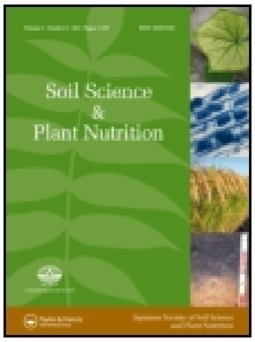

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Effect of Rice Variety on Methane Emission from an Indonesian Paddy Field

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Variations in CH_4 emission from a Sumatra paddy field in which 8 popular modern varieties in Indonesia were grown were compared in the 1994/1995 rainy season. Total amounts of CH_4 emitted during the period of rice growth were in the ranges of 32.6-41.7 and 51.3-64.6 g CH_4 m^{-2} for the plots amended with chemical fertilizer only and those amended with both rice straw and chemical fertilizer, respectively. The mean CH_4 emission rate was highest in the plot with the variety Bengawan solo and lowest in the plots with the varieties Atomita-4 and Way seputih among the plots which received chemical fertilizer, while highest in the plot with Way seputih and lowest in the plot with Bengawan solo among the plots amended with both rice straw and chemical fertilizer. The increase in the mean CH_4 emission rates by rice straw application was higher for the plots planted with Way seputih (1.98 times) and Atomita-4 (1.77 times) than for the plots with Bengawan solo (1.23 times) and IR-64 (1.35 times). The plots with Walanai and Cisanggarung recorded intermediate mean emission rates and the increase in CH_4 emission by rice straw application was also intermediate (1.57-1.64 times). It was noteworthy that Way seputih and Atomita-4 were derived from the variety Cisadane, Bengawan solo and IR-64 from the variety IR-54, and Walanai and Cisanggarung from the varieties IR-36 and Pelita 1-1, respectively.

The amounts of CH_4 emitted for 1 kg grain production ranged from 53 (Atomita-4) to 74 (Kapuas and Walanai) and from 89-93 (IR-64, Bengawan solo, and Atomita-4) to 121 (Kapuas) g CH_4 kg^{-1} of grain for the plots amended with chemical fertilizer and those amended with rice straw and chemical fertilizer, respectively.

Key Words: **methane emission, rice straw, rice variety, seasonal variation, yield.**

Paddy fields are one of the major sources of atmospheric methane in relation to the greenhouse effect. Many studies have been conducted on the estimation of the amounts of methane fluxes under different growth conditions, in relation to the effects of cultivation (Seiler et al. 1984; Holzapfel-Pschorn et al. 1986; Sass et al. 1990, 1991; Lindau et al. 1991), soil type (Sass et al. 1990, 1991, 1994; Yagi and Minami 1990; Kimura et al. 1991), fertilizer application (Cicerone et al. 1983; Holzapfel-Pschorn and Seiler 1986; Schütz et al. 1989;

Yagi and Minami 1990; Kimura et al. 1991; Lauren et al. 1994), seasonal variation (Cicerone et al. 1983; Holzapfel-Pschorn and Seiler 1986; Holzapfel-Pschorn et al. 1986; Schütz et al. 1989; Sass et al. 1990, 1991; Yagi and Minami 1990; Kimura et al. 1991), diurnal variation (Cicerone et al. 1983; Seiler et al. 1984; Holzapfel-Pschorn and Seiler 1986; Schütz et al. 1989; Yagi and Minami 1990; Miura et al. 1992), temperature (Holzapfel-Pschorn and Seiler 1986; Schütz et al. 1989, 1990; Sass et al. 1990, 1991; Yagi and Minami 1990; Miura et al. 1992), water management (Yagi et al. 1990; Sass et al. 1992; Murase et al. 1993), and gypsum application (Delwiche and Cicerone 1993; Denier van der gon and Neue 1994). It was reported that the amount and the constituents of root exudates were different among pea and soybean varieties (Kraft 1974; Keeling 1974). In addition, the root system and the activity of roots oxidizing the root environment are expected to differ depending on the varieties. Rice variety, therefore, is considered to be an important factor affecting the CH_4 fluxes from rice paddies, but the effect of rice variety on CH_4 fluxes has not been fully documented (Watanabe et al. 1995).

