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Methane emission on intensive rice farming with water frequency and fertilizer management in North Sumatera

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Abstract: Rice cultivation during four planting seasons by using cultivation system improvements, especially in the management provision of water and fertilizer, other than increasing rice production can also reduce methane emission which is often rumored as a cause of global warming. Efforts to reduce methane emission from paddy fields must be done because of the impact of ecological damage caused by climate change due to global warming. It is estimated that by the year 2100 the average surface temperature of the earth will increase up 2 to 3° C. The experiment was conducted in the village of Purbaganda, Pematang Bandar District, Simalungun over four planting seasons from July 2011 until June 2012. The research design used in the study was split plot design which was organized into groups based on the difficulty of obtaining an ideal environmental uniformity in the field. Watering System treatment as main plot factor (A) and fertilization as subplot factor (B), with three replications. The treatments in the main plot were intermittent and continuous irrigation system, conducted to determine the amount of methane emissions in each planting season. For subplot, the fertilization treatments were based on laboratory analysis of soil, and Fertilization Recommendation of the Minister of Agriculture regulation No. 40 OT.140/2007. These were then combined with probiotic fertilization. The results showed that the pattern of methane emission varies in each treatment. The average methane emission was highest in treatment A1B1 with 338.50 kg ha^{-1} per season, and lowest in A2B6 treatment with 63.25 kg ha^{-1} per season. A2B6 treatment that used fertilization according to laboratory analysis with probiotic fertilization experienced intermittent irrigation process. The higher dosage of fertilizer N in treatment A1B1 led to higher methane emission than treatment A2B6. N fertilizer in rice fields can increase methane emissions due to increased rice growth, which was the source of methane biomass that increased the emission lines. Interaction between flooding and fertilization treatments that gave the highest emission during the four planting seasons was A1B1 and the lowest was A2B6. Comparison between the interaction of A1B1 and A2B6 on methane emission results was significantly different (DMRT test, $P = 0.05$).

Keywords: Methane Emission, Intensive Rice Cultivation, Intermittent and Fertilization

1. Introduction

According to Intergovernmental Panel on Climate Change [10], sources of greenhouse gases (GHGs) from agricultural activities are grouped as follows: 1) enteric fermentation; 2) livestock waste management; 3) agricultural burning; 4) burning pastures; 5) agricultural lime usage; 6) urea usage; 7) direct and indirect emissions of N_2O from the soil; 8) indirect N_2O emissions from livestock waste; and 9) irrigated land. Enteric fermentation process emitted methane while the management of livestock waste produced emissions of methane and N_2O.

The sources of N_2O emissions from agricultural land were from N fertilizer, crop residue management, organic materials, and land conversion that led to mineralization of soil organic matter [27]. CO_2 emissions came from liming and urea fertilizing, while non-CO_2 emissions came from burnt crop residues such as straw (rice, corn, sugarcane) and from the burning process done at the time of conversion. Irrigation emitted methane due to anaerobic process that occurred in decomposition of organic matter in waterlogged rice soils and released into the atmosphere by plants [5] [30]. Methane gas volume from wetlands were affected by the planting season, type of irrigation, organic and non-organic fertilizers, soil type, temperature, and varieties [12].

Climate change is the most serious challenge facing the world today. Global warming caused by greenhouse gases (GHG) such as carbon dioxide (CO_2), methane, and nitrous oxide (N_2O) was often associated with agriculture. Wetlands are a significant source of methane due to the waterlogged soil condition that facilitated the formation of methane. The considerable size of agricultural areas, especially in developing countries, was identified as one of the major sources and contributors to the increase in atmospheric methane concentrations [24]; [11]. On a national scale, contribution of GHG emissions to the total paddy soil are still quite high. Therefore, efforts to reduce methane emissions from paddy soil must still be done. Mitigation measures chosen should not sacrifice aspects of production and is local-specific. In addition, mitigation efforts priority need to be directed to wetlands ecosystem that have a high potential for methane emissions, which is on irrigated land. Wetland rice fields are an important source of methane, a potent greenhouse gas [24] [11]. The first field measurements were done in California [4]; [28], followed by extensive studies in Spain [17] and Italy [7] ; [14].

Methane emission from agricultural land was estimated at 100 Tg year^{-1} [25]; [18]. Indonesia that has 6.8% of the world's agricultural area allegedly contributed as much methane emissions as 3.4 to 4.5 Tg year^{-1} Tg (1 Tg = 10^{12} g). Based on this data, wetlands are not a main contributor to the increase in global methane emissions.

