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THE EFFECT OF RICE CULTIVARS ON METHANE EMISSION FROM IRRIGATED RICE FIELD

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ABSTRACT

Rice plants have been reported to affect methane (CH_4) emission from rice fields. The objectives of this study were to determine the effect of rice cultivars on CH_4 emission from flooded rice and to develop crop management strategies with low emitting rice cultivars while sustaining high yield. The four rice cultivars studied were Memberamo, Cisadane, IR64, and Way Apoburu. The CH_4 emissions were determined in the wet season of 2001/2002 (November-February) using an automated closed chamber technique in an irrigated field condition. Farmyard manure at the rate of 5 t ha^{-1} was given to the plots to ensure carbon was not limited. Root weight, root length, biomass, and number of tillers were determined at 17, 36, and 57 days after transplanting (DAT). The results showed that the mean CH_4 emission was highest in the plot planted with Cisadane (94.8 kg CH_4 ha^{-1}), and the lowest with IR64 (37.7 kg CH_4 ha^{-1}). The plots treated with Memberamo and Way Apoburu resulted an intermediate CH_4 emission at the average of 61.1 and 58.9 kg CH_4 ha^{-1}, respectively. There was no significant difference in yield between the cultivars tested. The yield of Memberamo, Cisadane, IR64, and Way Apoburu were 5.882, 5.764, 5.873 and 6.065 t ha^{-1}, respectively. Statistical analysis showed that there were no significant differences in the root weight and root length among cultivars. However, Cisadane gave the highest dry matter weight (222 g $hill^{-1}$) at 57 DAT compared to the other cultivars (175-190 g $hill^{-1}$). Plant tillers did not show significant differences between the cultivars. Regression analysis showed that CH_4 flux was significantly related with root weight, root length, aboveground biomass, and number of plant tillers. This finding shows that the use of selected cultivars, such as IR64, can potentially lower CH_4 emission without scarifying yield.

[*Keywords*: *Oryza sativa*, methane, rice fields]

INTRODUCTION

Rice field is one of the most important sources of atmospheric methane (CH_4) with a global emission ranging from 20 to 150 Tg CH_4 $year^{-1}$ (IPCC 1992; Neue and Sass 1998). The development of methods and strategies to reduce the emission of CH_4 from rice field is a central issue of ongoing efforts to protect the earth's atmosphere and to avert possible climatic changes.

Rice plant acts in three key functions regulating CH_4 budget: (1) as a source of methanogenic substrate, (2) as a conduit for CH_4 through a well developed intercellular 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 most promising strategy to reduce CH_4 emission from rice fields is to select and cultivate high-yielding rice cultivars which can reduce methane transport capacity (MTC) (Butterbach-Bahl *et al.* 1997). Inadequate information on the effect of rice cultivars on CH_4 emission is one of the limitations in estimating CH_4 emission from rice field. Research regarding the effect of rice cultivars on CH_4 emission becomes important nowadays because of significantly different results (Neue *et al.* 1994; Wang *et al.* 1997; Wang *et al.* 1999). Different ability of rice cultivars in emitting CH_4 gas were mostly related to the growth performance, i.e. number of plant tillers, plant above and belowground biomass (Aulakh *et al.* 2000). Setyanto *et al.* (2000) reported that differences in plant growth duration among rice cultivars affected the total seasonal CH_4 emission from flooded soil. Combination of various factors such as the supply of organic matter, size of the root space, and oxidation rate in the rhizosphere have also been identified to affect the CH_4 flux from various rice cultivars (Watanabe and Kimura 1996).

Most of irrigated lowlands in Indonesia are intensively cultivated for rice production. Sustained fertility of soils requires the maintenance of soil organic matter. For most of farmers, organic matter such as rice straw or animal manure is the main or may be the only source of plant nutrients. Addition of organic matter in the form of rice straw or animal manure is one of the best options because of its easiness to apply and it is also an important soil energy source and conditioner that will lead to the increase in rice yield. However, some reports showed that incorporation of rice straw enhanced CH_4 emission (Minami and Neue 1994; Lu *et al*. 2000; Setyanto *et al*. 2000; Wassmann *et al*. 2000). In Java, animal manure in the form of dry cow dung is commonly applied before starting the wet season rice crop. Sass and Fisher (1995) reported that the choice of rice cultivar has a substantial effect on the amount of CH_4 emitted to the atmosphere. This paper reports the effect of different rice cultivars on CH_4 emission from rice fields receiving high (5 t ha^{-1}) animal manure.

MATERIALS AND METHODS

Field experiment was conducted during the wet season of 2001/2002 (November-February) at Jakenan, Central Java, Indonesia. The soil properties are relatively acid, low CEC and low organic matter content, and is classified as Aeric Tropaquept with a silty loam texture (Table 1).

Table 1. Soil physical and chemical characteristics of Jakenan Experimental Farm, Central Java, before rice planting; soil samples were taken on 3 November 2001 (n = 3, mean + SD).

Soil analysis	Value
pH	
H_2O	5.1 + 0.23
KCl	4.6 + 0.22
Texture (%)	
Sand	42.3 + 3.01
Silt	48.2 + 3.42
Clay	9.5 + 3.26
Total organik C (%)	0.52 + 0.150
Total N (%)	0.03 + 0.007
C/N	15.9 + 4.44
Extract NH_4 acetate 1 N pH 7 (me 100 g^{-1})	
Ca	3.55 + 1.803
Mg	0.21 + 0.208
K	0.08 + 0.033
Na	0.26 + 0.046
Total	4.19 + 2.164
CEC (me 100 g^{-1})	4.59 + 2.071
Base saturation (%)	85.3 + 10.39
Total S (ppm)	129.5 + 79.62
Dithionite, Fe_2O_3 (%)	0.75 + 0.348
Oxalate, Fe_2O_3 (%)	0.25 + 0.036

The treatments were four rice cultivars, i.e. Memberamo, Cisadane, IR64, and Way Apoburu. Treatments were in triplicates using randomized complete block design. All of the experimental plots were continuously flooded with 5-cm standing water. To minimize water transmission between the plots, the bunds or the field border were lined with plastic until 30 cm beneath the soil surface. Fertilizers were given based on the recommended rates in the research area, consisting of 120 kg N in the form of urea, 90 kg K in the form of muriate of potash, and 60 kg of P in the form of single super phosphate, and animal manure of 5 t ha^{-1}. Changes in soil pH and Eh were continuously recorded every 4 days throughout the growing period.

