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METHANE EMISSION FROM PADDY FIELDS AS INFLUENCED BY DIFFERENT WATER REGIMES IN CENTRAL JAVA

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ABSTRACT

The concentration of methane (CH_4) in the atmosphere is increasing at 1% per annum and rice fields are one of the sources that contribute to about 10-15% of the atmospheric CH_4. One of the options to reduce greenhouse gas emission from rice fields is probably through water management. A field study was conducted to investigate the effects of water management practices on CH_4 emission from rice field plots on a silty sand Aeric Tropaquept soil at Research Station for Agricultural Environment Preservation, Jakenan, Central Java, Indonesia, during the dry season of March to June 2002. Four water regimes tested were: (1) 5 cm continuous flooding (CF), (2) 0-1 cm continuous flooding (ST), (3) intermittent irrigation (IR) where plots received continuously 5 cm of flooding with two times of draining at 15-20 and 25-30 days after transplanting (DAT), and (4) pulse irrigation (PI) where plots were watered until 5 cm level and left to dry by itself until the water table reached 30 cm beneath soil surface then watered again. The total CH_4 emissions of the four water treatments were 254, 185, 136 and 96 kg CH_4 ha^{-1} for CF, ST, IR and PI, respectively. Methane emission increased during the early growing season, which coincided with the low redox potential of -100 to -150 mV in all treatments. Dry matter weight of straw and filled grain among the water treatments did not show significant differences. Likewise, total grain yield at 14% moisture content was not significantly different among treatments. However, this result should be carefully interpreted because the rice plants in all water treatments were infested by stem borer, which reduced the total grain yield of IR64 between 11% and 16%. This study suggests that intermittent and pulse irrigation practices will be important not only for water use efficiency, but also for CH_4 emission reduction.

[***Keywords:*** Rice fields, methane, water management, continuous irrigation, intermittent irrigation, pulse irrigation]

INTRODUCTION

Atmospheric methane (CH_4) concentrations have increased more than doubled over the past 300 years (IPCC 1996). Among rice ecosystems, irrigated rice fields, which are expected to expand with population growth, has been contributing the highest in CH_4 emission compared to that of other land uses (Sass and Fisher 1994; Setyanto *et al.* 2000; Setyanto *et al.* 2004). The need for rice to feed the population in the next 25 years is increasing and this will rely on intensification and extensification of rice areas (IRRI 1995a).

Irrigated rice fields are the major source of atmospheric CH_4, which contribute to about 10-15% to the global CH_4 emission (Neue 1993; Sass and Fisher 1995). Recent studies showed that the increase of greenhouse gas concentrations in the atmosphere will affect the global environment. Without any attempt to reduce greenhouse gas, the temperature of the earth surface will increase 2-3^oC in the next 50-100 years (IPCC 1996). One of the possible options to reduce greenhouse gas emission from rice fields is by implementing water management practices that will favor high redox potential to suppress CH_4 production.

Water is one of the most important inputs in the Green Revolution (IRRI 1995b). Irrigated rice, in particular, is a heavy consumer of water; it takes some 5 m^3 of water to produce 1 kg of rice. On the other hand, water becomes scarcer in several parts of the world. Water demands are fast approaching the limits of resources (IRRI 1995b). The scarcity of water resources is also a problem in rice production in Indonesia. About 44% of the total harvested area is irrigated. Regulated irrigation alone accounts for 20% of the total harvested area (CBS 2002). Providing enough water to irrigate rice fields is one of the key management techniques to maintain high rice yield. Rice production in the coming years is expected to intensify as marked by increasing cropping intensity and use of higher chemical inputs and extensification. This may increase CH_4 emission.

