III. RESEARCH METHODOLOGY

Site Description

The study was carried out at the Sukamandi Research Institute for Food Crops (SURIF), West Java. The research institute is located about 80 km east of Jakarta, and about 16 km from north coast of Java (see Figure 12). The station is situated in the middle of large rice growing where rice is grown twice a year with the first from November to February and the second from April to August. The experimental site is about 16 m above sea level and geographically located at 6°20' S and 107°39' E. The topography is generally flat with very little slope of 1-2 m every 1000 m distance. The climatic type of the area is Aw according to Koppen or C/D according to Oldeman with a mean annual of rainfall 1200 mm. Rainy season is between November and May, while dry season is between June and October. The field experiment was carried out from April to August 1993 which coincided with the dry season planting period.

Ranges and monthly average values of daylight hours period (hr/day), relative humidity (%), and evaporation (mm/day) are given in Table 9. Table 9 also presents total rainfall and rainy days per month during the experiment. Data in Table 9 show that during the experiment, daylight hours period was from 0.1 to 10.2 hr/day with an average of 6.7 hr/day. It is clearly seen from Table 10 that daylight hours period increased from April to August, this was due to more rain in April and May when the weather was more cloudy. Higher daylight hours period occurred in July and August with less rainfall. Daily average of relative humidity recorded during the experiment ranged from 74 to 93% with a monthly average of 84%. The lowest evaporation observed was 2.0 mm/day and the highest was 6.9 mm/day.
Figure 12. Location of Sukamandi Research Institute for Food Crops in West Java, Indonesia
Table 9. Data of daylight hours period, relative humidity, evaporation and rainfall during the experiment, April - August 1993.

<table>
<thead>
<tr>
<th>Month</th>
<th>Range (hr/day)</th>
<th>Average</th>
<th>Range (°C)</th>
<th>Average</th>
<th>Range (mm/day)</th>
<th>Average</th>
<th>Total Raindays</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>0.1 - 9.4</td>
<td>5.8 ± 2.8</td>
<td>81 - 92</td>
<td>86 ± 3</td>
<td>2.0 - 5.9</td>
<td>3.9 ± 1.2</td>
<td>109</td>
</tr>
<tr>
<td>May</td>
<td>0.1 - 10.2</td>
<td>5.8 ± 2.7</td>
<td>82 - 92</td>
<td>86 ± 3</td>
<td>4.2 - 6.2</td>
<td>5.0 ± 0.5</td>
<td>105</td>
</tr>
<tr>
<td>June</td>
<td>0.3 - 3.3</td>
<td>6.0 ± 3.0</td>
<td>80 - 93</td>
<td>88 ± 4</td>
<td>4.2 - 6.2</td>
<td>5.0 ± 0.5</td>
<td>83</td>
</tr>
<tr>
<td>July</td>
<td>0.1 - 2.1</td>
<td>7.3 ± 2.6</td>
<td>74 - 88</td>
<td>82 ± 3</td>
<td>4.1 - 6.9</td>
<td>5.4 ± 0.8</td>
<td>29</td>
</tr>
<tr>
<td>August</td>
<td>0.4 - 2.2</td>
<td>7.6 ± 2.4</td>
<td>74 - 89</td>
<td>79 ± 3</td>
<td>4.2 - 8.2</td>
<td>6.1 ± 0.9</td>
<td>25</td>
</tr>
</tbody>
</table>

1) Readings were taken at 17:49 pm.
2) As daily average from three observations, each conducted at 6:49 am, 1:49 pm and 5:49 pm.
3) Readings were taken at 6:49 am.

Before 1968, the area was rainfed and cultivated with cassava and agave. After the completion of Jatiluhur Dam Project in 1968, the area was converted into irrigated rice fields. From 1968 to 1989 the area was intensively cultivated with a cropping pattern of rice-rice-fallow, and since 1989 the cropping pattern has changed to rice-rice-fish culture.

Before land preparation, two rice soil samples were taken up to 20 cm depth using core sampler. Results of the soil analysis are shown in Appendix 2. It is shown that the clay, silt and sand content were 53.5%, 29.7% and 16.7% respectively. Based on this result, the texture of the rice soil can be categorized as clay. Soil drainage is bad, and the color of the soil is greenish grey (5 BG 5/1) which indicate most of the time the soil is under reduced condition.

