Mitigation Scenario for Reducing Greenhouse Gas Emission from Rice Field by Water Management and Rice Cultivars

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ABSTRACT

Rice production is a significant anthropogenic source of methane (CH_4) and nitrous oxide (N_2O), two important greenhouse gases (GHGs). Several strategies for reducing GHGs emissions from paddy fields are water management and the use of low emission rice cultivars. The purpose of this study was to determine the effects of water management and rice cultivars on the grain yield and greenhouse gas (GHG) emissions. The research was conducted at the Indonesian Agricultural Environment Research Institute (IAERI), Pati District, Central Java Province during the dry season 2017 (March-June 2017). The study used a factorial randomized block design with the first factor were water managements: A_1 = continuous flooding at 5 cm height and A_2 = alternate wetting and drying/ AWD), and the second factor were rice cultivars: V_1 = Ciherang, V_2 = Inpari 32, V_3 = Mekongga with three replications. All treatments received an equal amount of farmyard manure and inorganic fertilizers. GHG measurements were done by using a closed chamber method. The results of this study indicated that the combination of AWD treatment with Ciherang, Inpari 32, and Mekongga rice cultivars significantly reduced CH_4 emissions by 23%, 46%, and 6%, respectively. The Inpari 32 rice variety produced the highest grain yield compared to others, but there were no significant differences in grain yield between all of the treatments. Therefore, AWD technique in combination with Inpari 32 rice cultivar could be a potential option for maintaining the yield-scaled global warming potential of rice production at a lower level, without reducing grain yield.

Keywords: Alternate wetting and drying, GHG emissions, and rice cultivars

ABSTRAK

Budidaya padi merupakan salah satu sumber emisi gas rumah kaca (GRK) antropogenik metana (CH_4) dan dinitrogen oksida (N_2O). Beberapa strategi untuk mengurangi emisi GRK dari lahan sawah antara lain melalui pengelolaan air dan penggunaan varietas padi yang dapat mengurangi emisi GRK pada level paling rendah. Tujuan penelitian adalah untuk mengetahui pengaruh pengelolaan air dan varietas padi terhadap hasil dan emisi GRK. Penelitian dilakukan di Balai Penelitian Lingkungan Pertanian (Balingtan), Pati-Jawa Tengah pada musim kemarau tahun 2017. Percobaan menggunakan rancangan acak kelompok lengkap factorial dengan faktor pertama adalah pengelolaan air (A_1 = tergenang secara terus menerus 5 cm dan A_2 = alternate wetting and drying / AWD / pengairan basah-kering), dan faktor kedua adalah varietas padi (V_1 = Ciherang, V_2 = Inpari 32, V_3 = Mekongga), masing-masing perlakuan terdiri dari 3 ulangan. Semua plot diberikan takaran pupuk organik dan anorganik yang sama. Pengukuran emisi GRK dilakukan dengan menggunakan metode sungkup tertutup. Hasil penelitian ini menunjukkan bahwa kombinasi perlakuan AWD dengan varietas Ciherang, Inpari 32 dan Mekongga signifikan menurunkan emisi CH_4 masing-masing sebesar 23%, 46% dan 6%. Padi Inpari 32 menghasilkan gabah tertinggi dibandingkan varietas yang lain. Teknik AWD yang dikombinasikan penggunaan varietas Inpari 32 merupakan opsi yang berpotensi menurunkan emisi GRK tanpa menurunkan hasil gabah.