When rice soil is flooded, O_2 is depleted, NO_3^-, Mn^{4+}, Fe^{3+} and SO_4^{2-} are reduced, and CH_4 is formed through methanogenic process. Soil redox potential (Eh) is a key factor that control CH_4 formation. Wang *et al*. (1992) reported that CH_4 flux significantly decreased with the increase of soil redox potential. Methanogenic bacteria is a facultative anaerobic bacteria which can only function at redox potential ranged between -150 and -200 mV, although it was also reported that several strains existed at a higher redox potential. Waterlogged rice soil often display redox potential up to -200 mV for several days after flooding which depends on the oxide mineral concentration in the soil. High concentration of this mineral (for example hematite) could buffer the redox potential drop until several weeks. However, it was also expected that draining of water from a continuously flooded soil would buffer the redox potential drop due to enhanced oxygen diffusion and at the end could deplete the CH_4 formation in the soil rhizosphere. This study was carried out to evaluate CH_4 fluxes in rice fields under different water regimes and identify suitable irrigation practices that reduce CH_4 emission.

MATERIALS AND METHODS

Agricultural Practices and Treatments

This study was conducted at Jakenan Experimental Farm of Research Station for Agricultural Environment Preservation, Central Java, Indonesia during the dry season (March-June) of 2002. The soil was classified as Aeric Tropaquept with silty sand texture. The soils had relatively high acidity, low CEC and low organic matter content (Table 1). To ensure that carbon is not a limiting factor for CH_4 emission, 5 t ha^{-1} of air dried cattle manure was incorporated to the soil.

Experimental plots of 5 m x 5 m were plowed and puddled two times at 10 and 2 days before rice transplanting to level the plots. The inner side border of the plots was lined with plastic sheets to 40 cm soil depth to prevent horizontal water transport between plots.

Seedlings of IR64 rice variety was transplanted at 25 days after sowing in seedbed with planting distance of 20 cm x 20 cm. Cattle manure was applied to the soil at 5 days before rice transplanting. IR64 was used in this experiment because it was commonly planted by farmers in Central Java and almost 60% rice farmers in Indonesia. Fertilizer applied were 120 kg N as urea, 60 kg P_2O_5 as SP-36, and 90 kg K_2O as KCl per ha. Urea and potassium fertilizers were given in three splits at 6, 21 and 36 days after transplanting (DAT) with the same amount in every split, while phosphorus fertilizer was incorporated once as basal application one day before rice transplanting.

Table 1. Soil characteristics at Jakenan Experimental Farm, Central Java, before planting the dry season rice in 2002 (n = 3, mean + SD).

Soil characteristics	Value
pH (H_2O)	5.20 + 0.100
pH (KCl)	4.33 + 0.058
Soil texture (%)	
Sand	38.33 + 1.528
Silt	48.00 + 3.606
Clay	13.67 + 2.082
Total organic C (%)	0.53 + 0.015
Total N (%)	0.05 + 0.006
Extractable P (mg kg^{-1})	35.33 + 1.528
C/N	10.6 + 2.50
CEC ($cmol_c$ kg^{-1})	4.75 + 0.282
Exch. cations ($cmol_c$ kg^{-1})	
Ca	2.69 + 0.151
Mg	0.32 + 0.031
K	0.09 + 0.006
Na	0.23 + 0.058
Base saturation (%)	89.66 + 0.577
Total SO_4 (%)	0.08 + 0.010
Fe_2O_3 (%)	0.95 + 0.123

Four water management practices were performed in this study. They were: (1) conventional irrigation (5 cm water height), (2) saturated irrigation (0-1 cm water height), (3) intermittent, and (4) pulse irrigation. Water treatment was conducted from day 0 to 70 DAT for all treatments. The two irrigation practices mentioned earlier are commonly implemented in regulated and semi-regulated irrigation areas in Central Java. The intermittent irrigation plots received irrigation 5 cm water level since the early growth stage (0 DAT). Draining of the water was conducted twice at 15-20 DAT and 30-35 DAT. Within the 20-30 DAT periods the plots were totally flooded. During the drying periods, CH_4 emissions and changes in redox potential and soil pH were recorded daily until the plots were flooded (Fig. 1). To maintain the water level in case the plots received additional water from heavy