According to Buresh et al. (1991), the soil type at the Research Institute is classified under subgroup as Aeric Tropaqualf. Based on the soil horizon characteristics (Figure 11), the soil is classified under alfisol order and under suborder as aqualf. Because the soil is saturated with water all the time and has chroma in all soil layers at less than 2, thus the moisture regime of the soil is classified as aquic. The difference of soil temperature between wet and dry season is less than 5 °C, and the annual average of soil temperature is above 22 °C. Based on
In this condition, the soil under the great group is classified as Tropaqualf and under sub-group as Aeric Tropaqualf.

Figure 13. Wetland rice field soil profile at Sukamandi Research Institute for Food Crops (Fagi and Las, 1988).

Materials and Equipment

Materials and equipment used in this study included:
- Gas chromatograph Gow-Mac Model 69-350 equipped with Flame Ionization Detector
- Hewlett-Packard integrator Model 3396-A
- Standard gas CH₄, 1770 ppbv
- Polyethylene chambers, height: 22 cm, 45 cm, 68 cm and 87.5 cm.
- Aluminum bases
- Rice varieties: IR-64 and Cisadane
- Plastic syringes: 10 ml and 30 ml
Methodology

Experimental Design

The experiment in this study consisted of two treatments (factors): The first factor was irrigation water management and the second factor was rice variety. The first factor consisted of three levels, as follows:

1. **Continuous flooding-flowing** ($W_1$). The treatments plots were flooded and flowed with irrigation water with a depth of about 5 cm throughout the growing period. This treatment was chosen based on the fact that the optimum water depth for wetland rice is 5 cm (Fagi and Sanusi, 1983) or between 5 - 7 cm (De Datta et al., 1973). According to Fagi (1986), irrigation water depth widely practiced by the farmers at Jatiluhur irrigation area, West Java, is between 3 - 7 cm.

2. **Intermittent Irrigation** ($W_2$). This treatment consisted of flooding the field with 5 cm water depth, and then allowing the water to evaporate naturally until soil water condition was above water holding capacity. After this condition was attained, the field was then irrigated again with 5 cm water depth. This procedure was repeated until two weeks prior to harvest.

3. **Saturated soil condition** ($W_3$). The rice field soils were kept in saturated condition (macak-macak) by irrigating the field with enough water to make rice soils wet. The soil water condition was maintained until two weeks prior to harvest. This treatment was chosen based on the fact that there was no significant difference in...
rice yield between continuous flooding and saturated soil conditions (Bangun et al., 1983; Abas and Abdulrachman, 1985; Budi, 1987; Fagi et al., 1990).

The second factor consisted of three levels i.e. unplanted \( (V_o) \), planted with short growing period rice variety \( (V_1) \) and long growing period rice variety \( (V_2) \). The short growing period rice variety, selected for this study, was IR-64 and for the long growing period it was the Cisadane variety. These rice varieties both have different physiological as well as agronomic characteristics; besides, both varieties are widely grown in major rice producing areas in Indonesia. The characteristics of these varieties are listed in Table 10.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IR-64</th>
<th>Cisadane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date released</td>
<td>17 July 1986</td>
<td>18 February 1980</td>
</tr>
<tr>
<td>Hybrid between IR5657 and IR2061</td>
<td>Cere (indica)</td>
<td>Pelita I-1/BZ388</td>
</tr>
<tr>
<td>Cultivating days</td>
<td>115 days</td>
<td>135 - 145 days</td>
</tr>
<tr>
<td>Plant height</td>
<td>85 cm</td>
<td>105 - 120 cm</td>
</tr>
<tr>
<td>Number of tillers</td>
<td>Plenty</td>
<td>15 - 20 tillers</td>
</tr>
<tr>
<td>Weight per 1000 grains</td>
<td>27 g</td>
<td>28 - 29 g</td>
</tr>
<tr>
<td>Productivity</td>
<td>± 5.0 ton/ha</td>
<td>4.5 - 5.5 ton/ha</td>
</tr>
<tr>
<td>Plant shape</td>
<td>Straight</td>
<td>Straight</td>
</tr>
<tr>
<td>Foot color</td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td>Auricle color</td>
<td>Colorless</td>
<td>Colorless</td>
</tr>
<tr>
<td>Leaf tongue color</td>
<td>Colorless</td>
<td>Colorless</td>
</tr>
<tr>
<td>Leaf color</td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td>Leaf surface</td>
<td>Coarse</td>
<td>Coarse</td>
</tr>
<tr>
<td>Leaf position</td>
<td>Straight</td>
<td>Straight</td>
</tr>
<tr>
<td>Grain color</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>Amylose content</td>
<td>24.1%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Source: Djunainah et al. (1993)