Methane Flux Measurement

Methane fluxes were measured with an automated closed chamber method. This measurement system was a modified version of the system originally described by Schutz and Seiler (1989). The measurements were started 5 days before rice transplanting and finished 1 day after harvest. Within the whole growing season, 12 bihourly CH_4 fluxes (at time 01:00, 03:00, 05:00… 23:00) were computed from each experimental plot daily. The data were calculated using a computer program written in BASIC. The program calculates the linear regression coefficient (gradient) of concentration against time, and the standard error of gradient. If the standard error was greater than 10%, it would indicate significantly non-linearity, a warning would then flag up and the flux will be rejected. The software runs on the equation derived from Lantin *et al.* (1995).

Each experimental plot was installed with one chamber made of plexi-glass with the size of 1 m x 1m x 1 m. Each chamber was equipped with an electrical fan to promote the same concentration of CH_4 gas within the different height of the chamber.

Plant Growth Parameters and Root Sampling

Plant growth parameters observed were plant height, number of tillers, and root distribution (total root length and dry matter weight). Root samples were taken with a cylindrical chamber using the monolith method (Smith *et al.* 1994) at two different layers, i.e. 0-10 cm and 10-20 cm of the topsoil. The data were recorded three times, i.e. at the maximum tillering, primordial and early flowering stage, in triplicates during the growing season. Yield components recorded were dry matter weight of aboveground biomass, grain yield, and filled and unfilled spikelets. Plant aboveground biomass and yield were taken from 2 x 2 harvested areas, while filled and unfilled spikelets were from two hills within the plot. The hills were counted for its number of effective tillers and selected randomly from the experimental plots.

RESULTS AND DISCUSSION

Daily CH_4 Flux and Redox Potential Status of the Experimental Plots

The flux patterns for all of the cultivars were similar. They were low during the early planting stage (1-15 days after transplanting = DAT) and started to increase after 15 DAT until it reached the early generative or primordial stage (35-55 DAT), and then slightly decreased (Fig. 1). Low CH_4 flux during the early growth stage of the rice plant was due to low levels of methanogenesis and poor conduction of CH_4 from the soil to the atmosphere. The CH_4 flux pattern recorded from this study was similar with that reported by Nouchi (1994) and Sass and Fisher (1996). The higher rates of CH_4 production during the reproductive and ripening stage were due to the degradation of the available organic carbon in the form of root exudates (Nouchi 1994). According to Sass and Fisher (1996), the increase of CH_4 flux at this stage was due to the presence of metabolizable organic carbon, i.e. root exudates released as an impact of photosynthetic activity and anaerobic degradation of indigenous organic carbon of soil. The variation of downward transport of oxygen in different rice varieties could also cause changes in CH_4 emission (Yoshida 1981). Rice plant provides substrate for methanogenic bacteria through root exudation or decaying matter during senescence (Raimbault *et al.* 1977). Considerable variation in the root exudate pattern of different rice cultivars exists (Nouchi 1994).

To illustrate the seasonal variation and to see the differences in the influence of cultivars on CH_4 emission, cumulative CH_4 fluxes were calculated (Fig. 2). This figure clearly shows the different ability of rice cultivars in emitting CH_4. The highest amount of CH_4 was emitted by Cisadane and the lowest was from IR64. High flux of Cisadane was probably due to the longer growth duration as compared with the other cultivars, and also, the cultivar has more plant biomass, which appeared to be one of the factors affecting CH_4 emission from rice field (Aulakh *et al.* 2000).

Preharvest drainage normally triggered CH_4 flux due to the release of soil entrapped CH_4 (Van der Gon *et al.* 1996; Setyanto *et al.* 2000). However in this study, the flush was not so clear because of high rainfall. Van der Gon *et al.* (1996) also reported similar results,