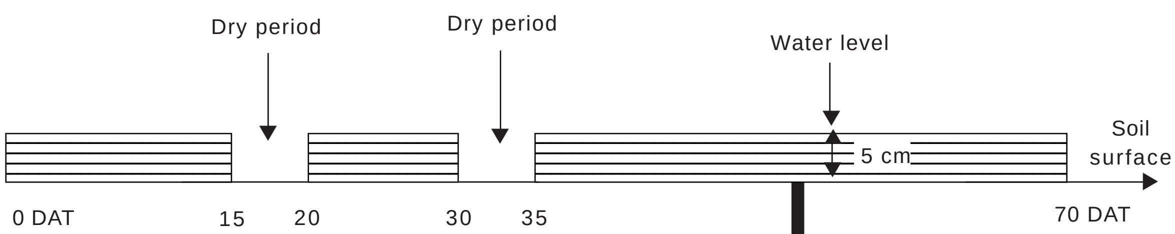

Fig. 1. Intermittent irrigation.

rains, water control gauges were inserted along the four sides of the plot bunds. Water level was carefully controlled and the height was also recorded daily.

The pulse irrigation plot was flooded at the early growth stage (0 DAT), but the water level was not maintained. Instead, it was left to dry up by itself until the water table reached 30 cm beneath soil surface. To determine the soil water table, a piezometer, 5 cm diameter cylindrical PVC tube with small holes around was inserted into the soil until 60 cm depth. At the top of the tube, leaving 20 cm above soil surface, a rubber septum was placed to seal the PVC tube to prevent additional water from rain. The depth of water level was recorded with a 1 m height small-size ruler daily. When the water table depth reached 30 cm beneath soil surface, the plot was again watered until 5 cm height (Fig. 2).

Data Collection

Methane emissions were recorded every 4 days since the early growth stage of rice. Continuous measurement of CH_4 flux was facilitated by the chamber method-automatic sampling technique (IAEA 1993). The system used was designed by the Fraunhofer Institute for Atmospheric Environmental Research (Germany). The measuring system was composed of gas-collecting plexiglass boxes with the dimension of 1 m x 1 m x 1 m. Methane fluxes were recorded every 4 days using the system, but during draining of plots on intermittent irrigation treatment, the gas sampling was conducted daily to see the CH_4 flux pattern prior to draining.

Changes in redox potential (Eh) and pH of the soil were recorded every 4 days from 4 to 83 DAT. Soil redox potential and pH were recorded using Eh/pH meter model Scott Handy Lab 1. A glass platinum electrode was established at the middle of rice hill until the depth of 15 cm. Each experimental plot received one platinum electrode. Plant components measured were dry matter weight (DMW) of aboveground biomass collected from 2 m x 2 m harvest area, while measurements of filled and unfilled grain were taken from three hills in every plot.

Statistical Analysis

The data were statistically analyzed using proc analysis of variance (ANOVA) with Statistical Analysis System (SAS) version 6.12 software. The Duncan's multiple range test (DMRT) was used for comparison between means at $P<0.05$. Percentage data derived from count data, such as filled and unfilled grain per hill were transformed by using $(X)^{0.5}$ before analysis using proc ANOVA.

RESULTS AND DISCUSSION

Seasonal CH_4 Flux and Redox Potential

The patterns of CH_4 emission from rice fields as affected by water regimes are shown in Fig. 3 and water level patterns are in Figs. 3 and 4. Methane emission started to increase within the first week after flooding. In 5 cm continuous flooding (Fig. 3a), CH_4 emission increased during the first three days of irrigation and then was quite stable afterwards until 10 days before harvest. This could probably be due to the stable redox potential (average -123 mV) of the soil implemented by this treatment. At late drainage, 71 DAT, there was a short-term spike in CH_4 emissions followed by a deep plunge that last until harvest. This was due to the release of CH_4 entrapped in soil macropores.

Saturated water condition with the average depth of water between 0.8 and 1 cm experienced similar emission pattern as 5 cm continuous flooding, but in different quantities. The respected mean emissions until 20 DAT