Kata Kunci: Emisi gas rumah kaca, perlakuan basah-kering, varietas padi

INTRODUCTION

Rice is one of the most main food in Asian countries, particularly in Indonesia. Rice requires a lot of water in its cultivation. Climate change has reduced the availability of irrigation water, thus threatening the sustainability of rice production systems. Rice field is one of the sources of greenhouse gas emissions such as methane (CH_4) and nitrous oxide (N_2O) thus contributes to global warming and other negative effects in the agricultural sector (Majumdar 2003; IPCC 2014). One of the strategies to mitigate greenhouse gas emissions from the rice field is water management as well as alternate wetting and drying techniques (AWD). AWD is a water management technique in which the fields are drained and re-flooded one or more times during the growing season. It has been promoted as a strategy to decrease irrigation water use and reduce GHG emissions from rice cultivation while maintaining or improving yields (Richards and Sander 2014). Many studies have shown that AWD reduced water use by more than 30%, without decreasing yield. The 15 cm AWD treatment is a safe irrigation technique to reduce GHG emissions without reducing grain yield (Setyanto *et al*. 2018). AWD treatments significantly reduced GHG emissions and grain total of As heavy metal with no reduction in grain yield. Milled grain total As, which averaged 0.114 mg kg^{-1} in the control, was reduced by 59–65% by the AWD treatments (La Hue *et al*. 2016).

The mitigation techniques have been done to reduce the emissions of these two gases, but simultaneous GHG mitigation has not been studied. CH_4 mitigation may increase N_2O emissions and vice versa. The mitigation strategy must be effective, widely applicable, technically feasible, economical, fast, environmentally friendly, and socially acceptable.

Rice plant roles in three key functions related with CH_4 production: (1) as a source of the methanogenic substrate, (2) as a conduit for CH_4 through a well developed inter-cellular air spaces (aerenchyma), and (3) as active CH_4-oxidizing site in the rice rhizosphere by supporting O_2 counter transport through the aerenchyma system. Several studies showed that CH_4 emitted from rice field to the atmosphere is transported mostly (60-90%) through the aerenchyma of the rice plants rather than molecular diffusion across water-air interfaces or release of gas bubbles (Aulakh *et al*. 2000). The variability of rice cultivars with different growth phases could affect GHG emitted from the soil-atmosphere system. Therefore, rice cultivar selection with low CH_4 emission and high yield was very needed to mitigate GHG emission from the rice field. The purpose of this study was to determine the effect of water management systems and rice varieties on rice yield and GHG emissions.

MATERIALS AND METHODS

Study Site

The research was conducted in the experiment field of the Indonesian Agricultural Environment Research Institute, Pati District, Central Java Province from March to June 2017. The soil in the study sites was classified as Aeric Endoaquepts.

Experimental Setup

The experiment was designed using a 2×3 factorial randomized block design with the first factor was water managements (A1 = Continuous flooding at 5 cm and A2 = Alternate Wetting and Drying / AWD), and the second factor was rice varieties (V1 = Ciherang, V2 = Inpari 32, V3 = Mekongga), with triplicates using a plot size of a 5 m × 6 m each. The experimental field consisted of 6 treatments and 3 replications. These popular modern varieties in Indonesia were cultivated in areas differing in physiographical characteristics.

All treatments received the similar dosages of farmyard manures (FYM) and chemical fertilizers. The FYM with a dose of 3 Mg ha^{-1} was given during the soil preparation. Chemical fertilizers consisted of P (SP 36) 90 kg P_2O_5 ha^{-1}, N fertilizer (Urea) 120 kg N ha^{-1}, and K fertilizer (KCl) 90 kg K_2O ha^{-1}. P fertilization was utilised during the soil tillage as a basalt fertilizer. The first fertilization was in the form of ½ N and ½ K fertilizer, the second and the third fertilization were given based on Leaf Color Chart (LCC), which was adjusted to the plant needs. The observed parameters were fluxes CH_4 and N_2O, pH and Eh of the soil, the plant height and the number of tillers, and the grain yield.

