenhouse
gases in rice cultivation, especially CH₄, is the use of water management. Despite being a primary need, not all phases of rice growth require abundant water. At certain times, plants need a lot of water especially during the stages of seedling and panicle filling. In addition, the soil also needs to be desiccated to create aerobic conditions so that the roots can respire and microorganism’s activity can increase soil fertility [5].

To regulate drying and wetting irrigation in rice cultivation, there is a developed and applied technology such as Alternate and Wetting Drying (AWD) system. AWD is a water saving management technique in irrigated rice cultivation that was initiated by the International Rice Research Institute (IRRI). At the beginning of the water management, the land is flooded and the water level will decrease naturally for several days (up to 10 days) or reach a certain level below the land surface [6]. Water conservation by the AWD technique in rice production can reduce CH₄ emissions [7]. Water use in producing rice can be cut down by as much as 25% using AWD. However, this water conservation not only reduces CH₄ emission by 11-97% but also decreases the yield by 13% - 33% [8]. Therefore, there need to be great techniques to reduce the impact of lowering yield. Reducing water consumption can be applied in the rice field without affecting the yield.

Kato [9] suggested that there are many factors that cause yield reduction; some of them are climate and soil properties (physical and chemical soil properties). The factors also include drainage frequency, duration of flooding, and water shortage situation. These conditions affect crop growth. Therefore, by adding organic matter, the plant can grow well without losing yield. It is also claimed that increasing organic matter contributes directly and affects soil properties. Organic matter not only helps stabilize soil aggregates and pores by binding to organic matter and soil organisms, but also very well and thoroughly affects the increasing the capacity of soil moisture mixed with mineral soils, especially in the top layer of soil with more organic material content and more water can be stored. The objective of this study was to determine the effect of water management and organic matter addition on grain yield, CH₄ emissions, and water use efficiency.

2. Materials and methods

2.1. Time and location of the study
This study was conducted at the Jaken Experimental Station, Indonesian Agricultural Environment Research Institute, Pati Central Java from November 2019 to March 2020 in the rainfed condition. The rainfall conditions are presented in figure 1. Soil Classification was silt loam, Aeric Endoaquepts. Endoaquepts soil type has the characteristics of a topsoil with a pH of 5.7, 34% sand texture, 56% dust, 10% clay, organic C 0.18%, N total 0.05%, C ratio / N 3.39, total P 108.3 ppm, total K 319.1 ppm, CEC 8.69 cmol kg⁻¹, Micro element Fe 0.06%, Ca 0.51% and Mg 0.04% [10].

2.2. Research design
The treatments consisted of two factors. A) water management: 1) continuous flooding, at 5 cm (Cf) and 2) Alternate Wetting-Drying, at a 15 cm (Aw) System. B) providing organic matters treatment: 1) by giving farmyard manure (Or) 2) without giving farmyard manure (No). The daily water level measurement was done at 4:00-5:00 pm using piezometers which were made from PVC pipe and installed on each plot. The four treatments were laid out in Completely Randomized Block Design with four replications. The blocks of the experiment were 6x6 m. Plastic sheets set around 40 cm soil depth was used in each block to prevent water permeation.

A rice variety, Inpari 32, was planted at 20x20 cm. Farmyard manure was given about 3-ton ha⁻¹ and applied during or after tillage and also 120 kg of N, 60 kg of P₂O₅, and 90 kg of K₂O were applied in each block. Pests, diseases, and weeds were appropriately controlled.
2.3. Measurements

The observed parameters were rice yield, methane flux (CH$_4$), and surface water level. The closed chamber method was applied to measure CH$_4$ fluxes. The chamber made of plexiglass had 50: 50:100 of length, width, height. A 20 ml syringes were used to take the gas with 0, 10, 20, 30 minutes intervals. Gas samples were taken from 7 am to 9 am and stored in 10 ml vacuumed vials. Gas sample concentrations were analyzed by Gas Chromatography (GC) type Variant 450-GC (Varian Inc., CA, USA) equipped with a flame ionization detector (FID) for CH$_4$ analysis. Calculating methane emissions was done using the trapezoidal integration method formula [11], as seen in equation 1:

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

(1)

E is flux (mgm$^2$ hari$^{-1}$), dc/dt is difference in CH$_4$ concentration per time (ppm minute$^{-1}$), Vch is Box volume (m$^3$), Ach is Box Area (m$^2$), mW is Molecul weight (g), mV is Molecule volume (22.4 l) and T is Average temperature (°C).