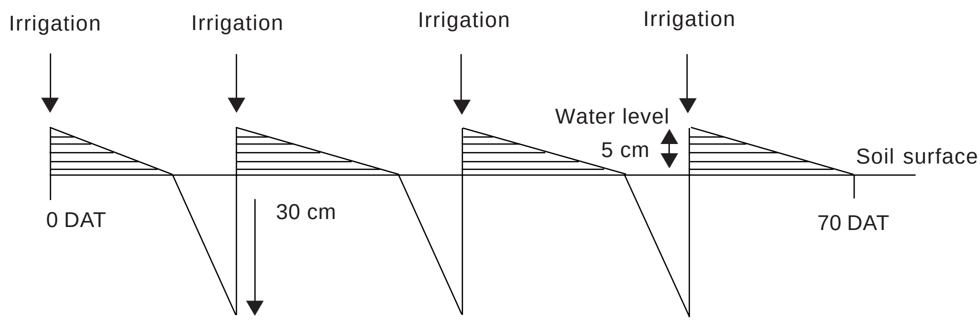

Fig. 2. Pulse irrigation.

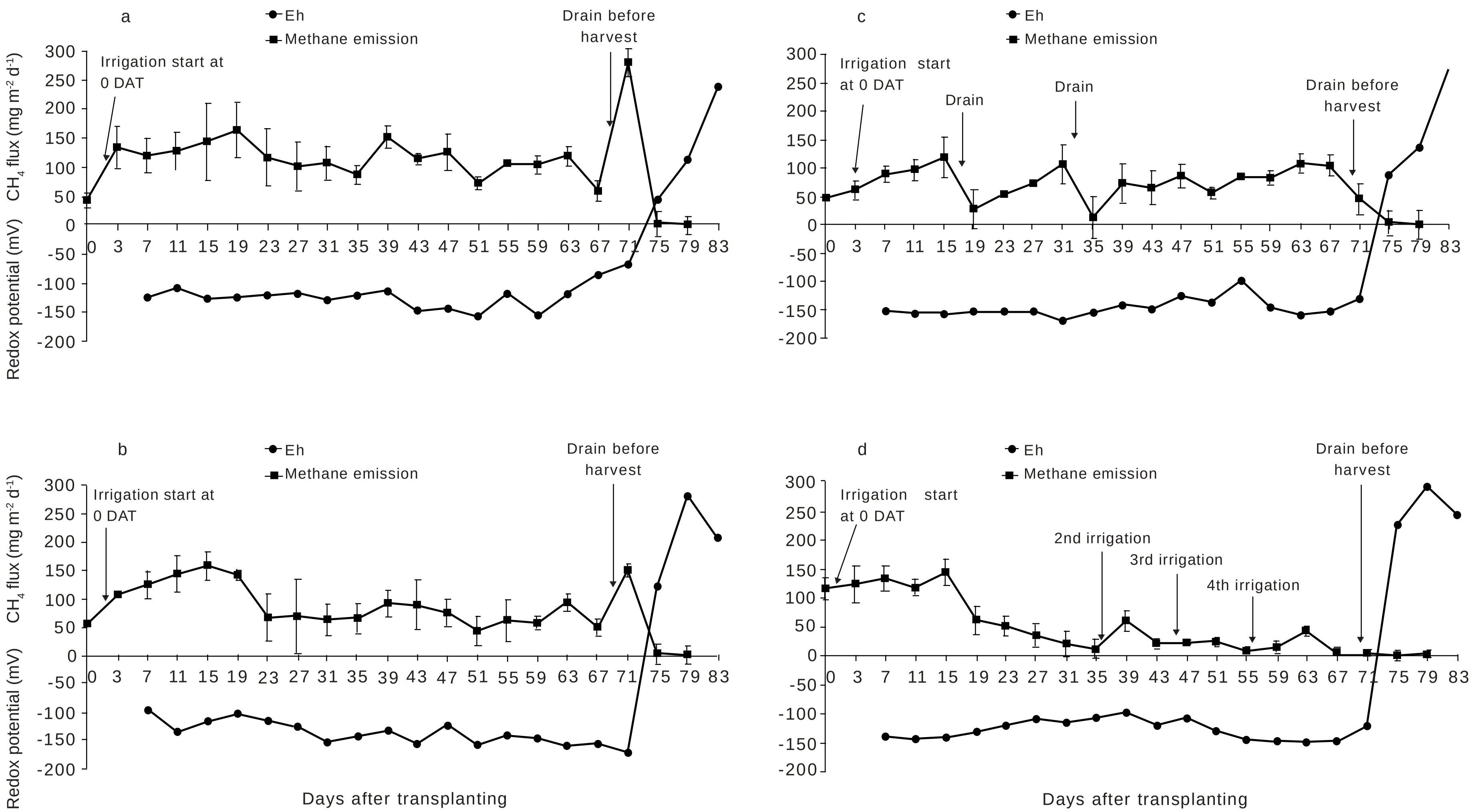

Fig. 3. Methane flux and redox potential patterns of rice fields established with IR64 treated under (a) 5 cm conventional flooding, (b) 0-1 cm continuous flooding, (c) intermittent irrigation and (d) pulse irrigation water regimes, Jakenan Experimental Farm, Central Java, dry season of 2002 (n = 3, means + SD, for CH_4 flux).