CH_4 Measurement

Gas sampling was done weekly by a closed chamber method by using a 50 cm × 50 cm × 100 cm chamber size for CH_4 measurement, and a 20 cm × 40 cm × 30 cm for N_2O. CH_4 and N_2O concentrations in the samples were analyzed by using a gas chromatograph equipped FID (Flame Ionization Detector) and ECD (Electron Capture Detector). Four hills of rice plants were covered

with a chamber. A rubber stopper, which was pierced with a glass tube and plugged with a septum, was attached at the ceiling of the chamber for collecting the gas samples. The gas samples were taken five times at 5 min intervals for CH_4 and 10 min for N_2O gasses by introducing the inside air into an evacuated 10 mL glass tube through the septum using a double-ended hypodermic needle. The measurement was replicated with 3 chambers in each treatment. Each time, the sampling was conducted between 06:00 AM - 07:00 AM. The rate of flux was calculated based on the change of gas concentration within the chamber's enclosed headspace, with time intervals 0 to 25 min for CH_4 and 0 to 50 min for N_2O during each sampling. The flux rate at the time of chamber closure was determined through the equation described by Minamikawa *et al.* (2015).

$$E = \frac{dc}{dt} \; x \; \frac{Vch}{Ach} \; x \; p \; x \; \frac{273.2}{273.2 \; + \; T}$$

where :

E   : flux of CH_4 or N_2O (mg $m^{-2}day^{-1}$)
dc/dt   : the concentration change over time of CH_4 or N_2O (ppm $menit^{-1}$)
Vch   : chamber volume (m^3)
Ach   : chamber area (m^2)
p : gas density (0.717 kg m^{-3} for CH_4 and 1.977 kg m^{-3} for N_2O at 0°C)
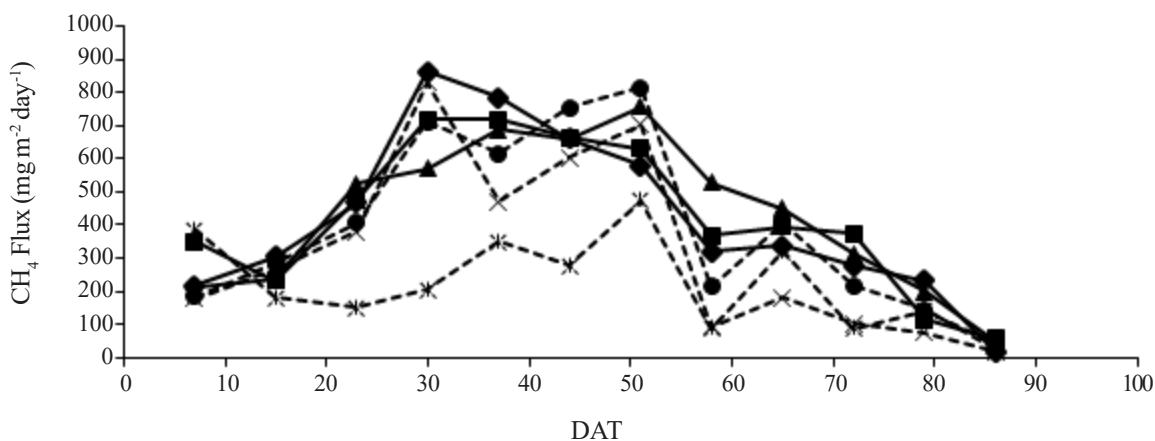T   : average of temperature during gas sampling (°C)