Increased cropping index (ICI) is a more practical and realistic step in increasing acreage and harvest towards a sustainable rice production because it does not require a relatively large cost and can increase farmers' income, regardless of various problems related to changes in environmental quality such as the quality of soil, water, GHG especially methane and the development of pests and diseases in rice. Research on patterns of change in environmental quality to an increase in central rice production was due to the change to 400 Rice Farming Index (Rice Cropping Index -400) cropping intensity to support sustainable rice production.

Increased intensity of cropping to increase rice productivity conducted by Rice Integrated Crop Management approach (ICM) is an alternative to intensive management of rice on irrigated land. ICM components include integrated pest management, integrated nutrient, water, and weed treatment which have been proven to increase yield rice to 1 t ha^{-1}. In Tamil Nadu, India, ICM implemented in 2002-2004 planting season increased yields by 1.5 t ha^{-1} [2]. Results of upland rice cultivation with ICM approach reached 4.3 t ha^{-}[22]. In Pinrang, South Sulawesi, agricultural intensification with ICM increased farmers' income by IDR 1,066,504 ha^{-1}, or 20.7% higher than that without ICM [1]. If ICM could suppress GHG emissions, this system would be an ideal rice crop management because in addition to saving agricultural inputs and increasing grain yield and farmers' income, it also reduces GHG emissions so the system becomes a sustainable and environmentally-friendly approach to rice cultivation. Wetland area, which has been rated as one emitter of greenhouse gases, will raise some arguments on its feasibility as sustainable wetland management.

This too will have an impact on the decline of paddy system benefits. Therefore, it is necessary for an in-depth study of GHG emissions from this wetland system, especially methane emissions during four planting seasons on main plots that used different irrigation treatments (continuous and intermittent irrigation). The subplot treatment used fertilization with varied levels. This study aims to analyze the level of methane emission and determine how much GHG emission of methane on technical irrigated wetland during the four seasons.

2. Materials and Methods

The research was conducted in July 2011 to July 2012 in the village of Purbaganda, District Bandar Simalungun Causeway which lies at $03^0$05'03" and $99^0$13'45.9" with climate type D1 according to Oldeman and ZOM 7 classification, with average rainfall at 1785 mm/year. The experimental design used in the study was split plot design which was organized into groups. This grouping is based on the difficulty of obtaining ideal environmental uniformity in the field. Watering System treatment as main plot factor (A) and fertilization as subplot factor (B with three replications. Treatment of irrigation systems was intermittent and continuous irrigation system (*continuous flooding*) in the main plots, conducted to determine the amount of methane emission in each planting season. Subplot treatment (fertilization treatment) was based on laboratory analysis of soil, and Fertilization Recommendation of the Minister of Agriculture regulation No. 40 OT.140/2007. These were then combined with probiotic fertilization. The treatments carried out were as follows:

1. Main Plot (A) with two Irrigation Systems:
    1.1. A1 = Irrigation Continuous Flow (*continuous flooding*),

   1.2. A2 = Intermittent (*control flooding*),
2. Sub Plot (B) with eight fertilization systems:
   2.1. B1 = Recommended Fertilization, Minister of Agriculture regulation No. 40 OT.140/2007,
   2.2. B2 = Recommendation Fertilization with Laboratory analysis,
   2.3. B3 = Regulation of 40 (100% dose) + probiotics,
   2.4. B4 = Regulation of 40 (70% dose) + probiotics,
   2.5. B5 = Agriculture minister rules 40 (40% dose) + probiotics,
   2.6. B6 = Laboratory analysis (100% dose) + probiotics,
   2.7. B7 = Laboratories Analysis (70% dose) + probiotics and
   2.8. B8 = Laboratory analysis (40% dose) + probiotics.

As many as 16 treatments were repeated with 3 replications in order to obtain 48 experimental plots. Linear equations of the experimental design was in accord with Gomez and Gomez (1994). Observation data was collected from plant height and productive tillers, plant biomass, soil pH and methane emission in the field which was measured by using a 50 cm x 50 cm x 103 cm flexiglass box. Gas sampling was conducted at 06.00 am using a 5 ml syringe from *polypropilen* with extraction interval of 6 minutes. To obtain the linearity of methane concentration increase in one unit of time, four extractions were carried out in each gas sampling at minute 6, 12, 18, and 24. In one growing season, gas samples were extracted 3 times per phase.