Twenty-five percent of the paddy fields in the world are distributed in Southeast Asia, but relatively few studies on CH_4 emission from paddy fields have been conducted in this region (Denier van der gon et al. 1992; Wassmann et al. 1994; Yagi et al. 1994; Jermsawatdipong et al. 1994). There are 10.6 million ha of paddy fields in Indonesia. The area accounts for 7.2% of the total paddy fields in the world, and is the largest among the countries in this region.

We reported the effects of the application of several kinds of fertilizers and intermittent irrigation on CH_4 emission, and the yearly and seasonal (rainy and dry seasons) variations of CH_4 emission from an Indonesian paddy field (Nugroho et al. 1994a, b, 1996). In this paper, we report the effect of rice variety on the amount of CH_4 emission from the same Indonesian paddy field used in the previous reports (Nugroho et al. 1994a, b, 1996).

MATERIALS AND METHODS

Experimental field and cultivation of rice plants. The experimental field was located in Taman Bogo, Central Lampung, Southern Sumatra, Indonesia. The soil is

Table 1. Physicochemical properties of soil.

	CF*	RS*
$pH(H_2O)$	5.0	5.1
pH(KCl)	3.8	3.8
Total-C(10^{-2} kg kg^{-1})	1.08	1.30
Total-N(10^{-2} kg kg^{-1})	0.14	0.16
CEC(cmol(+) kg^{-1})	5.16	ND
Available P(10^{-6} kg kg^{-1})**	1.60	1.72
Soil texture		
Sand	51%	ND
Silt	17%	ND
Clay	32%	ND

ND: Not determined

* CF: Plots amended with chemical fertilizer,
RS: Plots amended with rice straw and chemical fertilizer

**Bray I (Bray and Kurtz 1945)

Table 2. Characteristics of rice varieties.

	Bengawan solo	IR-74	IR-64	Atomita-4	Cisanggarung	Way seputih	Kapuas	Walanai
Type	Indica	Indica	Indica	Indica	Indica	Indica	Indica	Indica
Variety	modern	modern	modern	modern	modern	modern	modern	modern
Parents								
♂	$IR56^2$	IR19661-131-1-2	IR5657	Cisadane	IR2061-28-33/Pelita1-1	Cisadane	Pelita1-1	Pelita1-1/B3663
♀	IR841	IR15795-199-3-3	IR2061	(Irradiated)	IR36/Pelita1-1	IR36	CR94-12/IR20	$Pelita1\text{-}1^3/IR36$
Growth duration (day)	117	130	115	118	128	120	125	122
Height (cm)	95	85	85	115	90	100	95	115
Leaf								
- color	green	green	green	green	green	green	green	green
- surface	rough	rough	rough	rough	rough	rough	rough	rough
- flag	straight	straight	straight	bent	bent	bent	straight	straight
No of panicles	15-20	15-20	15-20	15-20	15-20	15-20	15-20	15-20
Weight of 1000 grains	23g	24g	27g	29-30g	28g	26g	28g	29g
Amylose (%)	17	22	24	21	24	22	23	25
Stickiness	slightly sticky	non-sticky	non-sticky	slightly sticky	non-sticky	slightly sticky	non-sticky	slightly sticky
Cultivation area	lowland paddy fields	paddy fields up to 500m* also adapted to dry season	lowland paddy fields well irrigated	paddy fields up to 600m*	paddy fields in 500-900m*	paddy fields up to 500m*	adapted to acid soils and tidal paddy fields	paddy fields up to 500m*

* above sea level

classified as a Typic Paleudult (Red Yellow Podzolic Soil). Chemical properties of the soil at the time of plowing are shown in Table 1. In both plots, CF plot amended with chemical fertilizer and RS plot amended with rice straw (5 t ha^{-1}) and chemical fertilizer, cultivation of IR-64 was started in the 1992/1993 rainy season. The difference in the treatments during the past two years was reflected in the total C and N contents in soil.