Figure 1. Seasonal variation in CH_4 flux under water management and rice varieties. A1 = Continuous flooding at 5 cm, A2 = Alternate Wetting and Drying / AWD, V1 = Ciherang, V2 = Inpari 32, V3 = Mekongga. ──◆──: A1V1; ──■──: A1V2; ──▲──: A1V3; --✕--: A2V1; --✳--: A2V2; --●--: A2V3.
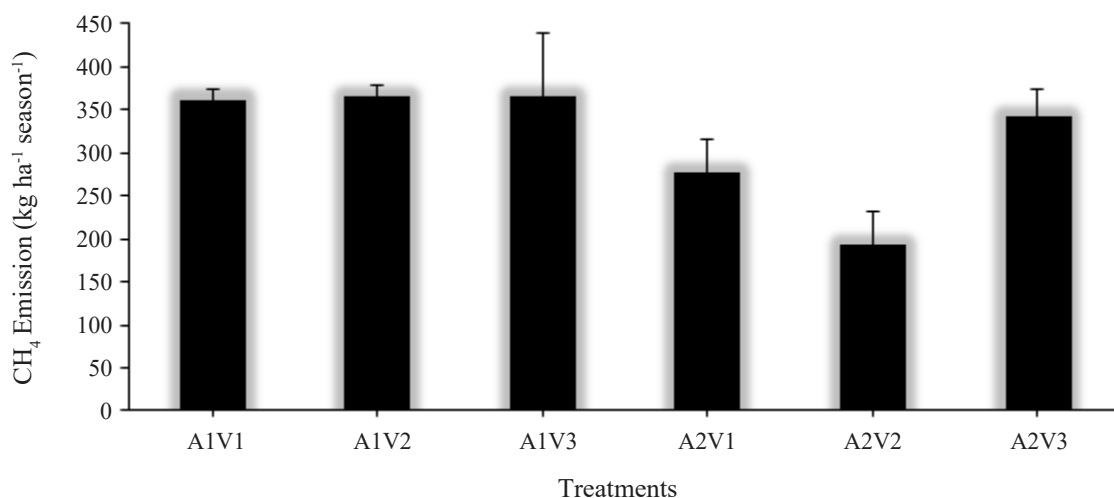

Figure 2. CH_4 emission under water management and rice varieties. A1 = Continuous flooding at 5 cm, A2 = Alternate Wetting and Drying / AWD, V1 = Ciherang, V2 = Inpari 32, V3 = Mekongga.

Tabel 1. Yield and component under water management and rice varieties.

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Treatments	Dry weight of biomass Mg ha^{-1}	Dry weight of root (gr)	Grain yield (Mg ha^{-1})	1000 grain weight (gr)	% filled grain	Grain per panicle	yield-scaled GWP
A$_1$V$_1$	3.6c	2.6a	4.0b	26.1c	62.9b	877b	0.53
A$_1$V$_2$	4.9a	2.7a	5.7a	27.4a	74.3a	1.135a	0.54
A$_1$V$_3$	3.5c	3.0a	4.0b	24.5d	73.0ab	836b	0.53
A$_2$V$_1$	3.9bc	2.4a	4.4b	26.6b	65.0ab	885b	0.53
A$_2$V$_2$	4.3b	2.3a	5.4a	27.7a	74.9a	1.018a	0.56
A$_2$V$_3$	3.8bc	2.7a	4.3b	25.3e	73.3ab	860b	0.53

Different lowercase letter indicate the significant differences (P < 0.05) based on LSD multiple range tests. A1 represents continuous flooding; A2 represents AWD; V1 represents Ciherang ; V2 represents Inpari 32 and V3 represents Mekongga.

RESULT AND DISCUSSION

Greenhouse Gas Flux and Global Warming Potential

The results showed that the CH$_4$ flux pattern in all treatments generally increased at the beginning of plant growth and increased rapidly in the active tillering phase (Figure 1). The CH$_4$ flux at all treatments reached its peaks in the maximum tillering phase and gradually declined after the maturity phase. The CH$_4$ flux ranged between 86-863 mg m^{-2}min^{-1}. The dynamics of the CH$_4$ flux were greatly influenced by the water conditions, in which the formation of CH$_4$ was optimum in continuous flooding. The CH$_4$ emissions from water treatment and rice varieties ranged from 193-367 kg ha^{-1}. The highest CH$_4$ emission was in A$_1$V$_3$ treatment, followed by A$_1$V$_2$, A$_1$V$_1$, A$_2$V$_3$, A$_2$V$_1$, and A$_2$V$_2$ respectively (Figure 2). In the Ciherang, Inpari 32, and Mekongga varieties, the AWD treatment decreased CH$_4$ emissions by 23%, 46%, and 6%, respectively. Interaction between water and rice varieties significantly affected CH$_4$ emissions. Water management influenced rice production and CH$_4$ and N$_2$O emissions from rice systems. AWD-15 cm treatment could reduce CH$_4$ emissions by 37.4-45.7% compared to conventional practices in South China (Liang *et al.* 2016). Also, AWD treatment was reported to reduce CH$_4$ emissions by 48 to 93% compared to those observed under continuous flooding systems (Xu *et al.* 2015; Linquist *et al.* 2015; Lahue *et al.* 2016).