The study was conducted using split-plot experimental design in three blocks of a randomized complete block design (block as replicates). The first factor, irrigation water management \( (W) \) was assigned as main plots, and the second factor, rice variety treatment \( (V) \) was assigned as subplots. The size of each main plot was 3 x 12 m. Each main plot was divided into three subplots, each of 3 x 4 m of which one
A subplot was assigned for unplanted plot and the other two subplots were for planted plots. Each block was consisted of three main plots. The experimental field layout is shown in Figure 14.

**Figure 14.** Layout of randomization of the first factor (water management) over the main plots and randomization of the second factor over the subplots

<table>
<thead>
<tr>
<th>BLOCK I</th>
<th>BLOCK II</th>
<th>BLOCK III</th>
</tr>
</thead>
<tbody>
<tr>
<td>W₁</td>
<td>W₂</td>
<td>W₀</td>
</tr>
<tr>
<td>V₀</td>
<td>V₁</td>
<td>V₀</td>
</tr>
<tr>
<td>V₀</td>
<td>V₂</td>
<td>V₀</td>
</tr>
<tr>
<td>V₀</td>
<td>V₀</td>
<td>V₀</td>
</tr>
</tbody>
</table>

**Where:**
- **W**: Main plot of continuous flooding-flowing with 5 cm water depth
- **W₀**: Main plot of intermittent irrigation, flooded with 5 cm water depth and allowed the water to evaporate until saturated soil condition was attained, afterward the plot was reflooded.
- **W₁**: Main plot of saturated soil condition
- **V**: Unplanted subplot
- **V₀**: Subplot with IR-64 rice variety
- **V₁**: Subplot with Cisadane rice variety
- **Border dike between main plots, 0.5 m width**
- **Border between subplots within main plot without any dike, 0.4 m width.**

Each main plots and blocks was separated by dikes. The border dike was lined with plastic sheet to avoid water seepage and interferences between one treatment to the others (Figure 15).
Field Preparation and Agricultural Practices

Preparation of the experimental plots prior to transplanting that consisted of land clearing, ploughing, harrowing and puddling were conducted as usually implemented by the local farmers. The rice field before use for this experiment was cultivated with Ciliwung rice variety. The amount of plant residue from the previous season which consisted of plant roots, stubble and straw, returned into the experimental plot was estimated to be 7 - 8 ton/ha. All of this organic matter was homogeneously incorporated into the experimental rice soils.

First land preparation was carried out three weeks before transplanting which consisted of ploughing the field using buffalo. Second land preparation was carried out two weeks prior to transplanting which consisted of puddling and leveling the experimental field. Two 21-day-old rice seedlings were transplanted with a distance of 25x25 cm in rows and columns. Each planted subplots consisted of 12 columns and 16 rows. The rice seedlings were transplanted on April 7, 1993.

Starting from the first land preparation until 3 days after the first fertilizer application, the rice soils in all treatment plots were kept in saturated condition. The first fertilizer application was conducted at 4 days after transplanting (4 DAT).

Mode of fertilizer application was by direct broadcasting and weed control was conducted manually (hand weeding). Rice field fertilization was done immediately
After weeding, during the entire growing period, fertilizer application and weeding were conducted three times as follows (see Figure 16): (a) First fertilizer application was applied four days after transplanting (DAT) with 67 kg urea/ha, 100 kg KCl/ha and 100 kg phosphate fertilizer/ha. From 0 DAT to 8 DAT (or 3 days after fertilizer application), all of the experimental plots were kept in saturated condition. As for the continuous flooding and intermittent water management treatments, irrigation was started at 8 DAT. (b) Second fertilizer application was applied at 22 DAT with 67 kg urea/ha. Before fertilizer application all experimental plots were drained and after fertilizer application the rice field soils were kept in saturated condition for 3-4 days; irrigation was resumed for the continuous flooding and intermittent water management treatments. (c) Third fertilizer application was applied at 43 DAT with 116 kg urea/ha. Before fertilizer application all experimental plots were drained and after application the rice field soils were kept in saturated soil condition for 3-4 days; irrigation for continuous and intermittent flooding main plots was resumed. These procedures were followed to make fertilizer applications more effective. Besides, these procedures are usually practiced by the local farmers.