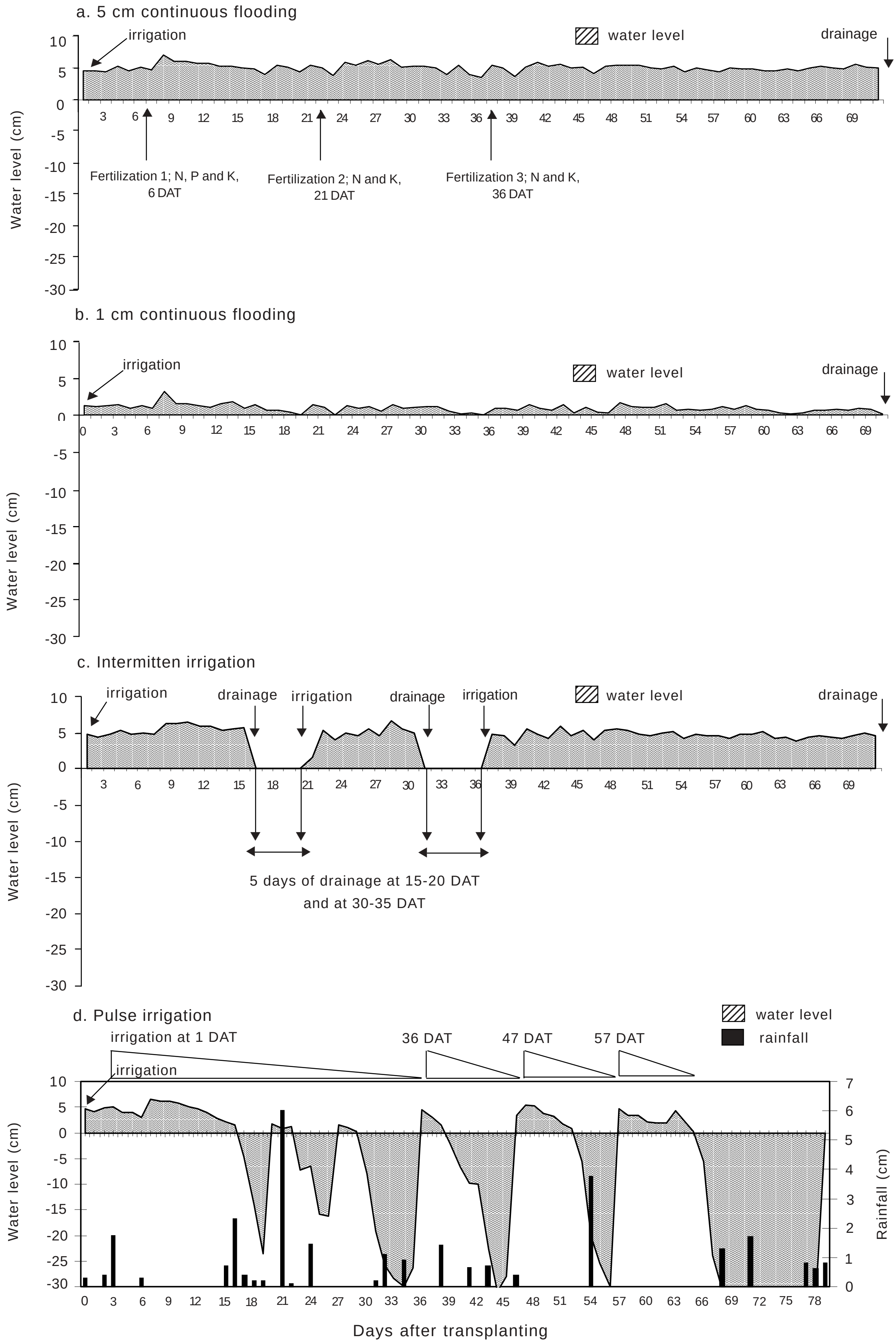

Fig. 4. The water level in the experimental plots treated under four different water regimes and the daily rainfall amount (Figure 4d, in bars), Jakenan Experimental Farm, Central Java, dry season of 2002.

were 161 and 168 mg CH_4 ha^{-1} for saturated and continuous flooding. The highest flux during planting time was recorded at 15 DAT, while a sharp increase after flooding prior to harvest was recorded at 71 DAT (Fig. 3b). This high flux (299 mg CH_4 m^{-2} d^{-1}) was due to the release of soil entrapped CH_4 prior to draining before harvest. Intermittent and pulse irrigation achieved highest CH_4 flux rate at 15 DAT (261 and 240 mg m^{-2} d^{-1}, respectively). Intermittent and pulse irrigation experienced different pattern of emission compared with the other two water treatments. The sharp increase of CH_4 emission at 15 DAT (Figs. 3c and 3d) was also due to the release of soil entrapped CH_4. This release was also reported by Neue *et al.* (1994) in their study on water regimes in the Philippines. They mentioned that before methanotropic bacteria consumed CH_4 entrapped in soil macropores, the bacteria would use CH_4 entrapped in micropores as their sole carbon source. Methane entrapped in macropores, which are not utilized by the microbes, will then be emitted to the atmosphere if draining of soil occurs.

Methane flux decreased sharply after drainage in intermittent irrigation due to aeration (Fig. 3c), while in pulse irrigation, the pattern of CH_4 flux decreased following the water table condition (Fig. 3d). Pulse irrigation is similar with the rice management in rainfed ecosystem in terms of water condition. Two-time drainage was performed for intermittent irrigation, at 15-20 DAT and 30-35 DAT, while in pulse irrigation it was four times at 1, 34, 44, and 55 DAT. These treatments did not significantly influence redox potential of the soil as compared to continuous flooding of 5 cm and 0-1 cm water level. The average redox potential of continuous flooding of 5 cm and 0-1 cm, intermittent, and pulse irrigation were -126, -123, -134, and -102 mV, respectively. These negative values may probably be due to high concentration of clay at 15 cm soil layer. At this depth, reduced condition may occur because of hardpan. Tuong *et al.