Phase 1 was done at 1 month days after planting (dap), phase 2 at 2 months, and phase 3 at 3 months dap. This sampling was continued throughout the four planting seasons. Methane concentration in each unit of time was measured using gas chromatography equipped with flame ionization detector with a column using N porapak. Injector temperature was 110^{0}C and column temperature was 92^{0}C. Flux (F) of methane emitted from an area of rice soil was calculated using the equation adopted from [8] as follows.

Formula:

$$F = \frac{dc}{dt} \times \frac{Vch}{Ach} \times \frac{mW}{mV} \times \frac{273{,}2}{(273{,}2 + T)}$$

Where:

F: flux of methane (mg/m^2/day)

dc/dt: differences in the concentration of methane per time (ppm/minute)

Vch: volume box (m^3)

Ach: area of box (m^2)

mW: wide box methane (g)

mV: constant volume of methane (22,411)

T: average temperature during sampling (^{o}C)

Value of 273.2: Kelvin temperature constant.

Data of methane emissions and plant parameters were analyzed using ANOVA (analysis of variance), and Duncan's Multiple Range Test (DMRT) was used to see the significant differences between treatments. The software used for statistical test was Statistical Analysis System (SAS) version 9,0. Correlation analysis was performed to examine the relationship between plant parameters with methane emissions and was done with Microsoft Excel 2007.

3. Results and Discussion

3.1. Methane Emissions

Methane emission patterns vary in each treatment as shown in Figure 1. The highest average value of methane emissions occurred in A1B1 treatment in the amount of 349 kg ha-^{1} per planting season. The lowest occurred in A2B6 with 58.33 kg ha-^{1} per planting season. A1B1 treatment was in accord with Fertilizer Recommendation by Minister of Agriculture regulation No. 40 of 2007 (112.5 N + 27 P2O5 + 30 K2O) with continuous flooding process that led to the creation of anaerobic conditions that are very suitable for methanogenic bacteria which produced methane.

In A2B6 treatment that used fertilization according to laboratory analysis (100% dose = 90 N + 40.8 + 22.3 P2O5 K2O) with probiotic fertilization, an intermittent irrigation process occurred. A1B1 used a higher dose of N than A2B6 that led to a higher methane emission than A2B6. N fertilizer in wetlands can increase methane emission due to increased rice growth as the source of methane in the form of biomass that increased the emission lines [3].

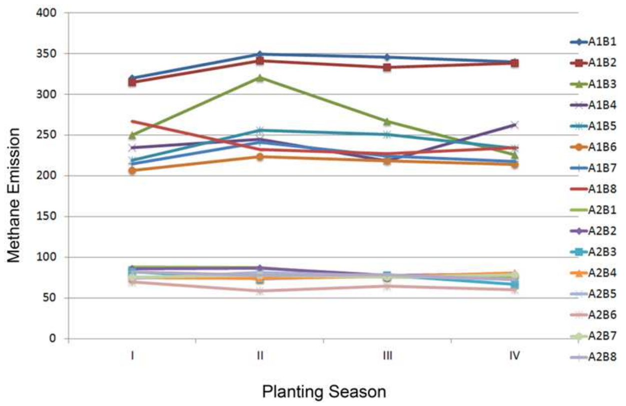

Figure 1. *Methane emissions for four planting seasons*

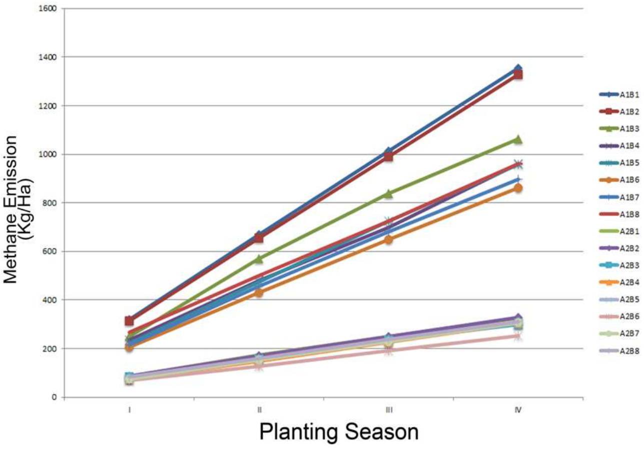

Figure 2. *Cumulative methane for four planting seasons*

Methane emission patterns during four planting seasons showed the tendency of increased methane emission due to increased intensity of cultivation with continuous flooding. However, in intermittent irrigation, emissions tended to be constant. Figure 2 shows the cumulative increase in methane emissions during the four seasons. The highest cumulative increase in methane emission in each planting season occurred in treatment A1B1 with average emissions of 338.5 kg ha-^{1} per season. The lowest was in treatment A2B6 (intermittent and fertilization by laboratory analysis as well as the addition of probiotic fertilizer).