The experimental field consisted of 16 plots; 8 plots with chemical fertilizer application and the other 8 plots subjected to the application of both chemical fertilizer and rice straw (IR-64: 5 t ha^{-1}). Eight varieties of rice plant (*Oryza sativa* L. cv. Bengawan solo, IR-74, IR-64, Atomita-4, Cisanggarung, Way seputih, Kapuas, and Walanai) were transplanted to the respective plots with the application of chemical fertilizer only or with additional application of rice straw. These popular modern varieties in Indonesia are cultivated in areas differing in physiographical characteristics (Table 2). The area of each plot was 7 m×11 m. The experiment was conducted in the 1994/1995 rainy season. The cultivation calendar is shown in Table 3.

Table 3. Cultivation calendar.

Plowing		
1st	Nov.28,1994	
2nd	Dec.14	
Flooding	Nov.30	
Transplanting	Dec.28	
Fertilization		
Rice Straw	Dec.21	(5 tons ha^{-1})
Chemical fertilizer		
Basal	Dec.28	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1}, Triple superphosphate:200kg ha^{-1}, KCl:100kg ha^{-1})
Top dressing (1st)	Jan.16,1995	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
Top dressing (2nd)		
Bengawan Solo	Feb.11	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
IR-74	Feb.21	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
IR-64	Feb.11	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
Atomita-4	Feb.15	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
Cisanggarung	Feb.21	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
Way seputih	Feb.18	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
Kapuas	Feb.18	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
Walanai	Feb.15	(Urea:67kg ha^{-1}, $(NH_4)_2SO_4$:33kg ha^{-1})
Weeding		
1st	Jan.11	
2nd	Feb. 9	
Heading	Same days at 2nd topdressing	
Drainage	Mar.18	
Harvest		
Bengawan Solo	Mar.29	
IR-74	Apr.11	
IR-64	Mar.29	
Atomita-4	Apr. 6	
Cisanggarung	Apr.11	
Way seputih	Apr. 6	
Kapuas	Apr. 6	
Walanai	Apr. 6	

Twenty-one day-old seedlings were transplanted (3 seedlings hill^{-1}) at a spacing of 20 cm × 20 cm to the experimental field, which was submerged before transplanting and was irrigated when needed to maintain the flooded conditions until the harvesting stage.

Measurement of CH_4 emission. Methane emission rates were measured every week throughout the growth period. Four hills of rice plants were covered with an acrylic box chamber (40 cm × 40 cm × 100 cm). Stakes were driven into the soil at the time of transplanting for the chambers to cover the same soil surface with four hills. A Tedlar® bag (2 L) was attached to the chamber to keep the inside pressure equal to the atmospheric pressure. A rubber stopper, which was pierced with a glass tube and plugged with a septum (Shimadzu Co., Japan), was attached at the ceiling of the chamber for collecting the gas samples. The gas samples were taken three times at 20 min intervals 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 plot. Each time, the sampling was conducted between 10:00–13:00 h.

The sample tubes were brought back to the Laboratory of Soil Biology, Faculty of Agriculture, Lampung University, and the CH_4 content in the tubes was determined on the same day with a gas chromatograph equipped with a flame ionization detector (GC-8AIF, Shimadzu Co.). Methane emission rates were calculated from the increase in CH_4 concentration in the chamber with time and the volume of the chamber.

RESULTS AND DISCUSSION

Seasonal variation of CH_4 emission rates

Figure 1 shows the 5-d means of daily maximum and minimum temperatures and the total amounts of rainfall for the 5-d periods. The temperature was uniform and within the narrow ranges of 29.7 and 35.1°C for the daily maximum temperature and 22.4 and 24.9°C for the daily minimum temperature, respectively.