Two weeks before harvesting the experimental plots were drained permanently, i.e. for IR-64 plots at 11 weeks after transplanting (WAT) and for Cisadane plots at 14 WAT. IR-64 rice variety was harvested at 13 WAT and Cisadane rice variety at 16 WAT.

To avoid soil disturbance during methane flux measurements, boardwalks (wooden bridges) were constructed from border dikes across each main plot. To prevent rat attacks, plastic fence were constructed surrounding the experimental field.

In each sub plot one grooved aluminum base was installed immediately after rice seedlings had been transplanted. In the middle of each aluminum base there was only one rice plant. The aluminum bases were installed permanently during the cultivation period, so that the equilibrium of methane in soil was not disturbed at the time of gas sampling.
Land preparation I
3 weeks before transplanting

Fertilization

Urea 116 kg/ha

43 DAT

IR-64 plots drained

WAT: Week After Transplanting

Transplanting

IR-64 plots harvested

Cisadane plots harvested

Figure 16. Schematic diagram showing agricultural practices implemented during the experiment.
Figure 17. Schematic illustration of a subplot planted with rice, 25 x 25 cm distance in rows and columns. It shows the position of rice plant randomly chosen for methane flux measurement.

Methane Flux and Ambient Methane Concentration Sampling Techniques

There are several techniques to determine methane flux from wetland rice. Chamber techniques (static techniques) are simple and have been widely used by those
studying methane fluxes. In this study, polyethylene chambers were used to trap methane emitted from rice plants in planted plots and rice soils in unplanted plots.

Figure 18. Schematic illustration of boardwalk arrangement and irrigation water flow in each main plot.

- Border dike
- Boardwalk
- Permanent aluminum base
- Metering gauge
- Irrigation water flow
The static chamber techniques method has certain limitations as it will change the micro environment inside the chamber. Due to this fact, in this experiment the plant was covered for a short duration for up to a maximum of 12 minutes to minimize micro environment changes inside the chamber.

During flux measurement, the aluminum bases were reached via the boardwalks. Each flux measurement in this experiment was conducted by placing a rigid polyethylene chamber gently onto the groove of aluminum base. All observations during the experiment were conducted from the boardwalks so that not to cause unwanted release of methane and also to avoid disturbing the environment of growing rice plant. Covering the rice plant with chamber will increase the temperature inside the chamber; therefore, during flux measurement the temperature inside and outside the chamber was recorded.

Methane flux determinations were made by taking samples of the head space in an open bottom chamber of cross sectional area 28 x 28 cm and the height of 22 cm (chamber 1), 45 cm (chamber 2), 68 cm (chamber 3) and 87.5 cm (chamber 4) depending on the height of rice plants. During growing period, chamber 1 was used for one-week-old rice plant and under fallow condition i.e. from 14 to 17 WAT for IR-64 plots and 17 WAT for Cisadane plots, chamber 2 was used for two- to five-week-old rice plant, chamber 3 for six- to seven-week-old rice plant, and chamber 4 for eight- to thirteen-week-old rice plant for IR-64 variety and eight- to sixteen-week-old rice plant for Cisadane variety. The chambers were placed over the vegetation with the bottom edge of the chamber placed below the water surface (for continuous flooding and intermittent irrigation treatments) and fitted into the groove in the permanent aluminum bases. At each flux measurement in saturated soil condition treatments, the groove of aluminum bases was filled with water prior to placing the chamber into the groove. The water in the groove isolates the air inside the chamber from the outside atmosphere. The permanent bases also ensure that the chamber will not touch the soil.
The chamber was equipped with a circulating fan to ensure complete gas mixing inside the chamber. The fan was switched on for one minute before the air sample was taken. Samples of air within the chamber were taken with time intervals of 3, 6, 9, and 12 minutes using a 10-ml plastic syringes (the exact time between samples were recorded). To avoid gas leaks from the syringes, immediately after the sample had been taken, the puncture of the needle was sealed using rubber stopper. After 12 minutes of measurements, the chamber was removed and the rice plants was exposed to natural condition. The chamber arrangement and sampling system is illustrated in Figure 19.