* (2002) also reported the existence of hardpan on their study at Jakenan Experimental Farm. The glass electrodes with 1 mm platinum tip used for redox measurement were inserted until 15 cm soil depth, which probably was in reduced condition. Therefore, redox status of the soil was negative. Result from this study also showed that increase of CH_4 emission during the early growing season coincided with the low redox potential of -100 to -150 mV in all water treatments. This study may also suggest that the redox potential electrode should be inserted above the hardpan layer to achieve different readings between the water treatments. During the study, plots also received total rainfall of 284 mm and a total of 25 rainy days from rice planting until harvest (Fig. 4d), which may also influence redox potential of the soil.

In the 5 cm continuous flooding treatment that within the 10 days after flooding, there were more bubbling than in the other treatments. This may suggest the importance of measuring CH_4 released from soil ebullition. However, this was less observed in intermittent, 0-1 cm continuous flooding, and pulse irrigation treatments. Results found in this study agree well with what was observed by Holzapfel *et al.* (1986). In their study on rice fields at Vercelli, Italy, they observed that rising gas bubbles occurred at early growth stage and analysis showed that CH_4 concentration due to ebullition ranged between 30% and 85% of the total CH_4 emitted at this stage. Concentration of dissolved CH_4 in the water of rice fields ranged 2-126 ml CH_4 l^{-1} of water during early growth stage. The concentrations were high in the first month after flooding, when most of the CH_4 emission from the rice soil into the atmosphere was through gas bubbles. During maximum tillering until panicle initiation, most of the CH_4 was emitted through plant aerenchyma.