CH_4 emission rates from the plots with chemical fertilizer application showed a peak at around 6 and 8 weeks after transplanting, irrespective of the varieties (Fig. 2) (Nugroho et al. 1994a). The emission rates from the plots amended with rice straw and chemical fertilizer, in addition, showed peaks or shoulders in the early growth stage (4 weeks after transplanting) and in the late growth stage (8 weeks after transplanting). Higher CH_4 emission rates were generally recorded in the plots with rice straw and chemical fertilizer throughout the growth period than in the plots which received only chemical fertilizer.

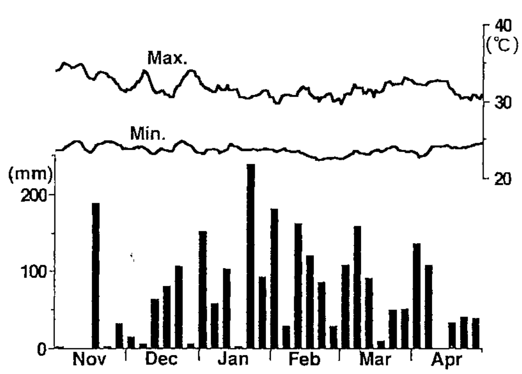

Fig. 1. Five-day means of daily maximum and minimum temperatures and total amount of rainfall for 5-d periods.

Mean CH_4 emission rates and total amount of CH_4 emission during the growth period of rice plant

Table 4 shows the mean CH_4 emission rates during the growth period. The means were in the range of 17.7-22.6 mg CH_4 m^{-2} h^{-1} for the chemical fertilizer plots (19.8±2.4 mg CH_4 m^{-2} h^{-1}) and 27.7-35.0 mg CH_4 m^{-2} h^{-1} for the plots amended with rice straw and chemical fertilizer (31.2±4.0 mg CH_4 m^{-2} h^{-1}), respectively. They were significantly different between the plots with chemical fertilizer and the plots amended with rice straw and chemical