Total methane emission during four planting seasons in one year is presented in Figure 3. Cumulatively, over the four planting seasons, the highest total emission was 1354 kg ha-^{1} found in treatment A1B1, while the lowest was 253 kg ha-^{1} in treatment A2B6. This result is consistent with the results by [29] which suggested that the soil condition with continuous flooding emits relatively higher emission than muddy and intermittent irrigation.

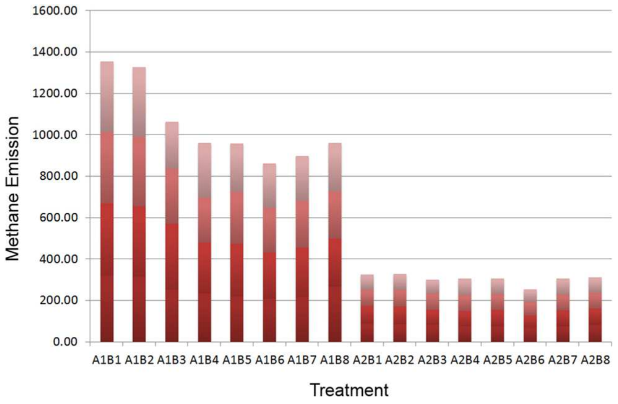

Figure 3. *Total methane emissions in each treatment during four planting seasons*

In A2B6 treatment that used fertilization according to laboratory analysis with probiotic fertilization, an intermittent irrigation process occurred. This is consistent with studies that showed intermittent treatment produced lower emission than continuous flooding. Drying created aerobic condition in the soil and methanotroph bacteria that oxidized methane into CO_2, therefore, lots of methane were oxidized before being released into the atmosphere [29]. Furthermore, [21] proposed that of all the methane produced in the soil only 16.6% were emitted and the rest was oxidized.

The low emission from intermittent irrigation was caused by the increase in soil oxidation-reduction value. Therefore, indirect reductive decomposition did not occur. Intermittent treatment was intended to regulate land condition to become dry and waterlogged consecutively. In addition to saving water, intermittent irrigation can give roots a chance to receive air, allowing it to grow deeper. Intermittent irrigation provides benefits to agricultural land such as preventing iron, preventing accumulation of H_2S which can impede root development, activate beneficial microbes, reduces collapse rate, reduces the number of unproductive tillers, harmonize ripening of grain, accelerates harvest time and eases the immersion of fertilizer in the soil. According to [20], the total emissions of methane with various rice crop management are very different, namely: total methane emissions in inundated non-ICM was 289.93 kg/ha/season; non-ICM with intermittent irrigation was 57.87 kg/ha/ season; ICM with intermittent irrigation was 78.33 kg/ha/season; and ICM with continuous flooding was 347.03 kg / ha / season.

Table 1. *The value of F towards methane emissions over four planting seasons*

Treatment	Planting season I		Planting season II		Planting season III		Planting season IV	
A	2374.64	**	418.29	**	2320.66	**	1651.66	**
B	8.00	**	13.61	**	13.20	**	25.00	**
AxB	4.64	**	8.67	**	11.95	**	19.15	**

** = significantly different at 1% level;
A = flooding system; B = fertilization; AxB = interaction between the fertilization and flooding factors

Based on the F value in Table 1, it can be seen that treatment flooding system (A), fertilization (B) as well as the interaction between irrigation and fertilization treatments (AxB) on methane emission results were significantly different at 1% level. This suggests that the different flooding treatments (A1 and A2) had a significant effect on the results of methane emissions. Similarly, the different fertilizer treatments (B1, B2, B3, B4, B5, B6, B7 and B8) and the interaction of flooding and fertilization treatments (A1B1, A1B2, A1B3, A1B4, A1B5, A1B6, A1B7, A1B8, A2B1, a2b2, A2B3, A2B4, A2B5, A2B6, A2B7, and A1B8) also affected the results of methane emissions significantly.