Soil pH

Soil pH is one of the factors affecting CH_4 formation. Methanogens are pH-sensitive populations. Most of them grow under relatively narrow pH range of 6-8 (Oremland and Capone 1988). The optimum pH for CH_4 formation is about 7 (Alexander 1977; Oremland and Capone 1988). There are few strains of alkaliphilic (pH optima 8.1-9.7) bacteria that produce CH_4 (Oremland *et al.* 1982).

Results from this study showed that the soil pH at the early growing period was similar in all water treatments, which ranged between 6.2 and 6.8, and slowly decreased during 71-83 DAT with the pH range between 4.2 and 4.3 (Fig. 5). The mean pH of all water treatments were similar and ranged between 5.6 and 5.8. This condition occurs probably due to severe rainy days, which influence the moisture condition of the soil (Fig. 4d). CH_4 formation in Jakenan soil existed in a wider pH range of 4-7. Crawford (1984) reported that CH_4 production occurred in acidic environments such as peat bogs at a pH range of 4-5.

Total CH_4 Emissions

Pulse irrigation gave 58.9% reduction in seasonal CH_4 emission as compared with continuous flooding,

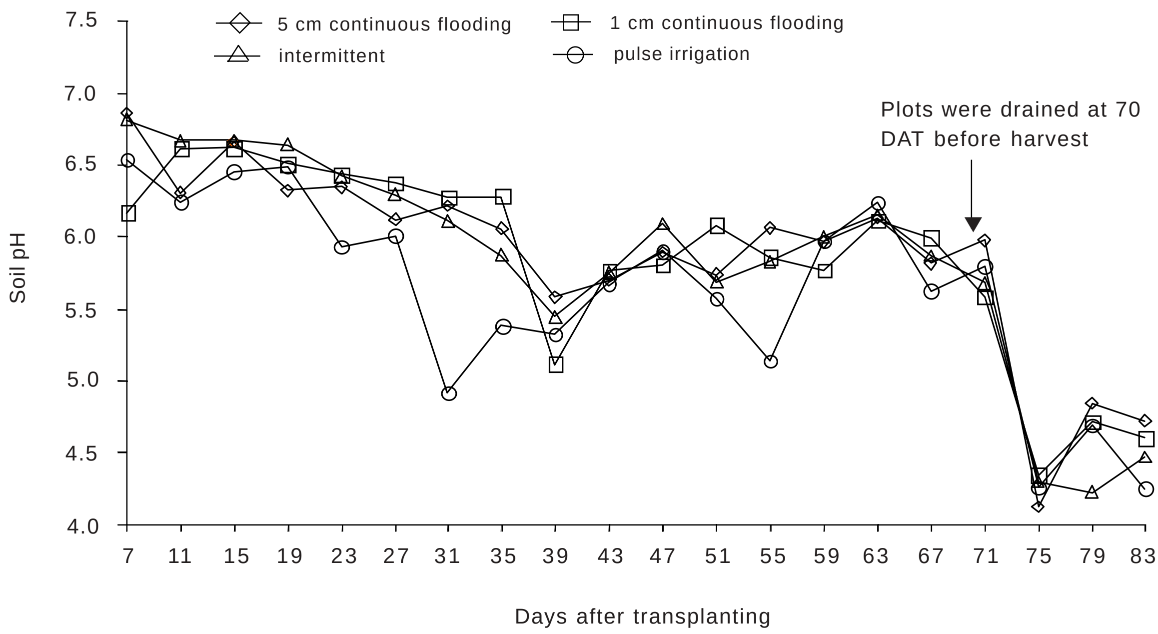

Fig. 5. Soil pH changes of rice fields under four different water regimes, Jakenan Experimental Farm, Central Java, dry season of 2002.

while intermittent and saturated irrigation resulted 27.2% and 48.6%, respectively (Table 2). However, there was no significant difference (P<0.05) between intermittent and pulse irrigation in total CH_4 emission. These values indicate that pulse irrigation, intermittent, and 0-1 cm continuous flooding could suppress CH_4 emission. Sass *et al*. (1992) from their study comparing four water management methods in Texas rice fields, USA, demonstrated that normal flooding with multiple drainage aeration (intermittent irrigation water management) could reduce methane emission up to 88% compared with normal flooded water condition. They also observed that the lowest CH_4 flux (0.6 mg m^{-2} h^{-1}) was obtained from multiple aeration treatment and the highest (6.3 mg m^{-2} h^{-1}) was

Table 2. Total CH_4 emission and yield of IR64 rice variety under four water regimes, Jakenan Experimental Farm, Central Java, dry season of 2002 (n = 3, means + SD).