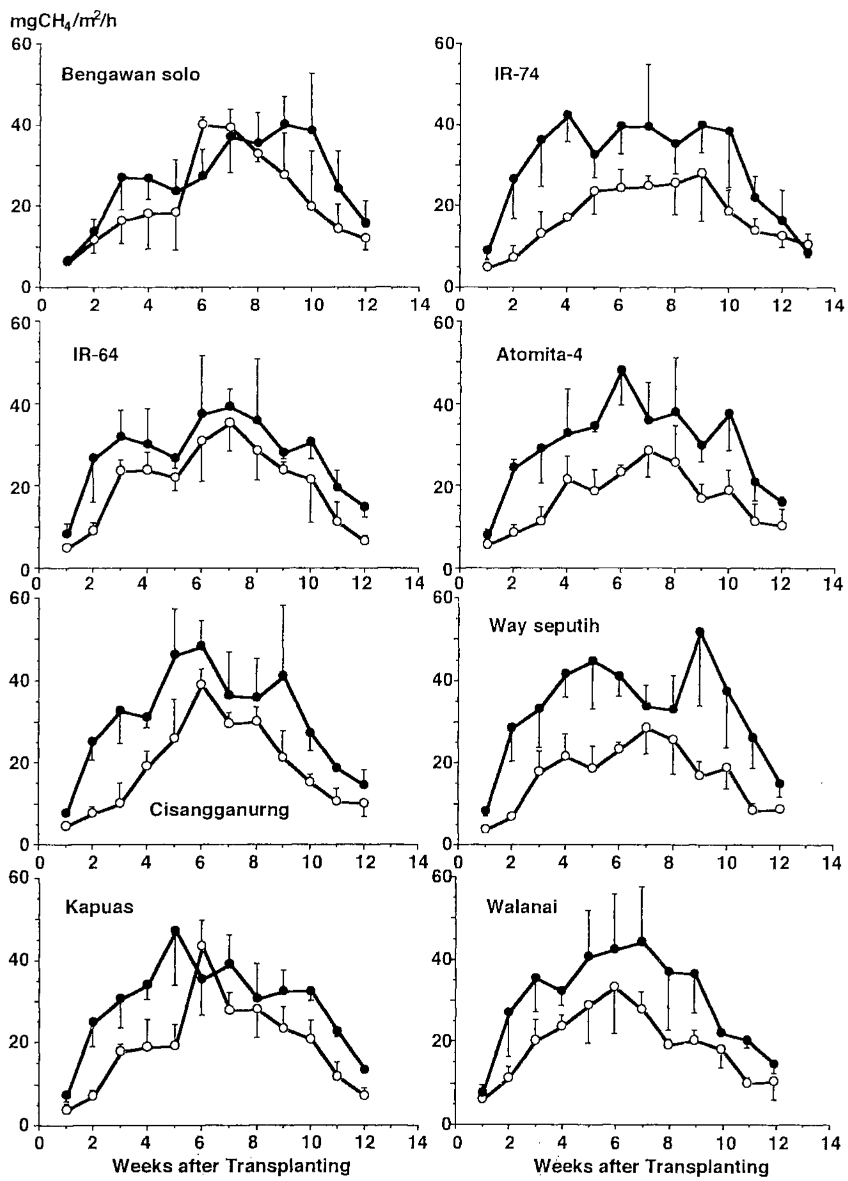

Fig. 2. Seasonal variation of methane emission rate. Bars indicate the standard deviation. ○, Plots with chemical fertilizer application; ●, plots with rice straw and chemical fertilizer application.

fertilizer ($p<0.01$).

The mean CH_4 emission rate was highest in the plot with the variety Bengawan solo followed by the plot with IR-64 and lowest in the plots with the varieties Atomita-4 and Way seputih among the plots amended with chemical fertilizer. Based on t-test among the respective rice varieties grown in the soil amended with chemical fertilizer or in the soil amended with rice straw and chemical fertilizer, the mean CH_4 emission rates from the plots with the varieties Bengawan solo, IR-64, and Kapuas were, though low, significantly higher than those from the plots with Atomita-4 and Way seputih ($p<0.1$; Table 5). The mean CH_4 emission rates from the plots amended with rice straw and chemical fertilizer were highest in the plot with Way seputih and lowest in the plot with Bengawan solo (significantly different, $p<0.1$; Table 5), again followed by the plot with IR-64. It was noteworthy that Way seputih and Atomita-4 were derived from the variety Cisadane, and Bengawan solo and IR-64 from the variety IR-54, respectively (Table 2). In addition, the plots with Walanai and Cisanggarung, both of which were derived from the varieties IR-36 and Pelita 1-1, recorded similar mean CH_4 emission rates irrespective of the application of rice straw (Tables 2 and 4). The rates were intermediate in the plots amended with chemical fertilizer and with rice straw and chemical fertilizer.

The increase in the mean CH_4 emission rates by rice straw application was higher for the plots planted with Way seputih (1.98 times) and Atomita-4 (1.77 times) than for the plots with Bengawan solo (1.23 times) and IR-64 (1.35 times). The increase of emission by rice straw application was intermediate for the plots with Walanai (1.57 times) and Cisanggarung (1.64 times). These findings reflected the significant effects of rice variety on CH_4 emission rates and the increase in CH_4 emission rates by rice straw application. Although

Table 4. Mean rate of CH_4 emission, total amount of CH_4 emitted, yield of unhulled rice, and amount of CH_4 emitted for 1 kg grain production.