All rice varieties have almost similar of growth perioAll rice varieties have almost similar growth period. Differences in CH$_4$ emissions might be caused by different rooting systems. The dry weight of Mekongga rice roots was highest among other varieties (Table 1) so that both in flooded conditions and AWD emitted the highest CH$_4$. The differences

of CH$_4$ emissions with different cultivars because of differences in the number of root exudates and degrading roots which influence carbon substrate availability (Wang *et al.* 1997); tiller numbers, leaf area, and quantity (Gogoi *et al.* 2008); CH$_4$ production, oxidation, and transport capacity (Ma *et al.* 2010); grain starch content (Su *et al.* 2015); duration in the field (Badawi and Ghanem 2001) and aerenchyma structure which affects methane transport from the soil to the atmosphere (Wassman *et al.* 1993). Physiologically, rice plants provide carbon substrate for methanogens, through root exudates, and emit CH$_4$ gas through aerenchyma (Wassman and Aulakh 2000; Zheng *et al.* 2014). CH$_4$ and N$_2$O emissions were positively correlated with root dry weight, leaf area, and number of tillers (Baruah *et al.* 2010). Rice plant affected CH$_4$ production by influencing soil Eh (Wang *et al.* 1997) because there were variations in root respiration and organic matter exudation among rice cultivars (Han *et al.* 2013). The CH$_4$ emitted by plant-mediated transport depends on the aerenchyma system among rice cultivars (Tokida *et al.* 2013).