Methane flux measurements in each treatment plot were conducted once a week from 1 WAT until few weeks after harvesting. IR-64 rice variety was harvested at 13 WAT and Cisadane rice variety at 16 WAT. Flux measurements for unplanted and planted plots were conducted until 17 WAT.
Methane flux measurements in this study were conducted three times a day i.e. at predawn, in the morning and in the afternoon. After the air had been drawn from the chamber, the samples were immediately analyzed for their methane concentration not more than 2 hours after sampling. The time intervals for taking and analyzing the samples for each block (9 treatment subplots or 45 air samples) were as follow:

a. At predawn. The samples were taken from 3'am to 5'am and were analyzed from 6'am to 9'am.

b. In the morning. The samples were taken from 7'am to 9'am and were analyzed from 10'am until 1'o'clock pm.

c. In the afternoon. The samples were taken from 1'o'clock pm to 3'o'clock pm and were analyzed from 4'o'clock pm to 7'o'clock pm.

Air samples for ambient methane concentration measurements were taken before drawing air samples from the chamber in each flux measurement using a 30-ml plastic syringes at 25-50 cm above the tip of rice plants.

Methane Concentration Determinations

During the experiment about 5508 air samples were analyzed for methane flux measurements and about 1377 ambient air samples were analyzed for ambient methane concentrations. Methane concentration was determined by a Gow-Mac Model 69-350 gas chromatograph equipped with a Flame Ionization Detector (FID). The gas sample was injected through a 2-ml sampling loop (see Figure 20) and separated on a Porapak N column (5 ft long x 1/8 inch OD diameter), with nitrogen as a carrier gas. The chromatographic operating conditions used for the air samples analysis are as follows:

- Column temperature : 40 °C.
- Detector temperature : 140 °C
- Carrier gas flow rate : 30 ml/minute
- Hydrogen gas flow rate : 25 ml/minute
- Compressed air flow rate : 250 - 300 ml/minute

The hydrogen and nitrogen gases utilized by the gas chromatograph were high purity (HP grade) gases, while compressed air was technical grade gas. All of the
Gases were purchased from PN Aneka Gas, a state-owned gas company. The hydrogen, nitrogen, and compressed air gases were individually controlled by a two-stage regulator with outlet pressures of 20 psi, 30 psi, and 30 psi, respectively.

Figure 20. Flow diagram of gas sampling valve (GSV) system.

The gas chromatograph had been well calibrated to measure methane with high precision at the Trace Gas Laboratory of Global Change Research Center (Oregon Graduate Institute, Oregon, USA). The signals of the gas chromatograph were linear for methane up to 500 ppmv. The gas chromatograph was calibrated once every 5-10 samples run using a standard of 1770 ppbv methane in air. The standard gas was supplied by the Trace Gas Laboratory of Global Change Research Center (Oregon Graduate Institute, Oregon, USA). Signal from the gas chromatograph was fed to the HP 3396A integrator and methane concentration was directly printed out based on peak area.

Under the gas chromatograph operating condition used for the analysis of air samples, it was found that the detection limit of the gas chromatograph was 9.5 ppbv. This detection limit for methane was obtained by injecting methane standard gas of 1770 ppbv through the 2-ml gas sampling loop into the column, the sample injection loop then loaded with carrier gas and injected into the column this procedure was
Repeated several times until there was no response signal from the gas chromatograph detected by the integrator. By repeating this procedure several times, the lowest signal that could be detected by the integrator was a methane concentration of 9.2 - 9.5 ppbv.

Recalibration data of the gas chromatograph showed that the deviation from standard gas in every 5 - 10 samples run was 1727 ppbv as the lowest and 1817 ppbv as the highest detected concentration. Complete data of standard gas readings and deviations from the actual value (1770 ppbv) in every 5 - 10 samples run are given in Appendix 3. From data (n = 343) in Appendix 3, it can be calculated that the reproducibility of all methane measurements during the study was 0.8% which was equivalent to 14.2 ppbv in the measurement of the standard. This error includes all possible drifts of the instrument.