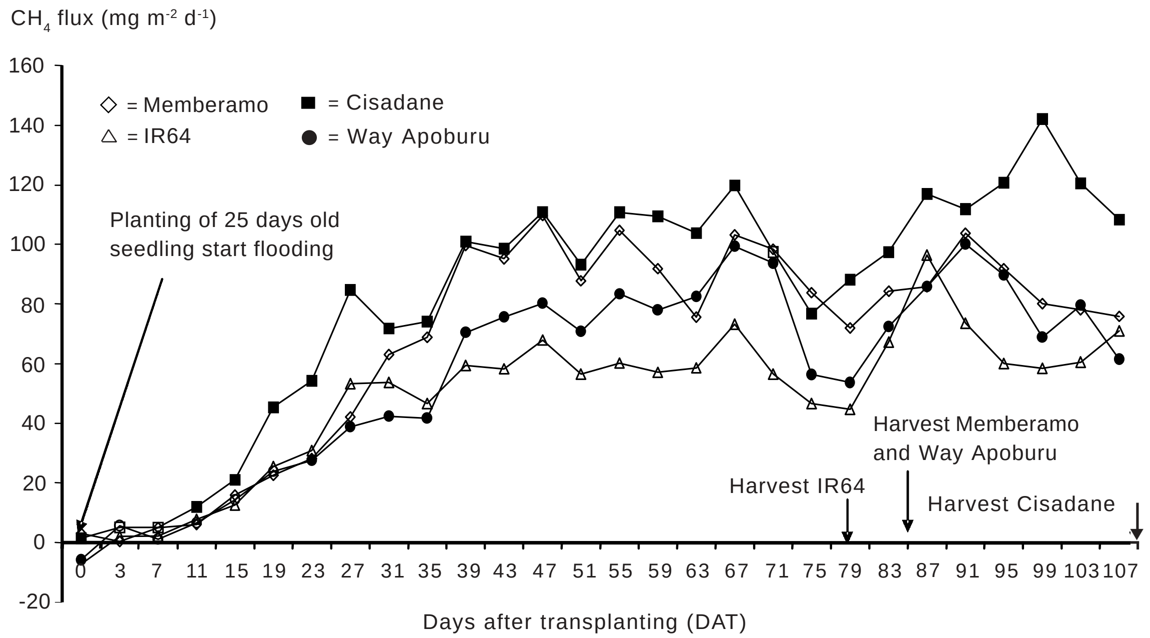

Fig. 1. Methane flux pattern of four rice cultivars, Jakenan Experimental Farm, Central Java, WS 2001/2002; the plots received irrigation water at 1 day before transplanting.

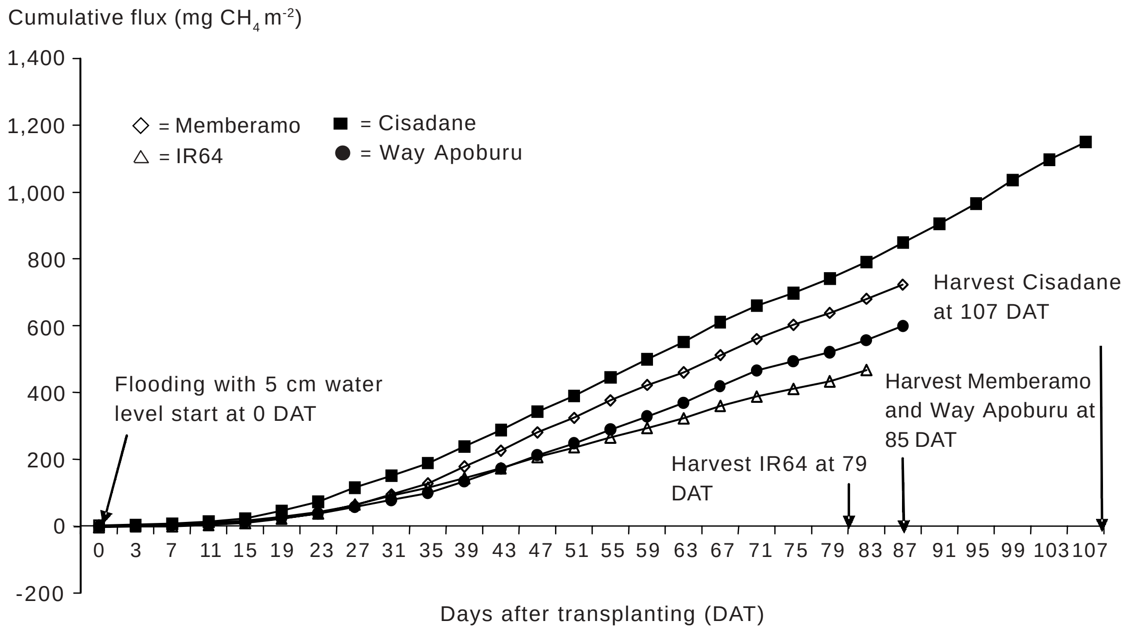

Fig. 2. Cumulative CH_4 emission showing the difference of four rice cultivars, Jakenan Experimental Farm, Central Java, WS 2001/2002.

where release of soil entrapped CH_4 upon preharvest drainage was not observed due to heavy rain. This indicates that considerable CH_4 flux continued well into the fallow period at a similar level as before harvest.

The CH_4 flux pattern found in this experiment gradually increased after transplanting until early generative stage (primordial) and then slightly declined and increased again just after harvest. Three peaks of CH_4 flux were observed at 45, 65 and at around 91-99 DAT (Fig. 1). These three peaks were probably related to the plant growth. The early CH_4 flux observed during early vegetative stage could be due to decomposition of remaining organic matter in the soil from previous season. The second, observed during the reproductive stage, was probably due to the actions of methanogenic soil bacteria on organic compounds released by rice plant as root exudates, and the third peak may be related to deterioration of root senescence and release of soil entrapped CH_4. Similar finding was reported by Schutz and Sailer (1989).

Low redox potentials in the experimental plots were observed during the growing season (Fig. 3). Soil redox potential is one of the main factors controlling CH_4 formation. The critical soil redox potential for initiation of CH_4 formation is approximately from -150 to -160 mV (Wang *et al.* 1992). In this study, the soil redox potential values were in the ranged between +192 and -213 mV. During the beginning of rice transplanting, CH_4 flux was within the range of 0.7-1.8 mg CH_4 m^{-2} d^{-1}. Methane flux started to increase at 11 DAT, with the range of 6.3-10.5 mg CH_4 m^{-2} d^{-1}. At this time, the redox potential ranged between 53 and -41 mV. Positive redox potential values occurred at 7 DAT and the lowest at 39 DAT for Cisadane cultivar. At the same time, the redox potential for other cultivars ranged between -105 and -199 mV. Methane flux reached the highest level for all cultivars and ranged within 29.9-63 mg CH_4 m^{-2} d^{-1} at 59 DAT. Interesting finding in this study was that CH_4 flux existed although redox potential was in positive range at 1-10 DAT. This was also reported by Yagi and Minami (1990), who observed CH_4 flux at high Eh level in some rice fields. These phenomena could be explained as follows: (1) CH_4 production occurs at microsites where the platinum (Pt) electrodes did not properly penetrate, (2) the 3-5 mm long tips of the Pt electrodes are larger than the microsites where CH_4 production occurs and therefore results in “touch” spots with various redox potentials; the highest value is recorded, and (3) CH_4 production has already started at Eh values higher than -150 mV. The last explanation contradicts with the sequential oxidation-reduction theory in flooded soils (Ponnamperuma 1972; Patrick, Jr. 1982). However, Fetzer and Conrad (1993) showed that the inhibition of CH_4 production at a redox potential higher than -150 mV is caused by introduction of free O_2 in the system. In an O_2 free medium, CH_4 production started at +50 mV, and