Rice yield (14% moisture content) was measured from 6 m$^2$ yield sampling in each block. AWD system was applied based on the daily measurement of the water surface level. The flow rate in the pipe was multiplied by the time of irrigation used to measure irrigation water usage (ton ha$^{-1}$). That measurement was applied to reflood the field and keep the water surface level of 15 cm.

3. Results and discussions

3.1. Grain yield

The highest average of rice yield was obtained by Aw-Or treatment of 7.27 ton ha$^{-1}$ during one growing season. Each treatment caused significantly different yields (table 1). The lowest rice yield was obtained by continuous flooding and without providing farmyard manure. AWD system and farmyard manure were factors that significantly affected the gained yield.

Figure 1. Rainfall condition during one a growing season.
Table 1. Rice yield in various treatments for water management combined with providing organic matter.

| Treatment | Dry Milled Grain (ton ha\(^{-1}\)) |
|-----------|-------------------------------|
| Cf-Or     | 7.03\(^{ab}\)               |
| Cf-No     | 6.42\(^{a}\)               |
| Aw-Or     | 7.27\(^{b}\)               |
| Aw-No     | 6.97\(^{ab}\)              |

Note: The numbers that followed by the same letter in the same column show no significant difference in the Tukey test of 5%. - Data source: primary research

Water management and providing inputs in the soil were important elements that influenced plant growth and also rice yield. Providing farmyard manure both in continuous flooding and AWD system led to a higher yield than without farmyard manure treatment. Providing organic matter such as farmyard manure affected soil permeability and aggregates [12]. Farmyard manure also increased physical properties and also nutrient uptake which gave positive impacts on plant growth, yield, and also yield component [13]. Organic matter contains various nutrients notably micronutrients that definitely affect the total of the tillers in each plant [14]. The number of productive tillers affects rice productivity. Hasanuzzaman [15] informed that increasing tillers in rice was influenced by the application of manure and inorganic fertilizer. In accordance with the number of tillers per square meter, the availability of nitrogen plays an important role in cell division. Satyanarayana [16] reported that providing farmyard manure can improve the N, P, and K uptake by 20, 12, and 9%. Farmyard manure treatment contributes to an increase in nutrients availability. Another study also reported that providing organic material in the form of manure can increase crop yield [17].

AWD-Or treatment gained a higher yield than the Cf-Or treatment while in both of the treatments farmyard manure was applied. This result indicated that the AWD system could save water irrigation without sacrificing the yield. The timing of the AWD system was an important key to avoid yield reduction. AWD system timing should be aligned with the plant growth stage. Carrijo [18] reported that applying AWD does not impact the yield both on the vegetative or reproductive stage.

3.2 Methane emission
The CH\(_4\) flux measurements showed that all treatments had a similar scheme. The CH\(_4\) flux increased with plant growth and reached a peak of 62 DAS (figure 2). At that age, plants entered the panicle growth stage. CH\(_4\) flux decreased again when entering the ripening phase. In the maximum tillering and panicle growth stage the highest CH\(_4\) fluxes were recorded [19]. It was related to the increasing availability of methanogenic bacteria that was detected in root exudates. The panicle initiation stage showed the highest flux since it had a correlation with the higher root vigor of biomass.

The reduction in CH\(_4\) emissions occurred in the AW-Or treatment. The Aw-No and Aw-Or treatments reduced CH\(_4\) emissions by 12% and 14% compared to conventional farming. The highest average of CH\(_4\) emissions was found in the Cf-No treatment of 386.5 mg CH\(_4\) m\(^{-2}\) d\(^{-1}\), while in the Aw-No and Aw-Or treatments were 331.9 mg CH\(_4\) m\(^{-2}\) d\(^{-1}\) and 317.9 mg CH\(_4\) m\(^{-2}\) d\(^{-1}\) (figure 3).
This indicated that irrigation water management in paddy fields greatly affected CH$_4$ emissions. The amount of archaeal and bacterial communities was influenced by desiccation and reflooding [20]. The CH$_4$ formation in the soil was a microbiological process which was controlled by several factors, one of them was potential redox. The flooded condition would reduce the redox potential and provide a suitable environment for methanogen growth [21]. Oxidative conditions during the dry period in the
active tillers and before the primordia phase relatively caused low CH$_4$ emission compared to the reductive conditions [22].