Water regimes	CH_4 emission (kg ha^{-1})	Yield (kg ha^{-1})
5 cm continuous flooding	254 + 29.0a	3482 + 167a
0-1 cm continuous flooding	185 + 12.9b	2990 + 188a
Intermittent irrigation	136 + 20.0c	3529 + 207a
Pulse irrigation	96 + 5.8c	2986 + 378a

Numbers in the same column followed with different letter were significantly different at P<0.05 by DMRT.

from continuous flooding. Husin (1994) on his study in wetland rice of Sukamandi, West Java, showed a higher reduction of 67% and 54% by using saturated and intermittent irrigation, respectively, compared with continuous flooding.

Plant Growth and Yield

There was no significant difference in grain yield as affected by different water management. However, the results on grain yield should be cautiously interpreted because of severe infestation of stem borer in all water treatments. Husin (1994), based on his research at Sukamandi, reported that there was no significant difference in grain yield between Cisadane and IR64 rice varieties treated under different water regimes. His result indicates that reducing and saving of irrigation water does not affect yield.

Application of 0-1 cm continuous flooding, intermittent, and pulse irrigation for rice cultivation significantly reduced the irrigation water consumption, however it could be susceptible to weed invasion and rat attack (Husin 1994). In this study, there was no severe damage due to weed and rat, but the infestation by stem borer was severe, which lead to the low grain yield. The infestation caused tiller destruction during panicle initiation stage, which reduced the number of effective tillers between 11% and 16%.

No significant differences among the water treatments on DMW of aboveground biomass, but sig-

Table 3. Straw dry matter weight, filled and unfilled grains of IR64 rice variety under four different water regimes, Jakenan Experimental Farm, Central Java, dry season of 2002 (n = 3, means + SD).

Water regimes	Straw ($kg\ ha^{-1}$)	Unfilled grain (%)	Filled grain (%)
5 cm continuous flooding	4775 + 200a	39.4 + 3.07a	60.6 + 7.01a
0-1 cm continuous flooding	4900 + 725a	35.7 + 3.91a	64.3 + 5.69a
Intermittent irrigation	4800 + 450a	25.9 + 1.68a	74.1 + 9.16a
Pulse irrigation	4950 + 425a	30.0 + 6.03b	70.0 + 11.55a

Numbers in the same column followed with different letter were significantly different at $P<0.05$ by DMRT.

nificant difference ($P<0.05$) in unfilled grain was recorded (Table 3). The lowest unfilled grain was in intermittent irrigation (25.9%) and the highest was in 5 cm continuous flooding (39.4%), while other water treatment was within the range of the mentioned percentage. No significant differences occurred on filled grains. According to Yoshida (1981), providing enough water for rice growth would promote high filled grain as long as nutrient supply was sufficient and climate was favourable for rice growth. In contrast, this study showed that water regimes did not affect the percentage of filled grains, which means that application of saturated, pulse and intermittent irrigation was not only consuming less water, but also had similar filled grains as 5 cm continuous flooding.

CONCLUSION

Emission of CH_4 could be reduced by intermittent or pulse irrigation, whereby saving water which is a scarce resource for farmers. The existence of hardpan and severe rainy days may lead to a low redox potential of soil in all water treatments. Changes in soil pH were similar in all treatments, which indicated that the water treatments did not affect soil pH.

Plant growth parameters (DMW of straw and filled grain) among the water treatments was not significantly different. Total grain yield was not affected by water treatments; however, this conclusion should be carefully interpreted because the rice plants in all treatments were infested by stem borer during panicle initiation stage.

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