Effect of Plant Spacing and Organic Fertilizer Doses on Methane Emission in Organic Rice Fields

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ABSTRACT

Methane (CH_4) emission from paddy rice fields is a global concern; however, engineering plant spacing can decrease CH_4 emission. Due to this, field research was conducted to measure CH_4 emissions from rice fields planted using *jarwo 2:1* spacing, which has a 25 × 12.5 cm and 50 cm for the plant-free area (PFA), compared to *tegel*, which has a spacing of 25 × 25 cm. Each field was treated with organic fertilizer (mixture of cow manure and neem compost in a ratio of 1:1) with one of four doses: 0, 3, 6 and 9 tons/ha. The results showed that chemical properties such as soluble-Fe, soil organic matter (SOM), soil acidity (pH), and redox potential (Eh) were significantly correlated with CH_4 emissions (0.52***, 0.47**, 0.36*, and -0.27* respectively). *Jarwo 2:1* had lower CH_4 emissions than *tegel* on all doses of fertilizer. The most efficient dose of fertilizer was 3 tons/ha applied *jarwo 2:1* because it was able to produce rice up to 12 tons/ha with CH_4 emissions of only 34 kg/ha/season, while CH_4 emissions in *tegel* was 39 kg/ha/season. It is concluded that *jarwo 2:1* with 3 tons/ha organic fertilizers can be recommended to farmers because it produces lower CH_4 emissions and higher rice yield.

1. INTRODUCTION

Climate change is one of the issues intensively discussed in the 21st century. Rice fields are one of the sources of greenhouse gas (GHG) emissions such as CH_4 and contributed 16% of total anthropogenic greenhouse gas in 2010 in which the agriculture sector itself contributed more than half, reaching 51% of anthropogenic CH_4 emissions at the global level. Of those emissions, 20% was from rice fields (IPCC, 2014). CH_4 is a major component of greenhouse gases and their quantification is essential to address the issues of Climate Change (Mandal et al., 2013).

Rice cultivation needs a high production with low GHG emission to protect environmental sustainability. However, increasing rice growth can stimulate CH_4 emissions which aggravate global climate change, since rice cultivation as one of the primary sources of this potential greenhouse gas. However, Jiang et al. (2017) stated that a rice cultivar with high yield can decrease CH_4 emission from rice fields that have high organic-C content. A rice cultivar with high yield significantly increased the abundance of methanotroph microorganisms and root porosity, suggesting that the larger and more porous root systems of high-yielding cultivars facilitated CH_4 oxidation by promoting O_2 transport to soils. High organic carbon-rich soils indicate that the soil has a high C/N ratio that causes the soil to lack nitrogen for protein synthesis during microbial growth and induces a decrease of CH_4 production (Prayitno, 2016). A high soil C/N ratio causes slow SOM decomposition that inhibits methane production due to the lack of available carbon as a source energy for methanogens (Liu et al., 2016). The promotion of organic farming practices will help to improve sustainable, environmentally friendly agricultural production (Yuttitham, 2019).

Plant spacing can affect CH_4 emission, and when spacing is tighter emissions are lower (Watanabe et al., 2000). Tight plant spacing causes more plants per unit surface area, thus increasing the volume of the root zone. If the transport of methane

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to the atmosphere is slowed down, more methane is oxidized because it spends a longer time in the oxidation zone (Khalil et al., 1998). Therefore, it needs a plant spacing engineered with tight spacing and PFA that is suspected to decrease CH_4 emission. Indonesia has developed this plant spacing engineering called *jarwo 2:1*, a cropping pattern that manipulates the location of the plant so that more rice grows at the edge of the crop, where every two rows of rice plants are interspersed with a wide row spacing (Nurhayati et al., 2015) (Figure 1). Thus, it obtains an optimal growing space for the growth and development of plants, facilitates the conduct of the treatment plants, creates a sub-optimal environment for plant-disturbing organisms and increases the population resulting in high yield (Susilastuti et al., 2018). Meanwhile, *tegel* is a conventional cropping pattern that is generally performed by farmers in Indonesia with a distance of 25 × 25 cm or wider which forms like tiles (Darmawan, 2016).

Even so, there are no reports of this plant spacing engineering on CH_4 emission. Due to that, this research was conducted to find out the effect of plant spacing engineering *jarwo 2:1* compared to *tegel* with different doses of fertilizer on CH_4 emission.