There were two possibilities that can cause the drifts within short time period (maximum of one hour) before the instrument was recalibrated, namely due to the electrical instability and technical grade of the compressed air used for the flame ionization detector (FID). It was very difficult to get UHP (ultra high purity) grade gases in Indonesia especially UHP grade of hydrogen and compressed air. Because every two weeks the FID consumed one tank of 2000 psi compressed air, but to get UHP grade of compressed air needs 1 to 2 months from the time of purchase order submission.

Effects of Plastic Syringes on Methane Concentration

Glass syringes are generally used by many investigators to draw air samples in methane flux measurement from rice fields (Chen et al., 1993; Nouchi, 1992; Khalil et al., 1991; Seiler et al., 1984). Nowadays, glass syringes are rarely sold in the market. When available, the price is very high (US $ 5 - 7 per piece) and the readystocks are not more than 10 - 15 pieces. We needed more than 200 syringes in
this experiment; for this reason, in this study plastic syringes were used instead of glass syringes. The syringes, before being used to draw air samples in each sampling, were tested for their leakages by first sealing the puncture of the needle using rubber stoppers and then pushing and releasing the plunger; if the plunger did not return to zero mark, the syringe was leaking and discarded.

Until recently, no publications are available on the study about the trace gas concentrations in disposable plastic syringes compared to glass syringes, and the effects of plastic syringes on methane concentration if kept for several hours prior to analysis. In this study, a simple experiment had been conducted to determine the inertness of the plastic syringes if used to draw air samples.

Ten 10-ml syringes were filled with 1770 ppbv standard methane gas directly drawn from the canister through a rubber septum. The syringes were flushed several times with the standard gas before final sampling. The syringes were then incubated under room temperature (26 - 27°C) for 12 hours. This incubation time was chosen due to the fact that maximum time spent for taking and analyzing the air samples within each sampling time (45 air samples) was 5 - 6 hours, this implies that the maximum resident time of the air sample inside the plastic syringe is 6 hours. The gas inside the syringe was injected into the gas chromatographic column via gas sampling valve, this procedure was performed alternately, one time for the sample and one time for the standard. Table 11 gives the result for ten analyses of gas sample and their deviation from the standard.

Average methane concentration detected in plastic syringes which were incubated for 12 hours was 1769 ± 15 ppbv, the standard deviation obtained was in agreement with the reproducibility of the measurements as mentioned above which was about 0.8%. All of the variance at right hand column falls within the range of -28 to +20. The sum of the variances divided by ten yielded a value of +10 ppbv, which was within uncertainty of each measurement and thus indicated that the use of plastic syringes did not affect the methane concentration obtained.
Table 11. Measurement result of standard gas kept in disposable plastic syringes for 12 hours and directly injected into the column via gas sampling valve. Their variance from standard gas of 1770 ppbv are also shown.

<table>
<thead>
<tr>
<th>Syringe Number</th>
<th>Methane Concentration Detected (ppbv)</th>
<th>Variance from Standard Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1756</td>
<td></td>
<td>- 14</td>
</tr>
<tr>
<td>1785</td>
<td></td>
<td>+ 15</td>
</tr>
<tr>
<td>1742</td>
<td></td>
<td>- 28</td>
</tr>
<tr>
<td>1758</td>
<td></td>
<td>- 12</td>
</tr>
<tr>
<td>1766</td>
<td></td>
<td>- 4</td>
</tr>
<tr>
<td>1790</td>
<td></td>
<td>+ 20</td>
</tr>
<tr>
<td>1765</td>
<td></td>
<td>- 5</td>
</tr>
<tr>
<td>1786</td>
<td></td>
<td>+ 16</td>
</tr>
<tr>
<td>1774</td>
<td></td>
<td>+ 4</td>
</tr>
<tr>
<td>1768</td>
<td></td>
<td>- 2</td>
</tr>
</tbody>
</table>