Soil redox potential during plant growth in all treatments was strongly influenced by the anaerobic condition. In anaerobic conditions, Eh value tended to decrease, whereas, in aerobic conditions, Eh tended to increase (Figure 3). The results of the Eh measurements during the growing season on all water treatments and varieties showed similar patterns. After 15 days of flooding, Eh decreased to -120 mV and then stabilized to 72 DAT, except in A2V2 treatment (AWD with Inpari 32 varieties) increased at 65 and 72 DAT due to aerobic conditions in the soil. A week before harvest, the soil conditions were dried in all treatments, so Eh increased. Soil pH observed at all treatments that there was a gradual decrease of acidity during the growing season (Figure 4). This may be caused by
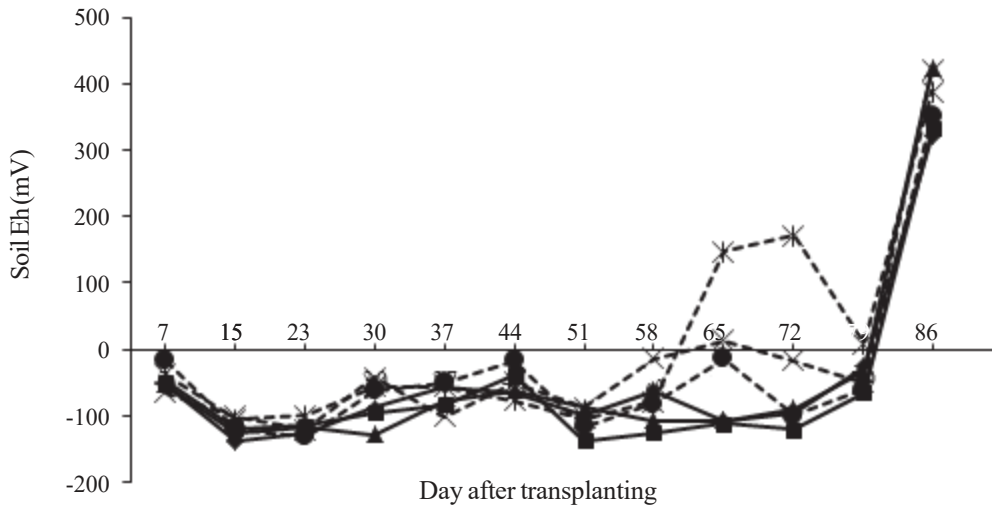
Figure 3. Eh under water management and rice varieties. A1 = Continuous flooding at 5 cm, A2 = Alternate Wetting and Drying / AWD, V1 = Ciherang, V2 = Inpari 32, V3 = Mekongga. ——◆—— : A1V1; ——■—— : A1V2; ——▲—— : A1V3; --×-- : A2V1; --✳-- : A2V2; --●--: A2V3.
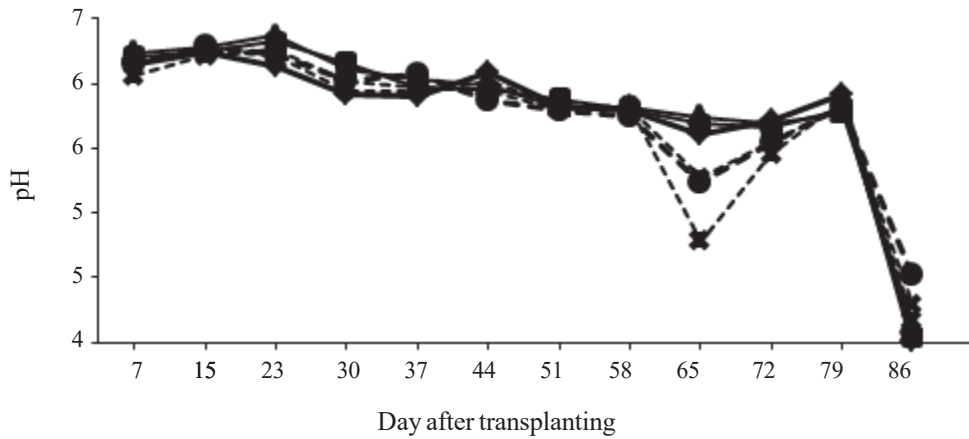

Figure 4. pH Observation under water management and rice varieties. A1 = Continuous flooding at 5 cm, A2 = Alternate Wetting and Drying / AWD, V1 = Ciherang, V2 = Inpari 32, V3 = Mekongga.——◆—— : A1V1; ——■—— : A1V2; ——▲—— : A1V3; --×-- : A2V1; --✳-- : A2V2; --●--: A2V3.
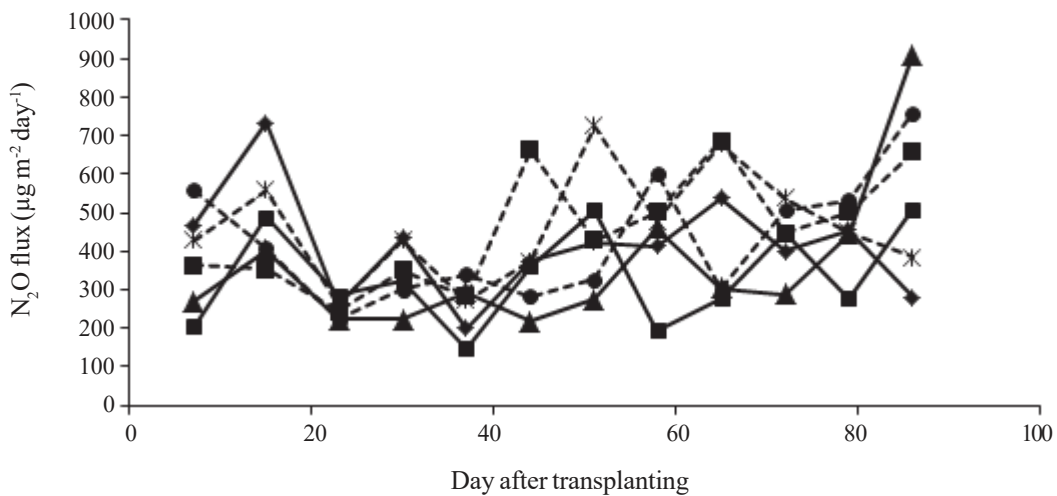