From the interaction between flooding and fertilization treatments (AxB), it can be seen that the highest emission during the four planting seasons was in A1B1 and the lowest was in A2B6. Comparison between A1B1 and A2B6 interaction on methane emission results was significantly different. To see the influence of fertilization and irrigation on methane emissions during four planting seasons can be seen in Table 2.

Table 2. *Effect of Fertilization and Irrigation on methane emissions during four planting seasons*

Treatment	PSI		PS II		PS III		PS IV	
A1B1	320.00	a	349.00	a	345.67	a	339.33	a
A1B2	314.67	a	341.33	a	333.00	a	338.00	a
A1B3	250.00	bc	320.67	a	266.67	b	225.33	c
A1B4	234.67	bcd	244.67	b	218.33	c	262.33	b
A1B5	219.00	cd	256.00	b	250.33	c	233.67	c
A1B6	206.33	d	223.33	b	218.00	c	214.00	c
A1B7	214.67	cd	241.00	b	224.00	c	217.67	c
A1B8	266.67	b	232.33	b	226.67	c	234.33	c
A2B1	87.67	e	87.33	c	75.33	d	75.00	d
A2B2	85.67	e	86.33	c	77.67	d	79.00	d
A2B3	82.33	e	73.33	c	78.00	d	66.33	d
A2B4	74.67	e	74.33	c	76.00	d	80.67	d
A2B5	74.00	e	81.33	c	77.00	d	72.33	d
A2B6	69.67	e	58.33	c	64.67	d	60.33	d
A2B7	75.33	e	77.33	c	75.67	d	78.33	d
A2B8	82.00	e	77.33	c	78.67	d	72.33	d

Equal numbers followed by the same letter are not significantly different at P = 0.05 DMRT

According to Table 2 it can be seen that the effect of fertilization on continuous flooding treatment (A1) were significantly different for methane emissions, while intermittent irrigation treatment (A2) for four planting seasons did not significantly affect methane emissions.

In the first planting season, fertilizer treatment B1 gave the highest methane emissions (320.00 kg ha-1) followed by fertilization B2 (314.67 kg ha-1). Statistically, the total methane emission from B1 and B2 was not significantly different (DMRT; P = 0.05), but significantly different to other fertilizers, i.e. B3, B4, B5, B6, B7 and B8.

In the second planting season, fertilizer treatment B1 also gave the highest methane emissions (349.00 kg ha-1) followed by B2 and B3. The total emission from all three was not significantly different, but significantly was to other fertilizers, i.e. B4, B5, B6, B7 and B8.

In the third planting season, fertilizer treatment B1 again gave the highest methane emissions (345.00 kg ha-1) followed by B2 (333.00 kg ha-1). While both treatments showed nearly equal methane emissions, they were significantly different compared to B3, B4, B5, B6, B7 and B8.

The fourth planting season was the same as the previous one, with fertilizer treatment B1 emitting the highest methane (339.33 kg ha-1) followed by fertilization B2 (338.00 kg ha-1). The total was almost equal, but significantly different with B3, B4, B5, B6, B7 and B8.

In general, during the four cropping seasons, i.e. A1B1 treatment with continuous flooding that followed the Fertilization Recommendation by Minister of Agriculture regulation No. 40 of 2007 showed the highest methane emissions, while the lowest was in intermittent water treatment A2B6 with fertilization laboratory analysis (100% dose) and probiotic fertilizer. The effect of fertilization on methane emissions during the four planting seasons can be seen in Table 3 below.

Table 3. *Effect of fertilization on methane emissions during the four planting seasons*

Fertilizing	PS I		PS II		PGS III		GS IV	
B1	203.83	a	218.17	A	210.50	a	207.17	a
B2	200.17	a	213.83	A	205.33	a	208.50	a
B3	166.17	bc	197.00	A	172.33	b	145.83	c
B4	154.67	bc	159.50	Bc	147.17	c	171.50	b
B5	146.50	c	168.67	b	163.67	bc	153.00	c
B6	138.00	c	140.83	C	141.33	c	137.17	c
B7	145.00	c	159.17	Bc	149.83	bc	148.00	c
B8	174.33	b	154.83	Bc	152.67	bc	153.33	c

Equal numbers followed by the same letter are not significantly different at P = 0.05 DMRT

The effect of fertilizer treatment on methane emission during the four planting seasons showed that B1 fertilization that followed the Fertilization Recommendation by Minister of Agriculture (112.5 N + 27 P2O5 + 30 K2O) generally produced the highest methane emissions. The lowest emission produced was in B6 that utilized laboratory analysis (100% dose N = 90 + 22.3 + 40.8 P2O5 K2O) fertilizer with probiotics. Based on the DMRT for the four planting seasons, the methane emission from B1 was significantly higher than B6. This indicated that fertilization affected the activity of methanogenic/methanotroph bacteria in forming methane emissions.