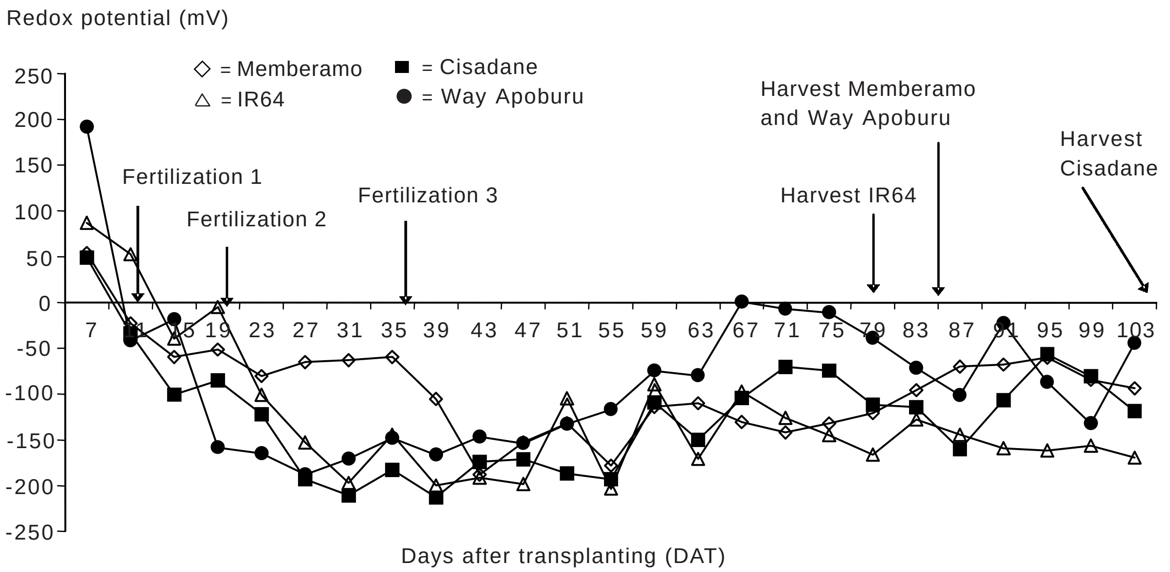

Fig. 3. Redox potential (Eh) changes of the soil under four different rice cultivars established through transplanted rice, Jakenan Experimental Farm, Central Java, WS 2001/2002.

continually increased until Eh +420 mV (Fetzer and Conrad 1993). This is not necessarily in contradiction with thermodynamics principles because microorganisms may well be able to lower their internal redox potential. Wang *et al.* (1993) used O_2 (or air) to control Eh in studying methanogenesis. Thus the inhibitory or toxic effects on methanogens may interfere with the study of Eh effects on methanogenesis. A redox potential of +420 mV would, under field conditions, always include the presence of free O_2, but at Eh values of +50 mV no free O_2 is present and according to the observations of Fetzer and Conrad (1993), CH_4 production could start. The effect of Eh and introduction of O_2 on methanogenesis in flooded soils planted to rice warrants further research because this concept is important for future process modeling. For example, in the rhizosphere where O_2 diffuses from the rice roots, a lower Eh may be required to start CH_4 production than in the bulk soil (Van der Gon *et al.* 1996).

Total CH_4 Emission and Yields

Methane emission from Cisadane was the highest (94.8 kg CH_4 ha^{-1}). Way Apoburu and Memberamo emitted CH_4 as much as 58.9 and 61.07 kg CH_4 ha^{-1}, respectively, while IR64 emitted the lowest (36.02 kg CH_4 ha^{-1}). In terms of yield, the cultivars did not show significant difference. Grain yield of Memberamo, Cisadane, IR64 and Way Apoburu were 5.882, 5.764, 5.873 and 6.065 t ha^{-1}, respectively (Table 2). This study showed that different cultivars emitted different amount of CH_4 without significant difference in yield. One would expect

Table 2. Total methane (CH_4) emission and grain yield (at 14% moisture content) of four rice cultivars, Jakenan Experimental Farm, Central Java, WS 2001/2002 (n = 3, means + SD).

Rice cultivar	Total number of days per season	Total CH_4 emission (kg ha^{-1})	Yield (kg ha^{-1})
Memberamo	83	61.1 + 7.88b	5882 + 319a
Cisadane	107	94.8 + 13.59a	5764 + 117a
IR64	79	37.7 + 6.99c	5873 + 181a
Way Apoburu	83	58.9 + 14.20b	6065 + 219a

Numbers in the same column followed by a common letter are not significantly different at P < 0.05 by DMRT.

that there are possibilities on using low CH_4 emitting rice cultivars as an approach to mitigate CH_4 from rice field.