**Methane Flux Calculation**

Methane flux is determined from the area covered by the chamber and the rate (δc/δt) of the concentration change in a set of four samples taken over a 12-minutes sampling period. The slope (the increase rate of methane), is estimated by linear regression:
The slope (\( \delta c/\delta t \)) is related to the flux (\( \phi \)) by the following equation (Khalil et al., 1991):

\[
\phi = \Gamma \frac{M V}{N_o A} \frac{\delta c}{\delta t}
\]

- \( M \) = Molecular weight of methane (g/mole)
- \( N_o \) = Avogadro number (molecule/mole)
- \( \Gamma \) = Density of air (molecules/cm³)
- \( A \) = Surface area covered by the chamber (cm²)
- \( V \) = Effective volume of the chamber after being corrected for the changing of the standing water in the rice field (cm³)
- \( \delta c/\delta t \) = Rate of increase of methane concentration inside the chamber (ppbvl/min)

Air density (\( \Gamma \)) inside the chamber is corrected with the average air temperature over 12-minute sampling period:

\[
\Gamma = 0.34848 \frac{P}{(273 + T)}
\]

- \( P \) = Density of air in g/cm³
- \( T \) = Pressure, 1013.25 milibars
- \( T \) = Average temperature inside the chamber in °C

\[
\phi = \Gamma \frac{M H}{N_o} \delta c/\delta t \times 10^{-6} \text{ mg/cm}^2/\text{min}
\]

\[
\phi = \Gamma \frac{M H}{N_o} \delta c/\delta t \times 0.6 \text{ mg/m}^2/\text{h}
\]

Where \( H \) is the height of the chamber. Height of the chamber is corrected for the changing depth of the standing water in the rice field, where height of the standing water in each main plot was recorded every day.

Environmental and Agronomic Variable Measurements

Beside methane flux measurements, variables affecting the formation and emission of methane from rice fields were also collected. The environmental parameters...
that affect the formation of methane in rice soils are soil temperature, redox potential (Eh) and pH. These parameters were measured weekly during methane flux measurement in each treatment plot.

Soil temperature was measured weekly using thermocouple thermometer at 5, 15 and 25 cm below soil surface, at the same time irrigation water temperature was also measured. Soil Eh was measured weekly only in each main plot (water management treatment) using Eh-meter equipped with a platinum-tipped electrode. Soil Eh measurement was conducted by dipping the electrode into the soil up to 5 cm depth allowing the electrode to stabilize for 2-3 hours before recording the Eh value.

pH was measured at 5 cm depth using pH meter equipped with combination electrode. Soil pH was measured weekly in each treatment plots immediately after measurement had been completed.

To measure the Eh kinetic of the flooded rice soils used in this research, a simple laboratory experiment was conducted. About 3 kg of dry rice soil was taken randomly from the rice field and was put into a 5-liter plastic container, the soil was flooded with tap water with standing water height of about 5 cm. The changes of Eh in this submerged soil was observed daily for about 30 days.

Weeds in each experimental plot were controlled manually (by hand weeding) three times during the growing period. Weeding was conducted prior to fertilizer application. The weeds were reached via the boardwalks and pulled out by hand so that not to cause great disturbance to experimental plots. Weed types and weed biomass from each subplots were also recorded. Samples of weed biomass were dried up to constant weight at 70 °C.

During the experiment from April until August 1993, ambient air temperature and light intensity were measured hourly every day. Air temperature was measured using maximum-minimum thermometer and light intensity using photometer Li-Cor Model 185B. Wind speed was observed three times per day i.e. at predawn, in the
morning and in the afternoon. Time extent of wind speed observation was equal to time spent for taking air samples per block (9 subplots).

Irrigation ditch, inlet L-Shaped pipe

Figure 21. Cross section illustration of the experimental rice field and L-shaped plastic pipe used to adjust flood water level.

Irrigation water in each treatment plot was carefully controlled using a L-shaped plastic pipe of 1 inch diameter (see Figure 21). The water depth for continuous flooding treatments was maintained at about 5 cm by adjusting the inlet or outlet of the irrigation water.

The flood water levels in continuous flooding and intermittent irrigation treatment plots were observed daily using a specially designed metering gauge as shown in Figure 22. Two metering gauges were installed in each experimental plots, one near water inlet and the other near water outlet.