2. METHODOLOGY

This research was carried out in organic rice fields in Imogiri, Indonesia (07º 56' 014" N, 110º 22' 292" E). The soil was classified into Inceptisols according to USDA (2014), and its parent material originated from volcanic deposits of young Merapi Mount. It has clay loam class texture (33% sand, 37% silt, 30% clay), with soil pH 6.6, Eh 9 mV, organic-C 2.3%, total-N 1.1%, available-P 1.4 mg/kg, available-K 0.15 mg/kg, soluble-Fe 8 mg/kg, and cation exchange capacity 29 cmol(+)/kg. There were two treatment factors selected in this experiment: *tegel* and *jarwo 2:1* cropping pattern, and doses of organic fertilizer (mixture of cow manure and neem fertilizer with a ratio of 1:1) applied at 0, 3, 6 and 9 tons/ha. Treatment areas were arranged in a Randomized Complete Block Design with three replications.

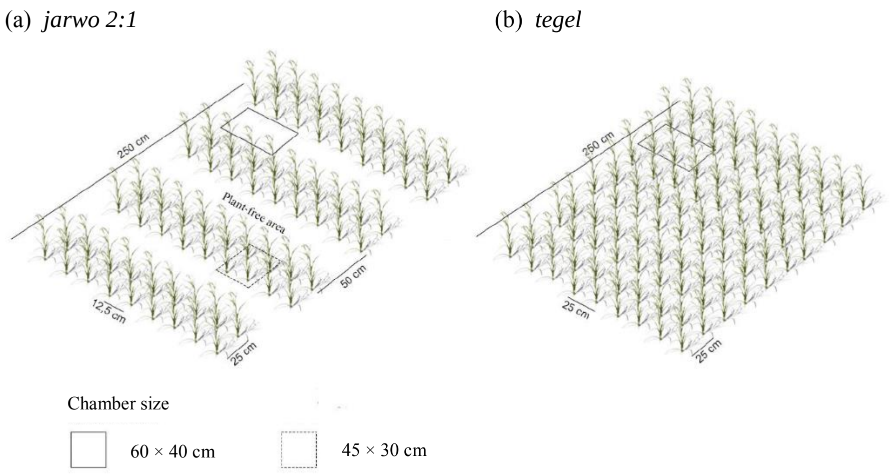


Figure 1. Chamber position when gas investigation conducted in (a) *jarwo 2:1* and (b) *tegel* cropping pattern.

The rice cultivar was cv. Mentik Wangi that was transplanted 20 days after germination into 2.5 × 4 m plot according to the cropping pattern applied (Figure 1). Organic fertilizer was applied a week before transplanting. Irrigation was carried out using the intermittent method, i.e., Flooded at 15, 45, 75 days and drained at 30, 60, 90 days after transplanting (DAT).

Soil observation was carried out on the variables of CH_4 flux (Abduh and Annisa, 2016), pH H_2O (Kabała et al., 2016), Eh (Toma et al., 2019), soluble-Fe (NH_4OAc extract at pH 4.8) (Shahandeh et al., 1994) and organic materials (Jha et al., 2014) with observational intervals of 15 DAT. CH_4 flux was measured by the closed chamber method. Gas extraction for *tegel* was carried out with one chamber, whereas for *jarwo 2:1* it was carried out with two chambers in plant area (PA) and PFA (Figure 1). Flux in each treatment was calculated using following equation (Abduh and Annisa, 2016):

$$E = \delta Csp/\delta t \times Wm/Vm \times Vch/Ach \times Tst/T+Tst \qquad (1)$$

In order to balance the observation results with *tegel*, flux calculation in *jarwo 2:1* was transformed. The CH_4 flux of PA was multiplied by 5.2 m^2. Meanwhile, the flux of the PFA was multiplied by 4.8 m^2 then the two emissions from PA and PFA were added up. The two values above were obtained based on the PA and the PFA in the planting plots. The formula used for CH_4 flux on *jarwo 2:1* is as follows:

$$CH_4 \text{ flux } \textit{jarwo 2:1} = \frac{[\text{flux PA}\times 4.8]+[\text{flux PFA}\times 5.2]}{10} \quad (2)$$

Data were analyzed with Analysis of Variance using GenStat. Significant effect between treatments then were tested using Least Significant Difference. After that, Pearson Correlation test was conducted to find out a close relationship between the variables. Statistically significant differences are reported at level 5%.

3. RESULTS AND DISCUSSION

There was dynamic in CH_4 flux value during the plant growth due to intermittent drainage. The highest CH_4 flux was observed at 45 DAT at vegetative stage (Figure 2). It occurred because of the high availability of organic substrates from root exudates which release acetic acid higher than at the generative stage which can stimulate methanogenic bacteria to actively produce CH_4 (Kerdchoechuen, 2005). The low CH_4 flux at transplanting and generative stages is due to the lack of active methanogens caused by drainage, which make soils have aerobic conditions that inhibit CH_4 production and increase CH_4 oxidation (Conrad, 2007).