3.3. Water use

In the AWD treatment, there were wet and dry cycles during plant growth. The water level in the AWD treatment would decrease if there was no rain to a certain level (figure 4). The amount of water that could be saved during one growing season was 32% and 38% (table 2), respectively in the Aw-No cm and Aw-Or treatments. Similar results were found by other researchers who stated that more water input is almost 38% lower than inundated treatment [23] Several studies also summarized [24] that AWD could reduce percolation, drainage, and evaporation by 15-20% without sacrificing the yield.

The total amount of water used by Cf treatment for the plant growth period was much higher than the AWD treatment (table 2). The AWD treatment was more efficient to save water and indicated the actual water requirement on the field. These effects indicated that AWD was very beneficial because it could reduce the need for irrigation water and save more water than continuous flooding. Bouman [25] uttered that AWD systems are considered more effective in irrigation agriculture where farmers use water pumps to support irrigation so that in addition to increasing water efficiency, they can also reduce other inputs in the form of fuel costs for water pumps [26]. In addition, water-saving technology in rice cultivation is also needed to resolve the water scarcity and drought problem as a consequence of the climate change effect. AWD techniques can be applied to irrigate land when water is really needed by plant roots to grow and develop better. Sriphirom [27] reported that the AWD system gives benefits in the scarcity of water areas where there is no rainfall water during the tilling stage so the farmer can save water to irrigate the main stage of rice growth and avoid the yield reduction since the water scarcity.

![Water levels in various water managements.](image)

**Figure 4.** Water levels in various water managements.

**Table 2.** Water added in various treatments.

| Parameter                  | Cf-Or    | Cf-No    | Aw-Or    | Aw-No    |
|---------------------------|----------|----------|----------|----------|
| Added water (t ha$^{-1}$)  | 2144.32  | 2366.15  | 1450.34  | 1469.60  |
| % water efficiency        | 0.32     | 0.38     |          |          |
4. Conclusion

The AWD treatment saved irrigation water and reduced greenhouse gas emissions by 12% and 14% and increased the rice yield in paddy fields by 3.3-8.5%. The treatment of Aw-Or reduced CH$_4$ emissions by 32-38% compared to flooded treatment. The highest grain yield was obtained by Aw-Or treatment which was 7.27 tons ha$^{-1}$ and was significantly different from others. The Aw-Or treatment was a safe technique for reducing GHG emissions from rice fields.

Acknowledgments

We thank the researchers and technical staff of MIRSA team and Laboratory assistant of Green House Gas Research Group, and also to our beloved office, IAERI, for allowing us to use the facilities. The Ministry of Agriculture, Forestry, and Fisheries of Japan has supported this research via an international research project "Technology Development for Circulatory Food Production Systems Responsive to Climate Change: Development of Mitigation option for greenhouse gas emissions from agricultural lands in Asia (MIRSA-3).