Cisadane emitted more CH_4 compared with other cultivars although it was not significantly different with Memberamo. This could be due to the longer growth period as compared with other cultivars. Similar observations have also been recorded for a long-duration variety, Ratna and Shyamla, which emitted more CH_4 than Ananda and Kranti, a short-duration variety (Adhya *et al.* 1994, Singh *et al.* 1998). Table 3 shows that Cisadane and Memberamo produced the highest dry matter weight of above-ground biomass, followed by Way Apoburu and IR-64. However, in terms of filled grain, IR64, Cisadane, and Way Apoburu were not significantly different, on the other hand, Memberamo produced the lowest filled grain and significantly different with the other three cultivars. Difference in the filled grain yield among the cultivars was probably related to different photosynthesis efficiency. According to Braatz and Hogan (1991), inefficient photosynthesis may enhance the production of root exudates which influenced the production of grain. Measurement of root exudates was not carried out in this study which limited the explanation above.

It was hypothesized that the differences in morphological and physiological traits among rice cultivars resulted variation on CH_4 emission (Wassmann and Aulakh 2000). During early growth stage, different rice cultivars would have been differ in nutrient requirement, which in turn affect the inherent substrates and fertilizers as exogenous substrates for CH_4 production of planted soil (Holzapfel-Pschorn and Seiler 1986). At late tillering stage, root exudates dominate CH_4 production of planted soil (Watanabe *et al.* 1997). Rice cultivars, however, have significant effects on CH_4 production of planted soil due to large variation in composition and content of root exudates (Lin and You 1989; Neue *et al.* 1996; Wang *et al.* 1997). The contribution of rice plant would also be dependent upon plant density. According to Jia *et al.* (2002), very high density of rice plants in paddy soils made CH_4 production lower than that of unplanted soil at tillering and panicle initiation stage. This would probably be due to the stimulating effect of plant roots on O_2 released during decomposition of native soil organic carbon exceeding CH_4 oxidation in rice rhizosphere (Jia *et al.* 2002). Therefore, over the duration of rice growth period, agricultural practices, nutrient supply and climate would modify the morphological and physiological traits of rice cultivars, hence affect CH_4 emission from rice field to the atmosphere.

The Effect of Root and Aboveground Biomass on CH_4 Flux

Table 4 shows that there was no significant difference among cultivars in terms of root weight at 0-10 cm soil layer in three different growth stages. At 10-20 cm soil layer, there were differences in root dry weight and total root length among cultivars. Cisadane showed the highest root weight at 17 DAT (0.57 + 0.08 g hill^{-1}), but the total root length did not show significant difference. Significant difference ($P < 0.05$) was observed on root dry weight and total root length at maximum tillering stage at 10-20 cm soil layer. Memberamo showed the highest root dry weight and the longest root length at 10-20 cm soil layer.

Plant tiller and height was measured in three different growth stages, i.e. early growth stage (17 DAT), maximum tillering (36 DAT), and the panicle initiation stage (57 DAT). Table 5 shows that there was no significant difference in number of plant tillers during the early growth and panicle initiation stage. Significant difference ($P < 0.05$) among cultivars in number of tillers occurred at maximum tillering stage. Way Apoburu had the highest number of tillers (18 + 2.8), while Cisadane was the lowest (16 + 1.5).

Table 3. Dry matter weight of sraw, filled and unfilled grain of four rice cultivars, Jakenan Experimental Farm, Central Java, WS 2001/2002 (n = 3, means + SD).

Rice cultivar	Straw dry weight (kg ha^{-1})	Unfilled grain (%)	Filled grain (%)
Memberamo	9475 + 750.0a	46.7 + 8.99	53.3 + 9.24
Cisadane	9450 + 500.0ab	37.4 + 10.42	62.6 + 6.18
IR64	7175 + 550.0c	38.2 + 6.20	61.8 + 11.68
Way Apoburu	8300 + 300.0bc	36.0 + 5.76	64.0 + 9.96

Numbers in the same column followed by a common letter are not significantly different at $P < 0.05$ by DMRT.

Table 4. Root weight and total root length of four rice cultivars at three different growth stages and at two different soil layers, Jakenan Experimental Farm, Central Java, WS 2001/ 2002 (n = 3, means + SD).

Growth stage/ rice cultivar	Root weight (g hill^{-1})		Total root lenght (cm hill^{-1})	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
17 DAT				
Memberamo	0.7 + 0.12a	0.43 + 0.200ab	103 + 19.4a	65 + 26.5a
Cisadane	1.2 + 0.40a	0.57 + 0.080a	144 + 48.7a	73 + 17.6a
IR64	1.0 + 0.37a	0.37 + 0.140ab	151 + 76.6a	57 + 32.5a
Way Apoburu	1.1 + 0.41a	0.29 + 0.070b	172 + 70.9a	46 + 17.3a
36 DAT				
Memberamo	3.4 + 0.16a	0.98 + 0.120a	505 + 66.3a	148 + 37.2a
Cisadane	4.3 + 1.11a	0.76 + 0.190ab	528 + 72.9a	73 + 17.6a
IR64	4.5 + 0.66a	0.57 + 0.110b	649 + 170.0a	83 + 25.5b
Way Apoburu	3.7 + 1.32a	0.66 + 0.140b	607 + 277.3a	107 + 41.8ab
57 DAT				
Memberamo	4.3 + 0.46a	1.45 + 0.580a	3942 + 232.3a	1338 + 595.0a
Cisadane	6.3 + 1.09a	0.98 + 0.180a	4888 + 947.5a	777 + 228.0a
IR64	4.4 + 1.37a	0.57 + 0.270a	4353 + 1759.7a	814 + 226.0a
Way Apoburu	5.5 + 0.97a	0.81 + 0.230a	5097 + 1175.8a	767 + 263.0a

DAT = days after transplanting
Numbers in the same column followed by a common letter are not significanly different at P < 0.05 by DMRT.

Table 5. Number of plant tiller and plant height of four rice cultivars at three different growth stages, Jakenan Experimental Farm, Central Java, WS 2001/2002 (n = 12, means + SD).