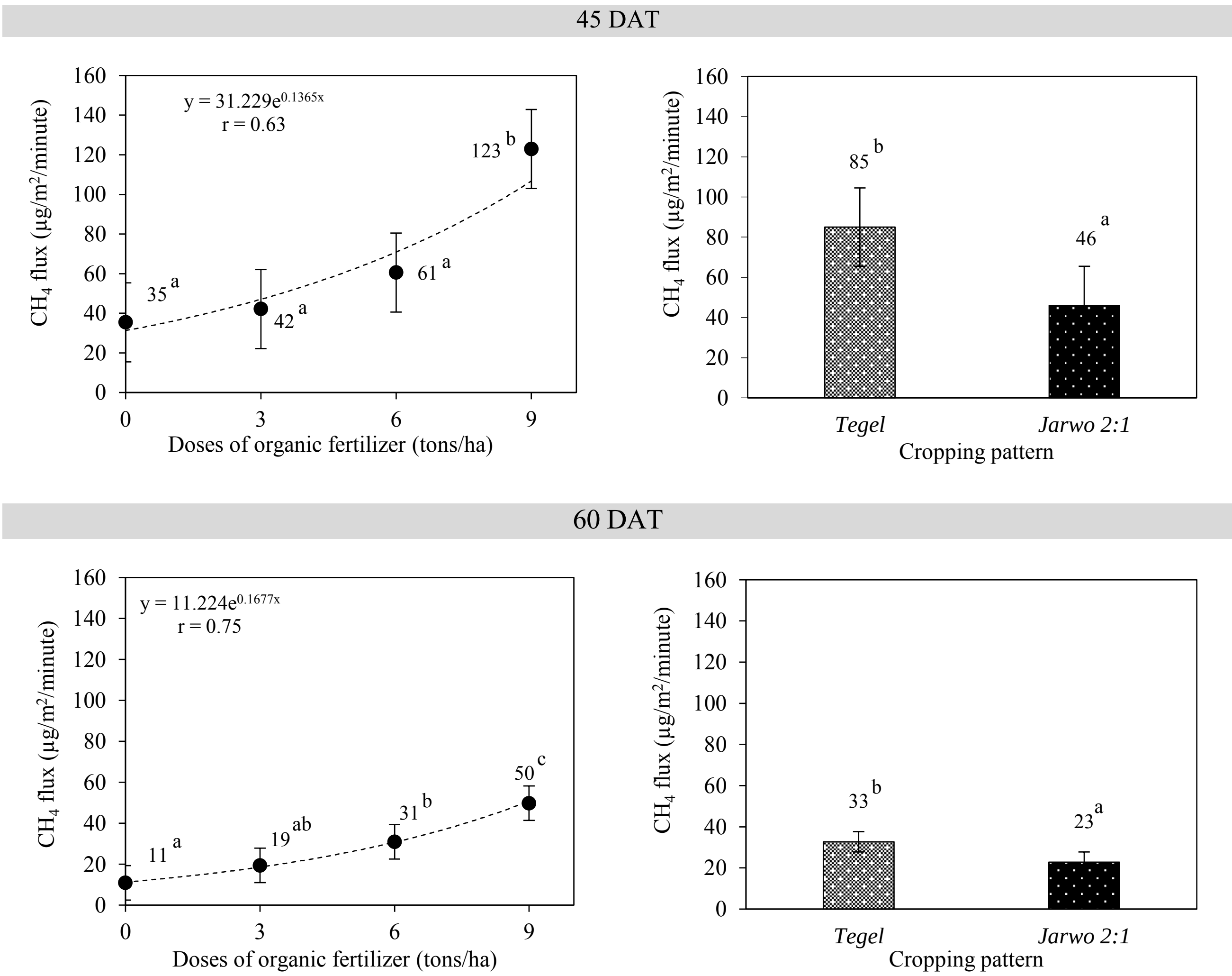


Figure 2. CH_4 flux in *jarwo 2:1* compared to *tegel* (right) and due to different organic fertilizer doses (left) at 45, 60, and 75 DAT. Data at left and right panels are showing the mean value of single factor of organic fertilizer doses and cropping pattern, respectively. Error bars represent standard error. A row of the continuous and dotted lines show the trend between doses of organic fertilizer with CH_4 flux. Mean values followed by the same letter are not significantly different based on the LSD test at a significance level of 5%.