Figure 22. Cross section of metering gauge used to measure flood water level.
Plant growth parameters which include tillers number per plant and plant height were recorded weekly from 1 WAT until harvest. These parameters were measured on randomly chosen non-fringe rice plants in each planted plots. Rice yield, number of productive tillers, number of filled and empty grains per panicle, total number of grains per panicle and weight of 1000 grains from each experimental plot measured after the plants had been harvested.

Secondary Data Collection

To estimate the total methane emission from wetland rice in Indonesia, secondary data on wetland rice were collected mainly from Indonesian Central Bureau of Statistics; Directorate General of Food Crops, Ministry of Agriculture; and World Rice Statistics published by IRRI. The collected data mainly consist of: (a) total wetland rice areas and area harvested in each province in Indonesia, (b) rice yield and total wetland rice production and (c) fertilizer consumption.

Data Analysis

Data on methane flux, ambient methane concentration, rice yield, weight per 1000 grains, productive tillers per plant, total grain per panicle, number of empty and filled grain per panicle, and dry weight of weed biomass from each treatment (water management and rice variety) were analyzed using split plot design. The mathematical model for any observation is as follows (Steel and Torrie, 1960):

$$X_{ijk} = \mu + \Gamma_i + \alpha_j + \delta_{ij} + \beta_k + (\alpha\beta)_{jk} + e_{ijk}$$

Where $X_{ijk}$ represents the observation in the $i$th block, on the $j$th main plot and the $k$th subplot. Where $i = 1,2,3$ blocks; $j = 1,2,3$ main plot treatments; $k = 1,2,3$ subplot treatments; $\mu$ is the general mean of the observations, $\Gamma_i$ is block random component, $\alpha_j$ is main plot random component, $\beta_k$ is subplot random component, $\delta_{ij}$ is interaction
between block and mainplot random component, \((a_\beta)_{jk}\) is interaction between block and subplot random component, and \(e_{ijk}\) is observation error.

Data from each treatment were subjected to analysis of variance and Duncan's multiple range test procedures using the Statistical Analysis System Software (SAS, 1987). Beside weekly data analysis, data of methane flux during the whole growing period were divided into four clusters. Data grouping were based on the agricultural practices applied in this research (see Figure 23).

### A. IR-64 Rice Variety Subplots

**Seasonal**

1-3 WAT

4-6 WAT

7 WAT-Drained

4 5 6 7 8 9 10 11 12 13 14 15 16 17

Week after Transplanting (WAT)

### B. Cisadane Rice Variety and Unplanted Subplots

**Seasonal**

1-3 WAT

4-6 WAT

7 WAT-Drained

4 5 6 7 8 9 10 11 12 13 14 15 16 17

Week after Transplanting (WAT)

Figure 23. Schematic illustration of methane flux data grouping during the growing period: (A) for IR-64 rice variety subplots, (B) for Cisadane rice variety and unplanted subplots.
Cluster I (1-3WAT): From transplanting until before second fertilizer application, i.e., group of methane flux data from 1 WAT until 3 WAT.

Cluster II (4-6WAT): After second fertilizer application until before third fertilizer application, i.e., group of methane flux data from 4 WAT until 6 WAT.

Cluster III (7WAT-Drained): After third fertilizer application until permanent drainage, i.e., group of data from 7 WAT until 11 WAT for IR-64 plots and 7 WAT until 14 WAT for Cisadane and unplanted plots.

Cluster IV (Seasonal): Seasonal methane flux, from transplanting until harvest, i.e., group of data from 1 WAT until 13 WAT for IR-64 plots, and 1 WAT until 16 WAT for Cisadane and unplanted plots.

Mean seasonal methane flux from each treatment of planted plots ($W_0V_1, W_0V_2, W_1V_1, W_1V_2, W_2V_1$ and $W_2V_2$) and secondary data concerning harvested area of wetland rice per year were used to estimate total methane emission from wetland rice in Indonesia, using a formula (Khalil et al., 1993b):

\[
F = \phi_m \cdot R_e \\
R_e = T_s \cdot A
\]

Where:
- $F$ = Average methane emission rate (g/m²/d)
- $\phi_m$ = Regional extrapolant (m²-days/yr)
- $R_e$ = Harvested area of wetland rice (m²)
- $T_s$ = Period of wetland rice cultivated (days/yr)