Rice cultivars	Number of plant tiller			Plant height (cm)		
	17 DAT	36 DAT	57 DAT	17 DAT	36 DAT	57 DAT
Memberamo	13 + 2.2a	17 + 2.5b	14 + 1.7a	46 + 3.4a	75 + 4.5a	99 + 4.0b
Cisadane	14 + 1.5a	16 + 1.5b	13 + 1.3a	44 + 2.4a	74 + 4.9a	103 + 3.5a
IR 64	14 + 2.6a	17 + 2.5b	14 + 2.4a	44 + 2.6a	66 + 3.1b	95 + 3.3bc
Way Apoburu	15 + 1.8a	18 + 2.8a	15 + 2.6a	46 + 3.4a	70 + 4.0a	92 + 5.6c

DAT = days after transplanting
Numbers in the same column followed by a common letter are not significantly differen at P < 0.05 by DMRT.

Correlation analysis was carried out to determine the relationship between the growth parameters and CH_4 flux (Fig. 4, 5, and 6). Significant correlation (P < 0.01) between number of plant tiller and CH_4 flux occurred only at 56 DAT (n = 12, r = 0.82), when all tillers were considered as developed tillerss (Fig. 4a). Aulakh *et al.* (2000) also found positive correlation between CH_4 flux and the number of developed tillers on ten rice cultivars tested. However, underdeveloped tillers, which keep on emerging at different times during plant growth and often end up unproductive, did not show any correlation with CH_4 flux. Aulakh *et al.* (2000) also showed that the combined number of developed and underdeveloped tillers did not exhibit a significant correlation with CH_4 flux in all of the cultivars tested. During the panicle initiation stage, only effective tillers occurred, therefore the finding from this study was similar to what was observed by Aulakh *et al.* (2000). Watanabe *et al.* (1995) could not find any correlation between CH_4 flux and number of plant tillers. Under greenhouse condition with constant supply of CH_4 to plant roots, Wang *et al.* (1997) reported that number of plant tillers positively correlated with CH_4 flux. The present results showed that number of plant tillers could be the major controlling factor of plant mediated CH_4 transport in widely different cultivars (Aulakh *et al.* 2000). Therefore, plant with less number of tillers would minimize CH_4 flux from the soil to the atmosphere. Figure 4b shows significant correlation (P < 0.01) between plant height

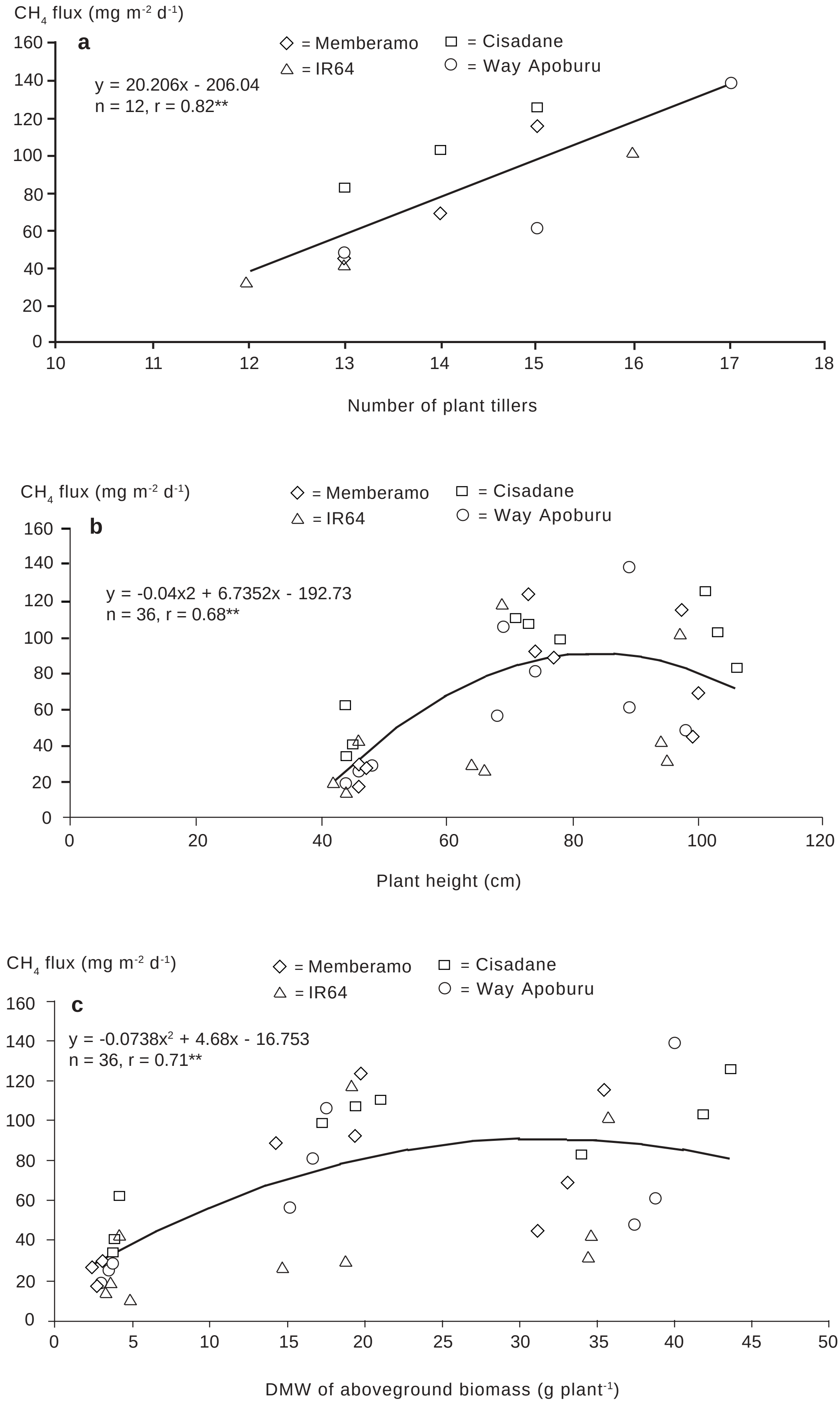

Fig. 4. Relationship between CH_4 flux and (a) number of plant tillers, (b) plant height, and (c) dry matter weight of aboveground biomass of four rice cultivars, Jakenan Experimental Farm, Central Java, WS 2001/2002 (** indicate significant correlation at P < 0.01).