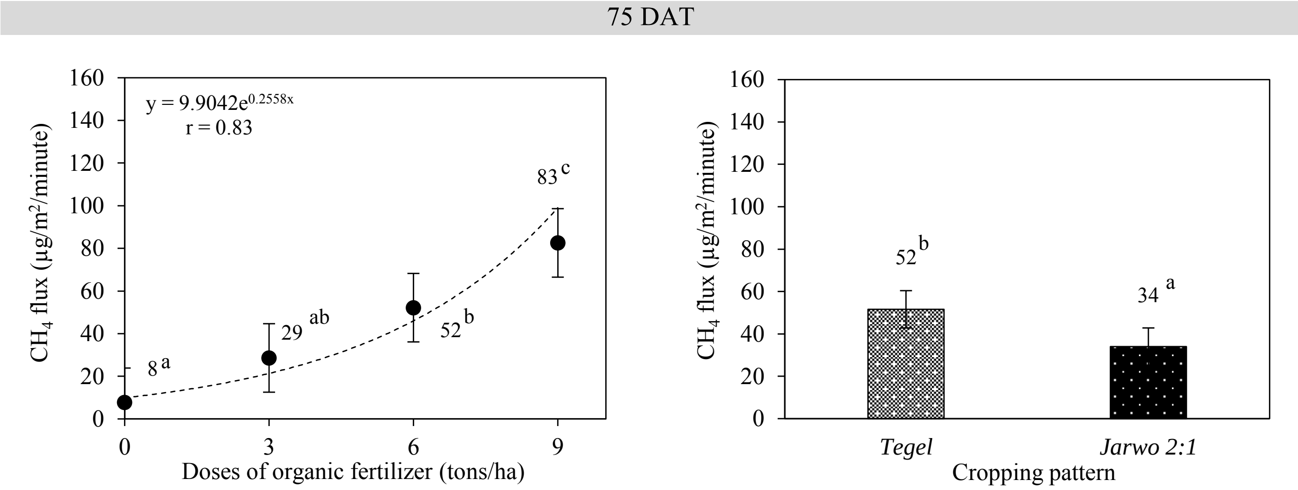


Figure 2. CH_4 flux in *jarwo 2:1* compared to *tegel* (right) and due to different organic fertilizer doses (left) at 45, 60, and 75 DAT. Data at left and right panels are showing the mean value of single factor of organic fertilizer doses and cropping pattern, respectively. Error bars represent standard error. A row of the continuous and dotted lines show the trend between doses of organic fertilizer with CH_4 flux. Mean values followed by the same letter are not significantly different based on the LSD test at a significance level of 5% (cont.).

Single treatment of cropping patterns and doses of organic fertilizer had significant effect on CH_4 flux. Doses of 3 and 6 tons/ha resulted in lower CH_4 flux compared to 9 tons/ha. Meanwhile, *jarwo 2:1* resulted in lower CH_4 flux compared to *tegel* (Figure 2). The combination of cropping patterns and doses of organic fertilizer has significant interaction effect on total CH_4 emissions. *Jarwo 2:1* could decrease CH_4 emissions by 17 kg/ha/season. Meanwhile, the best treatment is *jarwo 2:1* combined with 3 tons/ha organic fertilizers (Figure 3).

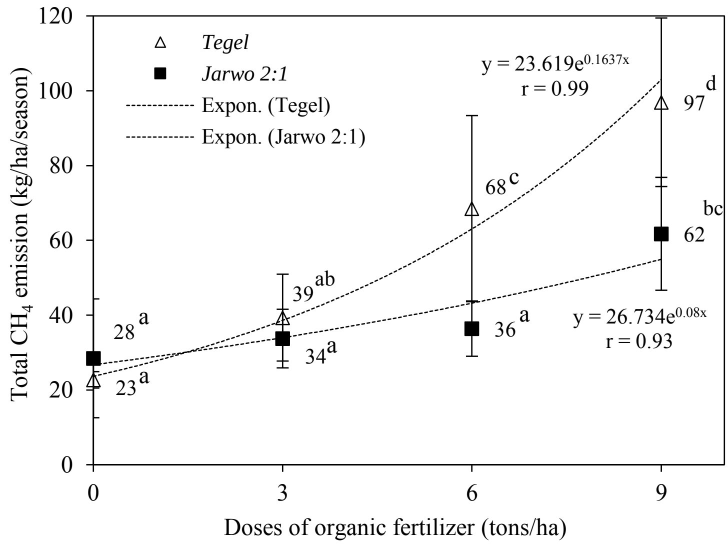


Figure 3. Total CH_4 emissions in *jarwo 2:1* compared to *tegel* with differents organic fertilizer doses. Error bars represent standard deviation. Arrow of the continuous and dotted lines show the trend between doses of organic fertilizer with CH_4 flux at *tegel* and *jarwo 2:1*. Mean followed by the same letter was not significantly different based on the LSD test at a significance level of 5%.