Figure 5. N$_2$O flux pattern under water management and rice varieties. A1 = Continuous flooding at 5 cm, A2 = Alternate Wetting and Drying / AWD, V1 = Ciherang, V2 = Inpari 32, V3 = Mekongga.——◆—— : A1V1; ——■—— : A1V2; ——▲—— : A1V3; --×-- : A2V1; --✳-- : A2V2; --●--: A2V3.
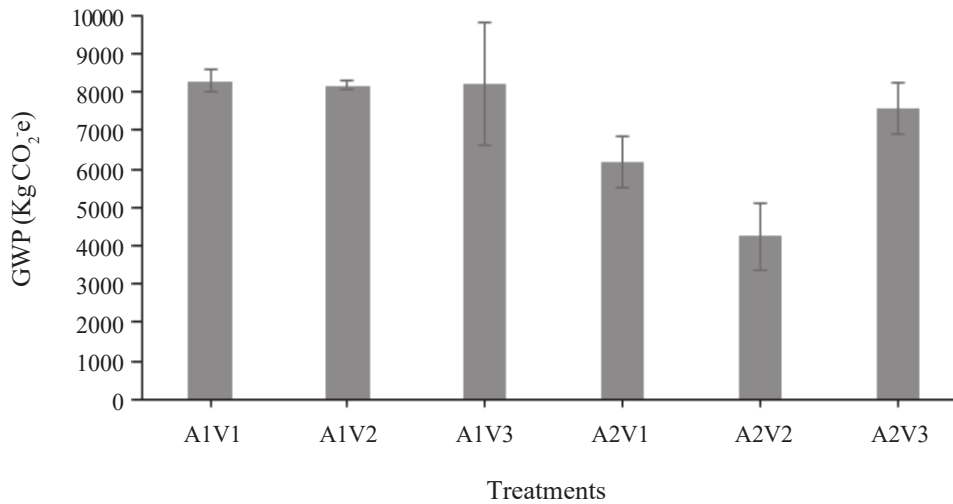
Figure 6. GWP under water management and rice varieties. A1 = Continuous flooding at 5 cm, A2 = Alternate Wetting and Drying / AWD, V1 = Ciherang, V2 = Inpari 32, V3 = Mekongga. —●— : A1V1; —■— : A1V2; —▲— : A1V3; --✖-- : A2V1; --✱-- : A2V2; --●--: A2V3.

organic acids produced by rice roots. These organic acids are the substrate of methanogen to produce CH_4.

Inorganic fertilization affects the N_2O flux pattern. Mishra *et al.* (2012) stated that the application of fertilization is closely related to N_2O emissions. Inorganic fertilization performed on the active tiller phase (7 DAT), the maximum tiller phase (21 HST) and the primordial phase (42 DAT) led to an increase in N_2O flux (Figure 5). The cumulative flux of N_2O is shown in Figure 6, the highest cumulative flux was present in the treatment of A_1V_1. The lowest N_2O flux cumulative was found in A_1V_2 treatment, followed by A_1V_3 and A_1V_1. In the flooded condition, the nitrification and denitrification process was slower so that the formation of N_2O was low. The highest N_2O emissions in the A_2V_2 treatment, due to the dry wet period of the AWD treatment, resulted in aerobic and aerobic conditions that were so suitable for nitrification and denitrification. Several studies reported similar N_2O emissions from soil under either AWD or continuous flooding (Johnson-Beebout *et al.* 2009; Kim *et al.* 2014), and trade-offs between CH_4 and N_2O emissions have also been reported (Zou *et al.* 2005; Kim *et al.* 2014). To concurrently reduce CH_4 and N_2O emissions, consequently, the GWP of irrigated rice, both water and nitrogen inputs need to be optimized (Johnson-Beebout *et al.* 2009).