and CH_4 flux (n = 36, r = 0.68). According to Aulakh *et al.* (2000), the relationship between plant height of developed tillers was related to the proportional enhanced continuity of aerenchyma channels with the increasing plant height of rice cultivar. Figure 4c shows significant correlation (P < 0.01) between aboveground biomass and CH_4 flux (n = 36, r = 0.71). The similar results were reported by Sass *et al.* (1990), Shalini-Singh *et al.* (1997), and Aulakh *et al.* (2000).

Strong correlations (P < 0.01) were found between CH_4 flux and total root dry weight and total root length at different soil layers (Fig. 5 and 6). All relationships showed positive exponential patterns. These results suggest that the increase in root parameters would determine the corresponding increase in CH_4 flux. Similar results were reported by Aulakh *et al.* (2000), who observed highly significant correlation between CH_4 transport capacity and root parameters (weight and length) of 10 rice cultivars tested in a greenhouse experiment in Germany, but the nature of the correlation varied among cultivars. One cultivar tested, i.e. Magat, showed a linear correlation between CH_4 transport capacity and root

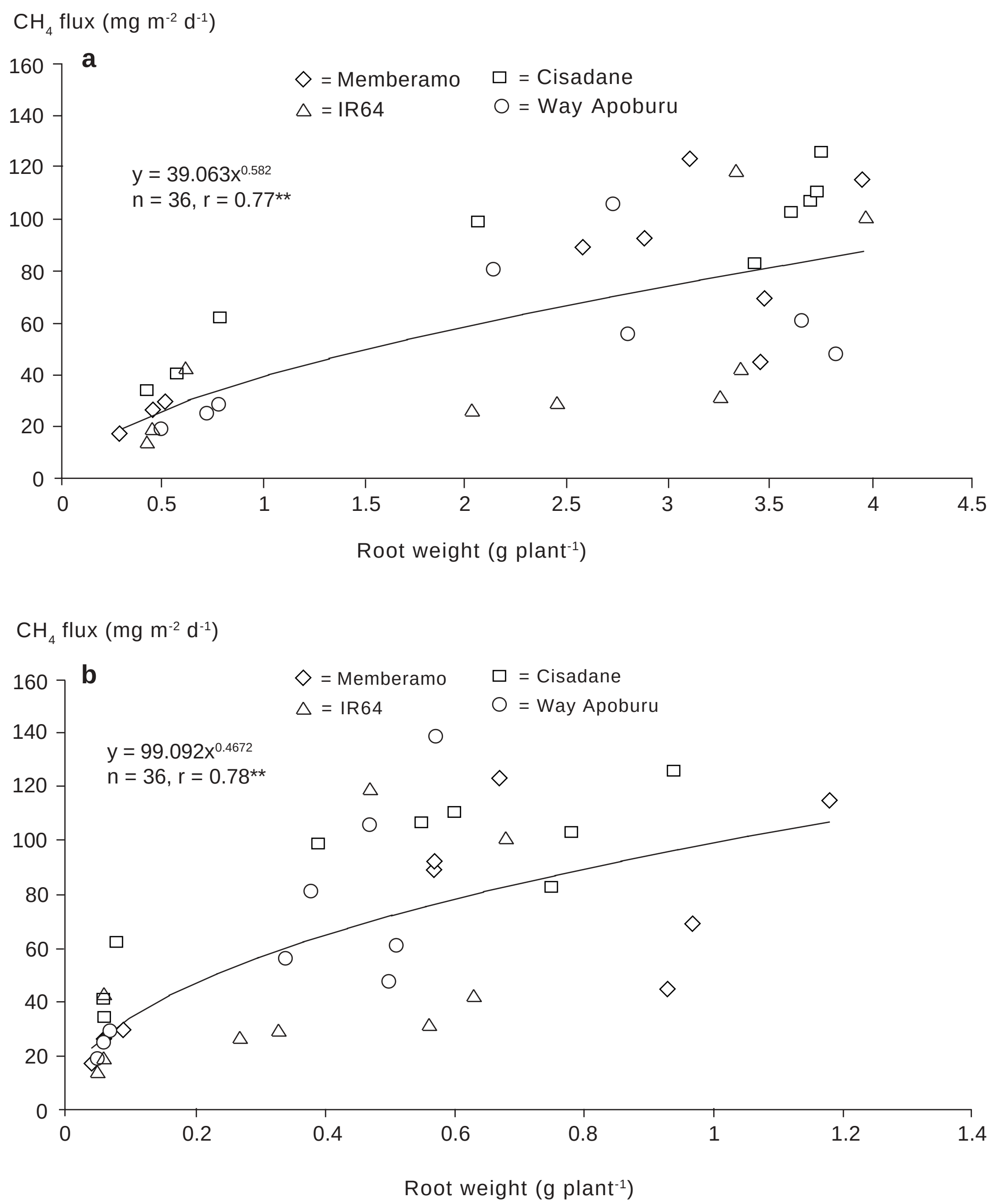

Fig. 5. Relationship between CH_4 flux and root dry weight of four rice cultivars, Jakenan Experimental Farm, Central Java, WS 2001/2004; root samples were taken from 0-10 cm (a) and 10-20 cm (b) (** indicate significant correlation at P < 0.01).