Figure 4, clearly shows the total CH_4 emission among *tegel*, *jarwo 2:1* PFA, and *jarwo 2:1* PA. The existence of PFA in *jarwo 2:1* can decrease CH_4 emissions because CH_4 flux tends to be very low due to the absence of a direct pathway of CH_4 from soil to the atmosphere, such as rice plants have through aerenchyma and this process contributes about 80-90% of the total CH_4 flux emitted to the atmosphere from the rice field (Cheng et al., 2006; Setyanto et al., 2004). PFA causes plants and soil to get more sunlight. Accumulated sunlight could have affected the efficiency of the photosynthesis process and make methanotrophs become more active (Arunrat et al., 2014; Wassmann et al., 2018). The methane oxidation rate in the rhizosphere was higher during warmer months which indicated more sunlight (Lombardi et al., 1997).

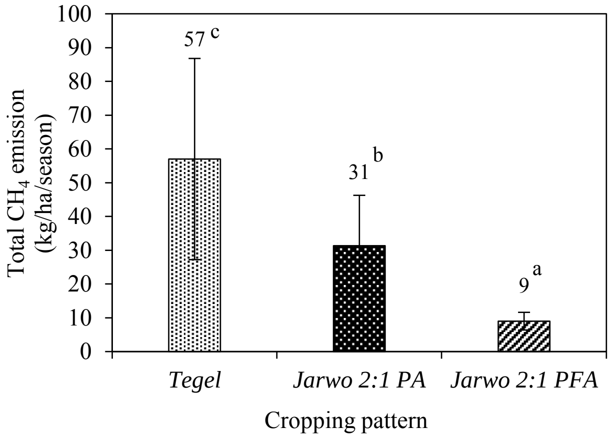
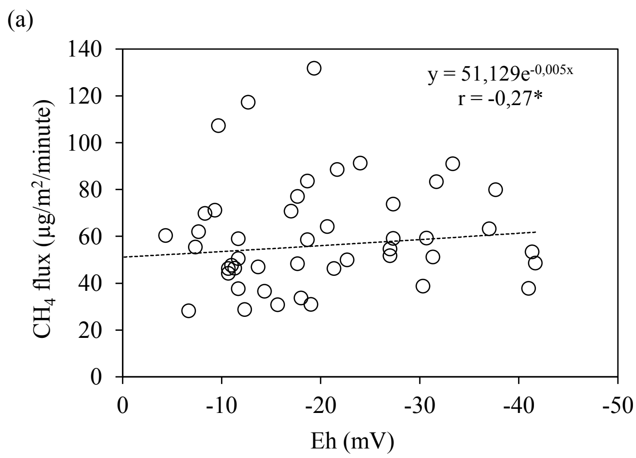


Figure 4. Total CH_4 emission in *tegel*, *jarwo 2:1* PA (plant area), and *jarwo 2:1* PFA (plant-free area). Error bars represent standard deviation. Mean values followed by the same letter were not significantly different based on the LSD test at a significance level of 5%.

Cropping patterns with tight plant spacing have a low CH_4 emission because tight spacing can lessen photosynthesis in old leaves of rice plants resulting in less substrate from root exudate for CH_4 production, so that it can delay soil reduction (Watanabe et al., 2000). Delay of soil reduction is caused by the ability of roots to oxidize by diffusing O_2 from the atmosphere to the rhizosphere through aerencyhma. So, that it is one of the important characteristics in rice cultivation which can control CH_4 production (Gutierrez et al., 2014). Therefore, the presence of PFA with tight plant spacing causes *jarwo 2:1* have lower total CH_4 emission than *tegel*.



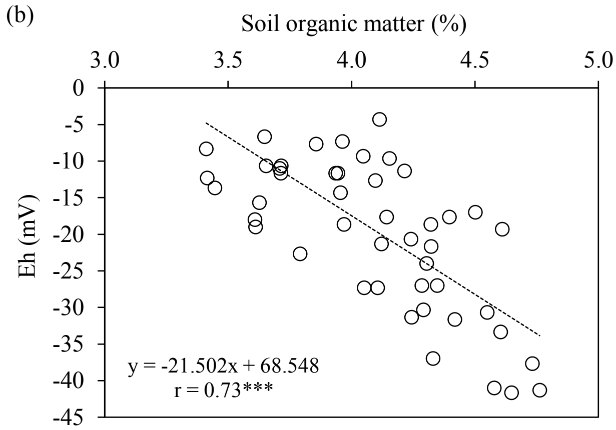


Figure 5. Relationship between Eh with CH_4 flux (a) and soil organic matter with Eh (b) in organic rice fields with different cropping patterns and organic fertilizer doses.