Plot	Mean rate of CH_4 emission ($mg\ CH_4\ m^{-2}\ h^{-1}$)	Total emission amounts ($g\ CH_4\ m^{-2}$)	Yield ($kg\ ha^{-1}$)	Amount of CH_4 emitted for 1 kg grain production ($g\ CH_4\ kg^{-1}$)
Plots amended with chemical fertilizer				
Bengawan solo	22.6±3.3	41.7±6.1	6200±730	67.3±9.8
IR-74	18.2±2.7	36.8±5.3	5650±560	65.1±9.4
IR-64	21.5±2.2	39.8±4.0	5920±470	67.2±6.8
Atomita-4	17.7±0.6	32.6±1.1	6200±160	52.6±1.8
Cisanggarung	19.8±1.4	36.5±2.6	5460±250	66.9±4.8
Way seputih	17.8±1.2	32.7±2.2	5580±250	58.6±3.9
Kapuas	20.5±0.8	37.8±1.6	5340±710	70.8±3.0
Walanai	20.2±1.7	37.4±3.1	5060±500	73.9±6.1
Plots amended with rice straw and chemical fertilizer				
Bengawan solo	27.7±1.2	51.3±2.3	5720±640	89.7±4.0
IR-74	31.6±6.0	63.7±12.1	6550±570	97.3±18.5
IR-64	29.0±1.6	53.6±3.0	6030±200	88.9±5.0
Atomita-4	31.3±4.2	57.8±7.8	6220±460	92.9±12.5
Cisanggarung	32.3±5.2	59.7±9.6	5520±420	108.2±17.4
Way seputih	35.0±5.6	64.6±10.4	5730±440	112.7±18.2
Kapuas	31.0±2.0	57.3±3.7	4750±520	120.6±7.8
Walanai	31.8±4.1	58.8±7.5	5490±650	107.1±13.7

* Values are means ± standard error of three replicates.

Table 5. Results of t-test for the differences in mean rates of CH_4 emission among respective rice varieties grown in soil amended with chemical fertilizer or in soil amended with rice straw and chemical fertilizer.

	Plots amended with chemical fertilizer								Plots amended with rice straw and chemical fertilizer						
	AT4	WS	IR74	CG	WA	KA	IR64	BS	BS	IR64	KA	AT4	IR74	WA	CG
Plots amended with chemical fertilizer															
AT4															
WS	NS														
IR74	NS	NS													
CG	×	NS	NS												
WA	×	NS	NS	NS											
KA	**	*	NS	NS	NS										
IR64	*	×	NS	NS	NS	NS									
BS	×	×	NS	NS	NS	NS	NS								
Plots amended with rice straw and chemical fertilizer															
BS	**	**	*	**	**	**	*	×							
IR64	**	**	**	**	**	**	**	*	NS						
KA	**	**	**	**	**	**	**	*	×	NS					
AT4	**	**	*	*	*	*	*	*	NS	NS	NS				
IR74	*	*	*	*	*	*	*	*	NS	NS	NS	NS			
WA	**	**	*	**	*	**	*	*	NS	NS	NS	NS	NS		
CG	**	**	*	*	*	*	*	×	NS	NS	NS	NS	NS	NS	
WS	***	***	**	**	**	**	**	**	×	NS	NS	NS	NS	NS	NS

AT4: Atomita-4, WS: Way seputih, IR74: IR-74, CG: Cisanggarung, WA: Walanai, KA: Kapuas, IR64: IR-64, BS: Bengawan solo
NS: not significant, ×, *, **: significantly different at 10%, 5%, and 1% levels, respectively.

the respective rice varieties may have influenced the amounts and the constituents of root exudate, root systems in soil, and the activity leading to oxidization of root environments differently, which eventually resulted in varietal differences in CH_4 emission from rice paddies, it remains to be determined characteristics of the respective varieties mainly determined the emission rates.