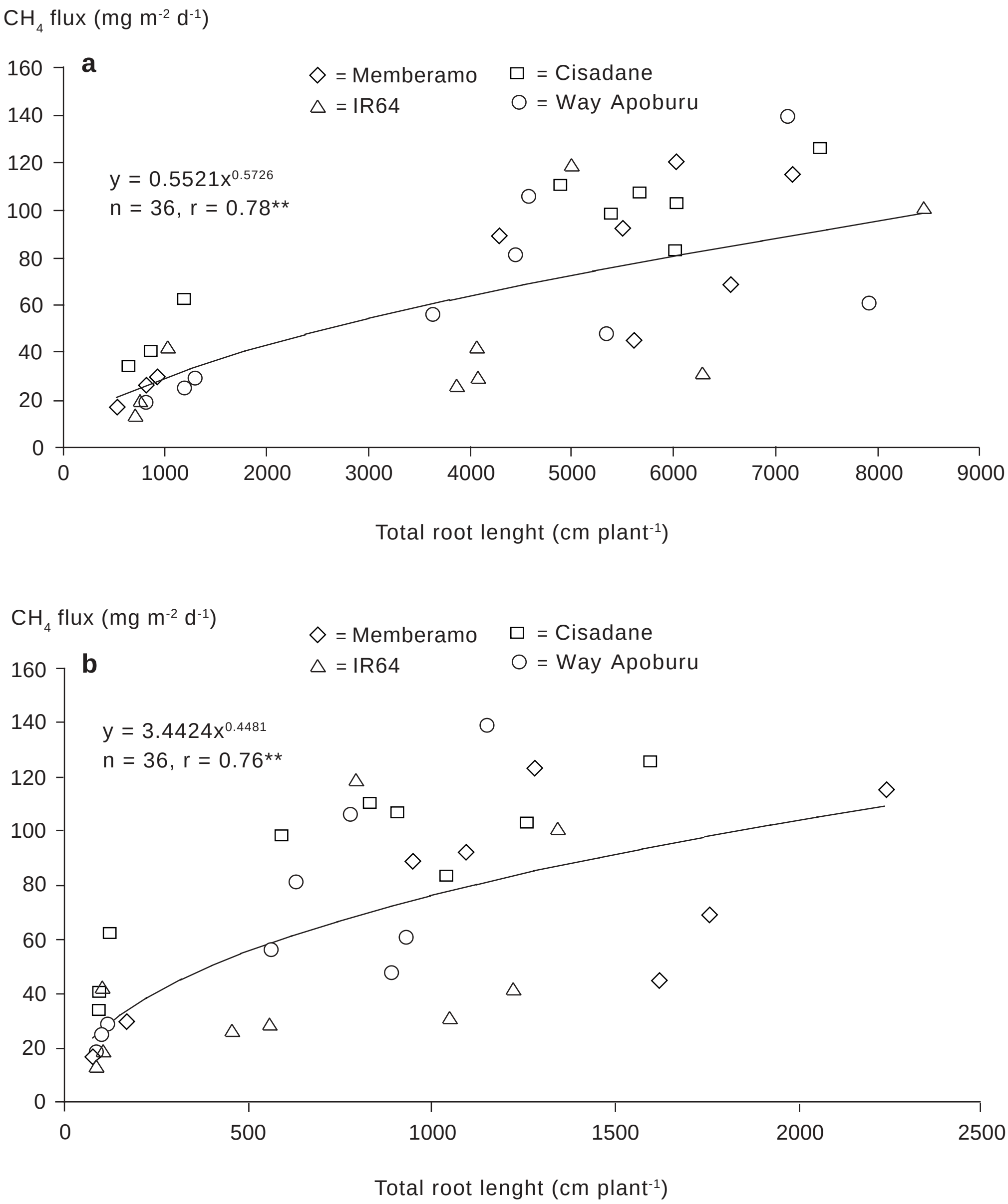

Fig. 6. Relationship between CH_4 flux and total root length of four rice cultivars, Jakenan Experimental Farm, Central Java, WS 2001/2002; root samples were taken from (a) 0-10 cm and (b) 10-20 cm (** indicate significant correlation at $P < 0.01$).

biomass, whereas other cultivars exhibited a logarithmic relationship. Further investigations, such as anatomical appearance of pattern and distribution of aerenchyma in different parts of rice plant and microscopic analysis including measurement of aerenchyma areas are needed to understand aerenchyma development in different cultivars.

This study pointed out that understanding of the influence of rice cultivars on CH_4 emission is important in an effort to reduce rice field contribution to CH_4 emission. This study was focussed on a few plant parameter observations, but lacks the observation of the mechanism of CH_4 emission inhibition. Thus, further study should include these mechanisms.

CONCLUSION

Rice cultivars showed a different ability in emitting CH_4 gas from flooded rice field. IR64, Way Apoburu, Memberamo, and Cisadane emitted total CH_4 as much as 37.7, 58.9, 61.1, and 94.8 kg ha^{-1}, respectively, with no significant difference in grain yield. Root parameters, aboveground biomass, and plant height exhibited significant correlation with CH_4 flux. Number of plant tillers, as a conduit for CH_4 transport from the rhizosphere, exhibited significant correlation only if it was considered as effective tillers.

Morphological properties such as root, biomass, number of plant tillers, and dry matter weight of aboveground biomass should be considered in rice breeding program to reduce CH_4 emission. Development of new plant type (NPT) cultivars that have minimum number of tillers but with higher proportion of productive tillers, and that can induce less amount of CH_4 seems to be an economically sound, and promising approach to mitigate CH_4 emission from rice fields.

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