Redox conditions in the rhizosphere are influenced by the nitrogen content in the soil, if nitrogen in the soil is in a deficiency condition, the rhizosphere tends to be more reductive (Kyuma, 2004). Insufficient nitrogen supply will cause the roots to release more organic substances, thereby stimulating faster bacterial proliferation and increasing oxygen consumption in the rhizosphere (Trolldenier, 1977). This situation can be overcome by utilizing mature compost to diminish nitrogen loss that occurs due to NO_3^- leaching so it can minimize nitrogen deficiency (Opoku et al., 2014). The oxidative ability of roots and nitrogen availability for plants can maintain high soil redox potentials in soils. Soil Eh in this study only ranged from -42 to 2 mV which indicates that CH_4 formation does not run optimally. The results show soil Eh is negatively correlated with CH_4 flux (Figure 5(a)). This explains how the high value of Eh causes a decrease in the value of CH_4 flux.

Although CH_4 formation is not optimal in root areas due to high Eh, CH_4 formation can occur at the soil depth which is not reached by plant roots. In deeper soil the CH_4 production is greater in relation to the distribution of methanogenic bacteria in the soil (Dinel et al., 1988). CH_4 gas formed by methanogens will move by diffusion towards the root surface so that CH_4 will be partially oxidized, of which about 10-30% of CH_4 is consumed by methanotrophs associated with rice roots (Krüger et al., 2002).

The low CH_4 emissions in *jarwo 2:1* (40 kg/ha/season) compared to *tegel* (57 kg/ha/season) is an opportunity that can be developed to suppress CH_4

emissions. Based on this study the productivity of *jarwo 2:1* is not significantly different compared to *tegel*, but higher doses of organic fertilizer (9 tons/ha) provided higher productivity than those with lower rates (Figure 6(a)). However, based on quantitative values, *jarwo 2:1* showed productivity that tended to be higher. *Jarwo 2:1* according to Giamerti and Yursak (2013), has more optimal plant growth and higher productivity reaching 6.6 tons/ha compared *tegel* which only 5.1 tons/ha. A dose of 3 tons/ha is an efficient dose producing yields of 12 tons/ha. Thus, it is very good to recommend *jarwo 2:1* with a dose of 3 tons/ha to the farmers because it has low emissions but also results in higher productivity.