Total amounts of CH_4 emitted during the period of rice growth are also shown in Table 4. In the calculation, the CH_4 emissions during the period between transplanting and the first measurement (7 d after transplanting) and during the period between the last measurement and harvest were omitted (drainage occurred within 1 week after the last sampling). The amounts were in the ranges of 32.6–41.7 and 51.3–64.6 g CH_4 m^{-2} for the plots amended with chemical fertilizer and those amended with rice straw and chemical fertilizer, respectively. As the duration of the periods when the CH_4 emission rates was measured were the same for the 7 varieties (12 weeks) except for variety IR-74 (13 weeks), the differences in CH_4 emission amounts among the varieties were similar to those observed in the mean CH_4 emission rates. The increase in the amounts of CH_4 emission by rice straw application were in the range from 9.6 g CH_4 m^{-2} for the plot with Bengawan solo to 31.9 g CH_4 m^{-2} for the plot with Way seputih.

We conducted the sampling between 10:00–13:00 h, as mentioned in the part on MATERIALS AND METHODS. As it was reported that a 10°C rise of temperature from 20 to 30°C increased the CH_4 emission rates nearly four times (Holzapfel-Pschorn and Seiler 1986; Schütz et al. 1989; Miura et al. 1992), the fluctuations of the soil temperature between this period might have influenced the CH_4 emission rates among the plots. However, gas sampling was conducted within 2 h each time. In addition, as the daily maximum and minimum temperatures in the atmosphere were rather uniform and the difference between them was less than 10°C throughout the growth period (Fig. 1), we estimated that the temperature fluctuations during the sampling period did not exert a significant effect on the CH_4 emission rates among the plots.

Amount of CH_4 emission for the production of unit weight of grain

The yield of grain and the amount of CH_4 emitted for 1 kg grain production are shown in Table 4. Grain yield was in the ranges of 5,060–6,200 kg ha^{-1} for the plots amended with chemical fertilizer, and 4,750–6,550 kg ha^{-1} for the plots amended with rice straw and chemical fertilizer, respectively. The effect of rice straw application on the grain yield was not recognized in this experiment. As shown in Table 2, the varieties tested in the present experiment were adapted to the area where the experimental field was located except for Cisanggarung, which is adapted to areas with high elevation (500–900 m). Cisanggarung gave intermediate yields for the plots with and without rice straw application in this experiment (Table 4).

The amount of CH_4 emitted for 1 kg grain production was in the ranges of 53–74 and 89–121 g CH_4 kg^{-1} of grain for the plots amended with chemical fertilizer (66 ± 9 g CH_4 kg^{-1} of grain) and those amended with rice straw and chemical fertilizer (99 ± 18 g CH_4 kg^{-1} of grain), respectively. The amount was significantly different between the plots amended with chemical fertilizer and the plots with rice straw and chemical fertilizer application ($p < 0.01$), presumably due to the remarkable increase in CH_4 emission by rice straw application (Table 4). The amount was the lowest (53 g CH_4 kg^{-1} of grain) in the plot with Atomita-4 and largest in the plots with Kapuas and Walanai (74 g CH_4 kg^{-1} of grain) among the plots amended with chemical fertilizer, while the amount was the lowest in the plots with IR-64, Bengawan solo and Atomita-4 (89–93 g CH_4 kg^{-1} of grain) and largest in the plot with Kapuas (121 g CH_4 kg^{-1} of grain) among the plots amended with rice straw and chemical fertilizer.

The lowest amount of CH_4 emitted for 1 kg grain production in the plot of Atomita-4 grown in the soil amended with chemical fertilizer was mainly due to the low amount of total CH_4 emission and high grain yield. On the contrary, the largest amount of CH_4 emitted for 1 kg production in the plot of Kapuas grown in the soil amended with rice straw and chemical fertilizer was due to the low grain yield. Thus, the amount of CH_4 emitted for 1 kg grain production markedly fluctuated depending on the rice variety and the application of rice straw, because on the one hand grain yields were different among the rice varieties, and on the other hand the CH_4 emission from rice paddies with and without rice straw application was differently influenced by the rice varieties.

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