Water treatment and rice varieties gave GWP vary widely, the highest GWP was seen A_1V_1 (Figure 6) accounted for 8.27 tons of CO_2-e ha⁻¹season⁻¹. The lowest GWP was A_2V_2 treatment (AWD with Inpari 32 variety) which is 4.24 ton ha⁻¹ season⁻¹. Since N_2O emissions from all treatments are relatively small, GHG emissions are greatly affected by CH_4 emissions. The GWP reduction of AWD treatment combined Ciherang, Inpari 32 and Mekongga varieties were 23%, 46%, and 6%, respectively. Inpari 32 rice variety emitted the lowest compared to Ciherang and Mekongga varieties in AWD treatment.

Effect of Water Managements and Rice Cultivars on Rice Yields

Inpari 32 and Mekongga rice varieties have higher performance and their number of tillers were also higher than Ciherang. The plant height of all rice varieties tested reached 95 cm. The number of tillers of Inpari 32 and Mekongga rice seedlings ranged from 9 to 10, while Ciherang only had 8-9 of tillers. Despite having the least tillers, Ciherang emitted CH_4 higher than Inpari 32 varieties on the AWD treatment. The growth period of all rice varieties used in this study was almost similar to 100 days.

The rice yields from water treatment and varieties are presented in Table 1. The highest grain yield was found in A_1V_2 treatment, which was 5.7 tons ha⁻¹. There was a decrease in yield on AWD treatment with Inpari 32 varieties, which only reached 5.4 ton ha⁻¹ or about 5%, but the decrease did not occur on the use of Ciherang and Mekongga varieties. The lowest grain yield was found in A_1V_3 treatment of 3.99 tons ha⁻¹. AWD treatment did not consistently decrease results in this study. The smallest of yield-scaled GWP, the ratio of GHGs emission by rice yield from the smallest were A_2V_2, A_1V_2, A_2V_1, A_2V_3, A_1V_1, A_1V_3, respectively of 0.92;

1.61; 1.62; 2.04; 2.27; and 2.32. The smaller the yield-scaled GWP means the smaller the emitted GHG to produce rice grain.

Inpari 32 has the highest plant biomass compared to Ciherang and Mekongga. This is also reflected in the highest dry weight of straw per hectare at A_1V_2 treatment (CF with Inpari 32 rice variety). However, Inpari 32 root biomass was the lowest among the tested varieties, although it was not significantly different. This may be related to the magnitude of the emitted CH_4, so that Inpari 32 has the lowest CH_4 emission in the AWD treatment. Root has a significant effect on CH_4 emission (Aulakh *et al.* 2000; Setyanto *et al.* 2004). The number of grains per panicle, the percentage of grain-filled, and the weight of 1000 grains of rice on Inpari 32 was the highest compared to Ciherang and Mekongga. Inpari 32 rice variety had a high biomass index, this means that photosynthesis was more efficient to produce grain. The results of the present study have shown that CH_4 emission from rice fields can be mitigated by proper management of irrigation water and high-yielding rice cultivars with low CH_4 emission. This approach is probably the most effective option for mitigating CH_4 emission.

CONCLUSSION

The treatment of AWD technique combined with Ciherang, Inpari 32, and Mekongga rice cultivars significantly decreased CH_4 emissions by 23%, 46%, and 6%, respectively. Grain yield was not a significant difference between all of the treatments. Therefore, the AWD technique in combination with Inpari 32 rice cultivar could be a potential option for maintaining the yield-scaled global warming potential of rice production at a lower level without reducing rice yield significantly compared to continuous flooding.

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