References

[1] Wassmann, R, Neue H U, Alberto M C et al 1996 Fluxes and pools of methane in wetland rice soils with varying organic inputs Environ. Monit. Assess 42 pp. 163–73
[2] Yao H, Conrad R, Wassmann, R, and Neue H U 1999 Effect of soil characteristics on sequential reduction and methane production in sixteen rice paddy soils from China, the Philippines, and Italy. Biogeochemistry 47 269–95
[3] Jayadeva, H, Setty T K, Prabhakara, Gowda R C, Devendra R, Malikarjun G B, Bandi A G 2009 Methane emission as influenced by different crop establishment techniques and organic manures Agricultural Science Digest 29 4 241–45
[4] Thakur A, Uphoff N, Antony E 2010 An assessment of physiological effects of system of rice intensification (SRI) practices compared with recommended rice cultivation practices in India Exp. Agric. 46 77–98
[5] Fageria N 2007 Yield physiology of rice J. Plant Nutr 30 843-79
[6] Richards, M and Sander B O 2014 Alternate wetting and drying in irrigated rice: Implementation guidance for policymakers and investors (Philippines)
[7] FAO 2017 Climate Smart Agriculture: Policies, Practice and Financing for Food Security, Adaptation and Mitigation (Rome: Electronic Publishing Policy and Support Branch Communication Division)
[8] Lagomarsino A, Agnelli A E, Linquist B, Adviento-Borbe M A, Agnelli A, Gavina G, et al 2016 Alternate wetting and drying of rice reduced CH$_4$ emissions but triggered N$_2$O peaks in a clayey soil of Central Italy Pedosphere 26 533–48
[9] Kato Y, Midori O, and Keisuke K 2009 field crops research yield potential and water use efficiency of aerobic rice (Oryza Sativa L.) in Japan Field Crops Res. 113 328–34
[10] Setyanto, P, Pramono A, Adriany T A, and Susilawati H L 2018 Alternate wetting and drying reduces methane emission from a rice paddy in Central Java, Indonesia without yield loss Soil Sci 1–8
[11] Minamikawa K, Tokida T, Sudo S, Padre A, and Yagi K 2015 Guidelines for Measuring CH$_4$ and N$_2$O Emissions from Rice Paddies by a Manually Operated Closed Chamber Method (Japan: National Institute for Agro-Environmental Sciences)
[12] Singh Y, Singh, B, Khera T S, Meelu O P 1994 Integrated management of green manure, farmyard manure, and nitrogen fertilizer in a rice-wheat rotation in northeastern india. Arid Soil Res. Rehab. 8 199–205
[13] Mondal S S and Chhetri M 1998 Integrated nutrient management for sustaining productivity and fertility under rice (oryza sativa)-based cropping system. indian J. Agr. Sci 68 337–40
[14] Belefant-Miller H 2007 Poultry litter induces tillering in rice J. Sustain. Agric 31 151-60
[15] Hasanuzzaman M, Ahamed K U, Rahmatullah N M, and Akhter N 2010 Plant growth characters and productivity of wetland rice (oryza sativa l.) as affected by application of different manures *Emir J Food Agric* 22 46–58

[16] Satyanarayana V, Prasad P V V, Murthy V R K, and Boote K J 2002 Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice *J. Plant Nutr* 25 2081–90

[17] Sudarsono, Arif W, Melati M, And Aziz S A 2014 Growth and yield of organic rice with cow manure application *Agrivita* 36 19–25

[18] Carrijo D R, Lundy M E, and Linquist B A 2017 Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis *Field Crops Res.* 203 173-80

[19] Gogoi N, and Baruah K K 2005 Methane emission characteristics and its relations with plant and soil parameters under irrigated rice ecosystem of northeast india *Chemosphere* 59 1677–84

[20] Reim A, Hernández M, Klose M, Chidthaisong A, Yuttitham M, and Conrad R 2017 Response of methanogenic microbial communities to desiccation stress in flooded and rain-fed paddy soil from thailand *Frontiers in microbiology* 8 785

[21] Watanabe T, Wang G, Katsutoshi T, Ohashi Y, Kimura M, Asakawa S 2010 Vertical changes in bacterial and archaeal communities with soil depth in Japanese paddy fields *Soil Sci* 56

[22] Pramono A and Adriany T A, Setyanto P 2018 *Soil Quality for Food Security and Healthy (Thailand)*

[23] Rejesus, R M, Palis F G, Rodriguez D G P, Lampayan R M, Bouman B A M 2010 Impact of the alternate wetting and drying (AWD) water-saving irrigation technique: evidence from rice producers in the philippines impact of the alternate wetting and drying (awd) water-saving irrigation technique: evidence from rice producers in the philippines *Food Policy* 36

[24] Bouman, B A M. Humphrey, E, Tuong, T P, and Barker, R 2007 Rice and water *Adv. Agron.* 92 187-237

[25] Roderick, E T 2009. The impact of integrated pest management information dissemination methods on insecticide use and efficiency: evidence from rice producers in south *Vietnam Review of Agric. Econ.* 314 814-33

[26] Lampayan, R M, Rejesus, R M, Singleton, G R, and Bouman, B A 2015 Adoption and economics of alternate wetting and drying water management for irrigated lowland rice *Field Crops Res.* 170 95–108

[27] Sripirom P., Chidthaisong A., Towprayoon S., 2018, Rice Cultivation to Cope with Drought Situation by Alternate Wet and Dry (AWD) Water Management System: Case Study of Ratchaburi Province, Thailand, Chemical Engineering Transactions, 63, 139-44