3.2. Correlation of Maximum Number of Tillers with Methane Emission

Correlation of the results of the methane component can be seen in Table 4 below.

Table 4. *Correlation of the Component of Methane Emissions*

Yield Component	Methane Emissions	
	A1	A2
Productive tillers	0.4236	-0.2522
Maximum number of tillers	0.2966	-0.3863

Correlation with the total number of productive tillers with total methane emission showed a positive correlation (r = 0.4236) in the flooding, while intermittent treatment showed a negative correlation (r = -0.2522). The same applies in the relationship that showed the maximum number of tillers. In flooding, the correlation was positive (r = 0.2966), while in intermittent treatment it was negative (r = -0.3863). These mean that an increase in the number of productive tillers or maximum number of tillers would increase the total methane emission by flooding. This is in line with observations by [26] which showed that the number of tillers can increase the density and number of aerenchyma vessels, increasing the transport capacity of methane. According to [23], the more root exudates formed, the higher the methane emission will be.

In contrast, in intermittent treatment, an increase in the number of productive tillers or maximum number of tillers will not increase the total methane emissions. According to [21], intensification by using flooded system (anaerobic) will hamper the biological properties of the soil in addition to increasing greenhouse gas emissions and inhibit the development of rice plants root system. Biological diversity is very limited under anaerobic conditions. Aerobic soil biota can not develop and it is estimated that only 25% of rice plant roots were well-developed. Cropping system with aerobic (moist) root system production was at least 3-4 times greater compared to flooded system. Optimal development of the root system, supported by biodiversity in the soil can increase rice yield potential.

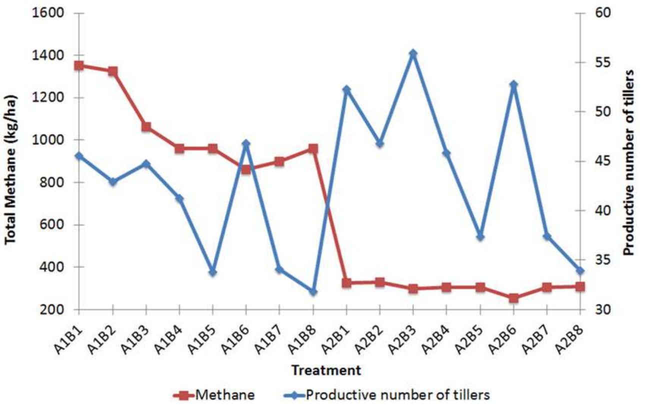

Figure 4. *Maximum Number of tillers in correlation with Total Methane Emissions*

Figure 4 shows the relationship between the maximum number of tillers with the total amount of methane. The increase in the number of tillers did not increase the total methane emission, depending on the treatment. This can be seen in treatment A1B6, A2B1, A2B3 and A2B6. Treatment A1B6 and A2B6 are B6 fertilization treatments at the same dosage (90 N + 22.3 + 40.8 P2O5 K2O) with probiotic fertilizer. Therefore, it can be concluded that B6 fertilization produced the lowest total methane emissions with continuous or intermittent flooding. The maximum number of tillers during four planting seasons in one year was the highest in treatment A2B3 in the amount of 105 tillers, followed by A2B6 with 104 tillers. However, for total emission, A2B6 produced the lowest methane emissions at 253 kg ha-^{1}, while A2B3 produced 300 kg ha-^{1} methane emissions.

Based on the previous explanation that the lowest methane emissions was from treatment A2B6, it is necessary to see its correlation with the maximum number of tillers with the total methane produced in treatment A2B6 (Figure 5).