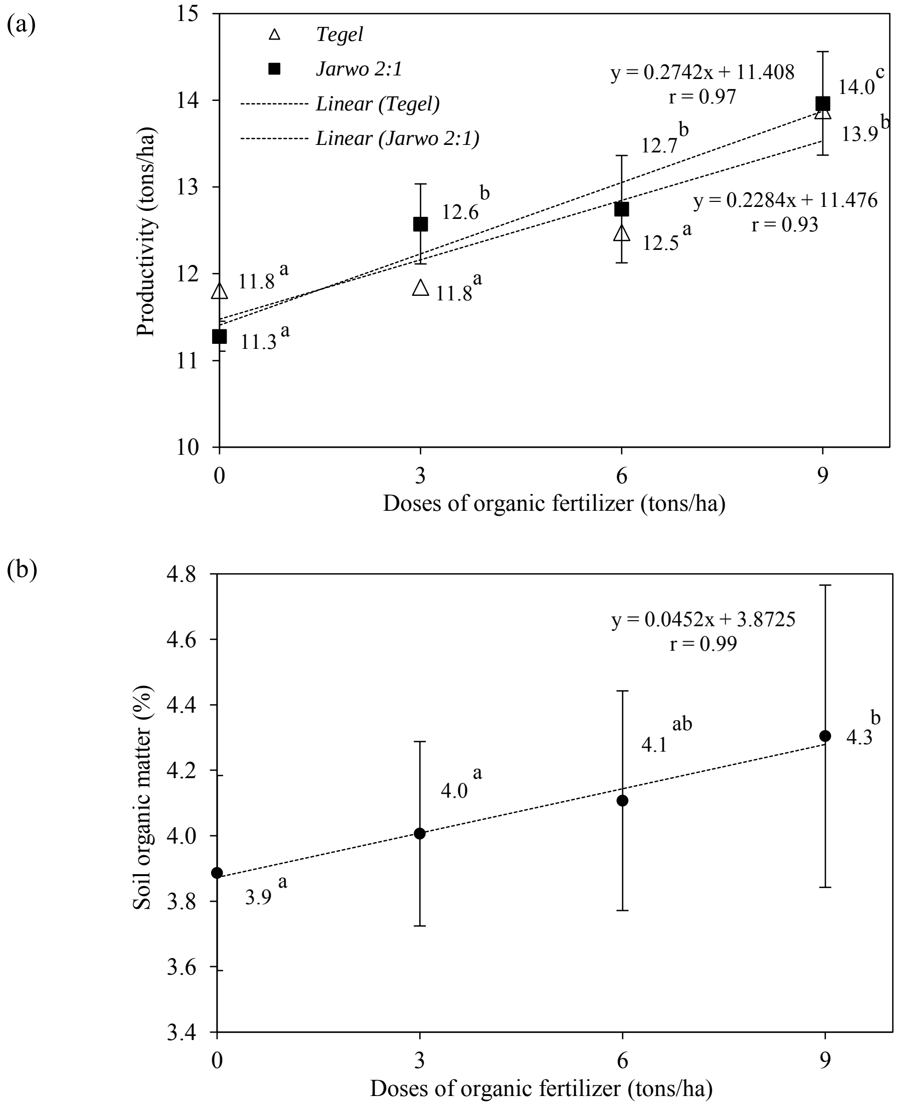


Figure 6. Productivity *jarwo 2:1* compared to *tegel* (a); SOM (soil organic matter) (b) with differents organic fertilizer doses. Error bars represent standard deviation. Arrow of the continuous and dotted lines show the trend among doses of organic fertilizer with productivity at *tegel*, *jarwo 2:1*, and SOM. Mean values followed by the same letter at same rows were not significantly different based on the LSD test at a significance level of 5%.

There is a relationship between the doses of organic fertilizer and CH_4 flux at 45, 60, and 75 DAT (Figure 2). The regression pattern is exponential in which the increase of organic fertilizer doses can increase CH_4 flux to a certain extent. CH_4 emissions are very strongly influenced by dosage of fertilizer application, where one unit of organic fertilizer dose increases emissions 2.7 to 4.1 compared to the absence of organic fertilizer (Wassmann et al., 1996). The application of organic fertilizer with different doses had significant effect on CH_4 flux in which the dose of 9 tons/ha gave the highest CH_4 flux. Meanwhile, the lowest CH_4 flux was found in the dose of 0 tons/ha even though it was not significantly different from the dose of 3 and 6 tons/ha (Figure 2). Furthermore, the increasing of dose of applied organic fertilizer can elevate SOM content (Figure 6(b)) that leads to a surge of CH_4 fluxes (Figure 7(c)). It is very clear that this relationship occurs because (1) organic matter will be transformed into simple substrates such as formate, ethanol, and acetate then used by methanogens to produce CH_4 to get energy (Malyan et al., 2016), (2) organic matter application may change soil microbial communities and their activities which would increase production of CH_4 (Zheng et al., 2007). High amounts of organic matter provide an abundant source of energy for methanogens to produce CH_4. This study is similar to the study of Humphreys et al. (2019) that indicated CH_4 emissions increase as soil organic matter increases.