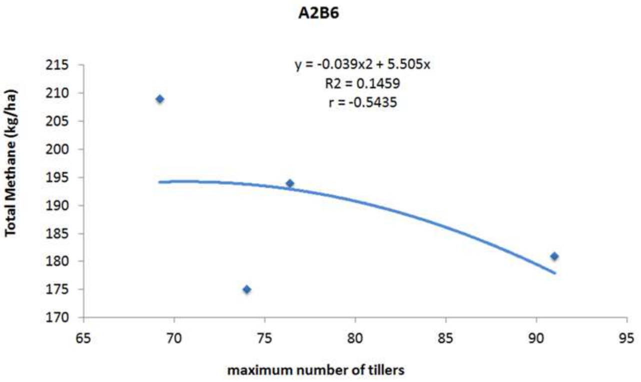

Figure 5. *Maximum Number of Tillers in correlation with Total Methane treatment A2B6*

From Figure 5, it can be seen that the correlation between the maximum number of tillers with the total emission was a strong negative correlation (r = -0.5435). The functional relationship between the maximum number of tillers with the total methane was R2 = 0.1459. This indicates that the maximum number of tillers affects the outcome of methane emissions. In A2B6 treatment, if the number of productive tillers increased, the emission actually declined.

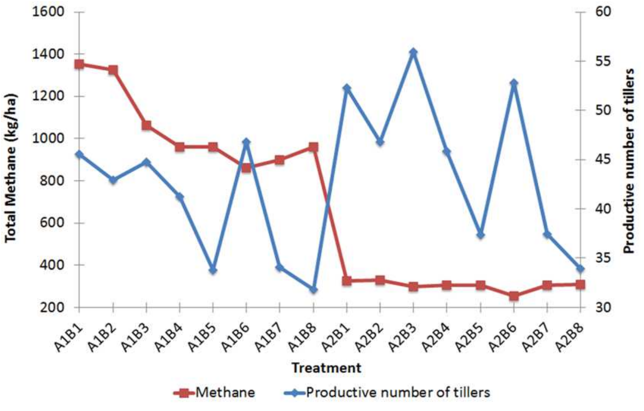

Figure 6. *The number of productive tillers with Total Methane Emissions*

From Figure 6 can be seen the correlation between the maximum number of tillers with the total emission in each treatment. The graph shows that the increase in the total or number of productive tillers did not increase the total methane emission, depending on the treatment. The highest number of productive tillers during four planting seasons in a year was in treatment A2B3 with 56 tillers followed by A2B6 with 53 tillers.

3.3. Correlation of Productive Number of Tillers with Methane Emission

Based on the previous explanation that the lowest methane emissions was from treatment A2B6, it is necessary to see its correlation with the number of productive tillers with the total methane produced in treatment A2B6 (Figure 7).

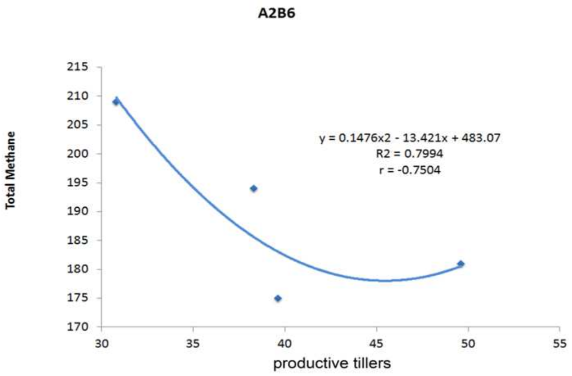

Figure 7. *Total Productive Tillers relationship with Total Methane treatment A2B6*

From Figure 7, it can be seen that the correlation between the total number of productive tillers with the total e mission was a strong negative correlation (r = -0.7504). The functional relationship was R2 = 0.7994, greater than the maximum number of tillers with R2 = 0.1459. This indicates that the maximum number of tillers affects the outcome of methane emissions.

4. Conclusions and Recommendations

Intensive rice cultivation by increasing cropping intensity does not degrade the quality of soil and water quality and methane emission can be reduced by up to 66.05% with ICM approach. Methane emissions during planting season with four treatments showed that A1B1 with continuous flooding that followed the Minister of Agriculture regulation on Fertilization Recommendation No. 40 of 2007 produced the highest methane emissions. The lowest emission was in A2B6 with intermittent flooding that followed fertilization laboratory analysis (100% dose) with probiotic fertilizer. The number of productive tillers was more influential on the outcome of methane emissions than the maximum number of tillers. In A2B6 treatment, if the number of productive tillers increased, the emission actually declined.

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