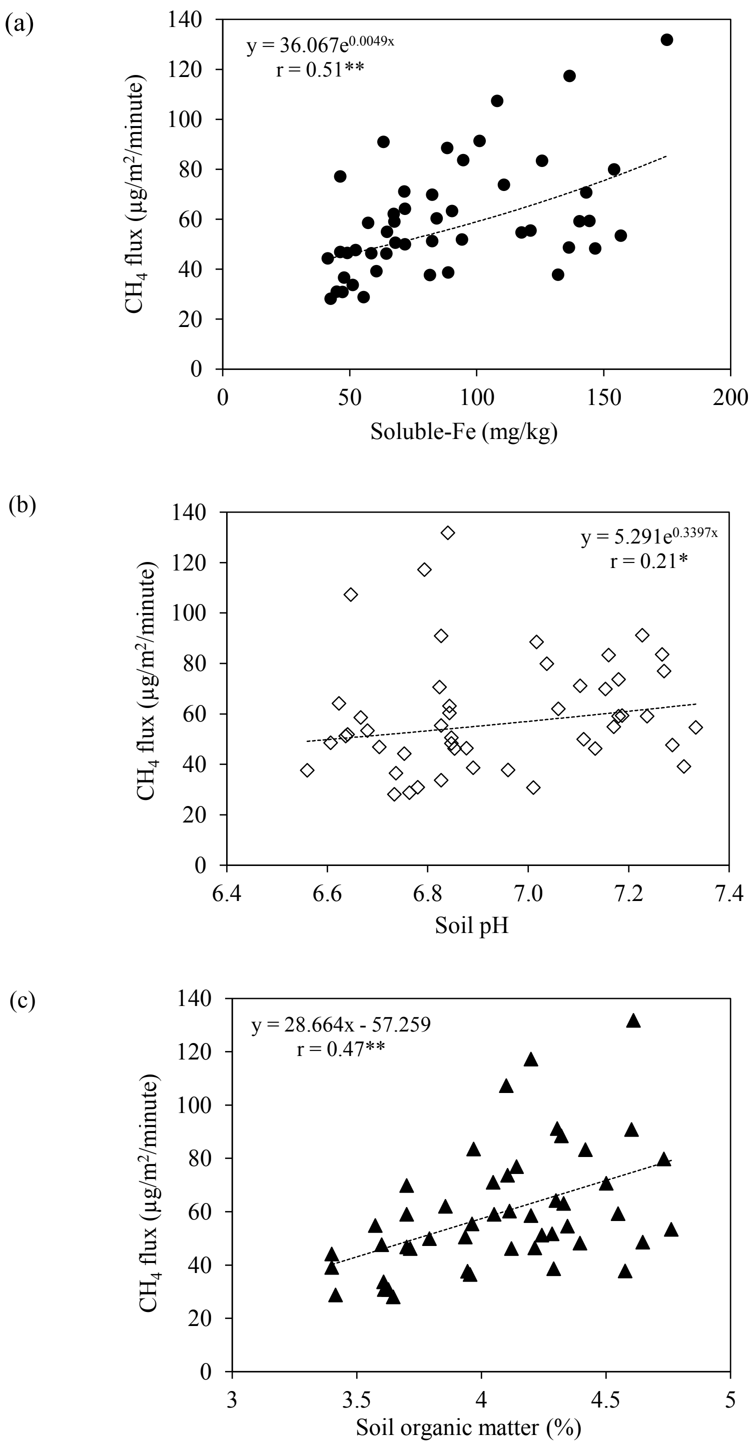


Figure 7. Relationship between soluble-Fe (a), soil pH (b), SOM (soil organic matter) (c), with CH_4 flux in organic rice fields with different cropping patterns and organic fertilizer doses.

The application of organic fertilizer with a mixture of neem compost functioning as a nitrification inhibitor can decrease CH_4 emissions by 8% compared to using only urea fertilization (Malla et al., 2005). The application of neem compost causes the nitrification process to be inhibited so that NH_4^+ is abundant in the soil causing competition with CH_4 oxidizing agents having the same site for O_2 as electron acceptors (Bédard and Knowles, 1989). This causes an increase in the population of nitrifier bacteria compared to methanotrophs, in which nitrifier bacteria can oxidize CH_4 but less effectively than methanotrophs (Malla et al., 2005).

There is a negative correlation between SOM and Eh (Figure 5(b)). Addition of SOM as electron donors can create a more reductive soil due to increases in the activity of heterotrophic bacteria (Sutton-Grier et al., 2011). Reductive soil conditions indicate that the soil is dominated by a reduction. One of them is the occurrence of iron reduction from Fe^{3+} to Fe^{2+}. This reduction affects the CH_4 emissions, in which higher amounts of Fe^{2+} in the soil causes an increase in CH_4 flux (Figure 7(a)). CH_4 flux is regulated by Fe reduction due to the electron flow in the soil concentrated to the reduction of Fe and CH_4 production, in which cumulative Fe^{3+} reduction acts as the dominant electron acceptor, which ranges from 79.5-99.7% of total electron consumption donors (Peng et al., 2015). Soil pH can affect CH_4 flux (Figure 7(b)). Methanogens are usually more active in soils with neutral pH ranging from 6.5-7.5 or slightly alkaline and are very sensitive to soil pH fluctuations (Weslien et al., 2009).

4. CONCLUSION

Soluble-Fe, OM, pH, and Eh influenced CH_4 emissions in which these factors showed Pearson correlation coefficients of 0.52***, 0.47**, 0.36*, and -0.27*, respectively. *Tegel* and *jarwo 2:1* produced CH_4 emissions of 57 kg/ha/season and 40 kg/ha/season, respectively. CH_4 emissions can be suppressed by 17 kg/ha/season using *jarwo 2:1*. Meanwhile, application of organic fertilizer at 3 tons/ha is the most efficient because it resulted in high rice productivity of 12 tons/ha and low CH_4 emissions. Total CH_4 emissions are affected by the interaction between cropping patterns and organic fertilizer doses, where the use of *jarwo 2:1* combined with 3 tons/ha organic fertilizers was able to suppress CH_4 emissions but could maintain high rice productivity.

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