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The dynamics of methane (CH4) emissions in organic and conventional paddy fields on Alfisols and Andisols at Karanganyar Regency, Indonesia

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Abstract. The increase in greenhouse gas concentration, one of which is Methane (CH_4), is the main cause of global warming and climate change. Organic materials which easily decomposed are the main sources of CH_4 production in paddy fields. The research aimed to find out and analyze the dynamics of CH_4 emission in each stage of rice growth, seasonal CH_4 emission, and rice productivity cultivated both organically and conventionally on Alfisols and Andisols at Karanganyar Regency, Indonesia. All treatments were conducted by local farmers with common agricultural practices. In conventional farming, for Andisols only fertilizer has applied the chemical whereas for Alfisols the chemical fertilizer was applied with the addition of fresh chicken manure. The sampling of CH_4 gas conducted four times in each location at 15, 35, 65, and 100 days after planting (DAP), respectively, using box chambers (50x50x100 cm). The gases were analyzed using gas chromatography, while productivity was determined by calculating total yield 2.5 m^{-2} (Indonesian Statistical Bureau). The treatment of Andisols C (Andisols with Conventional Farming Management) resulted in the highest CH_4 emission in paddy fields for one planting season. The highest CH_4 emissions were obtained at the active tillering phase (35 DAP), because of the effect of flooded conditions. For both andisols and alfisols conventional farming management resulted in higher rice productivity, whereas organic farming management resulted in better economically and in preserving the environment.

1. Introduction

Climate change is one of the major environmental problems that caused mainly by increasing emissions of anthropogenic greenhouse gases (GHG). Agriculture sector contributes about 20% of the present atmospheric GHG concentration [1]. In flood-irrigated rice fields, anaerobic soil conditions lead to CH_4 generation as the final product of organic compost decomposition by methanogenic archaea [1]. Soils can also act as a significant sink for CH_4, via oxidation by methanotrophic bacteria, and the net efflux is the balance between production and oxidation [2]. Decomposition and denitrification processes of soil organic matter (SOM) lead to the emission of GHG (CO_2, CH_4, N_2O) to the atmosphere [3]. Yagi and

Minami [4] reported that application of rice straw to the paddy fields significantly increased the CH_4 emission rates at all the sites in their research location in Ibaraki Prefecture Japan. Annual emission rates from the plots which received of rice straw in addition to the mineral fertilizer increased fold as compared with the mineral fertilizer plots. The addition of various sorts of readily decomposable organic materials increased CH_4 production in paddy [4].

Methane (CH_4) emissions, one of GHG, from biogenic sources account for more than 70% of the global CH_4 emissions [5]. Methane is a simple hydrocarbon with four equivalent C-H bonds, which is one of the greenhouse gases produced from the anaerobic decomposition of organic matter with the help of methane-forming bacteria. Methane concentration in the atmosphere has increased 3-fold during pre-industrial times [6]. Methane has the second destructive potential compared to CO_2 [7] and CH_4 has a global warming potential index of 25 times than the molecule of carbon dioxide (CO_2) and is predicted in the next 100 years to be 20% of contributors to greenhouse gases [7]. Rice is the main crop of paddy fields (150 million hectares, globally) and the biggest food needs, so the existence of paddy fields are an important concern [8].

Paddy fields are main sources of CH_4 emissions, accounting for 5–19% of the global anthropogenic CH_4 budget. Rice is the major cereal crop for more than half of the world's population, and the FAO has estimated that rice production needs to be increased by 40% by the end of the 2030s to meet the rising demand from the ever-increasing population [8]. This increased production may lead to increased emissions of CH_4 [7] and may require a higher application of nitrogenous fertilizers to paddy fields, which can lead to increased emissions of N_2O to the atmosphere [9]. CH_4 emission was positively correlated with CH_4 production, plant-mediated transport, ebullition, diffusion, and concentration of dissolved CH_4 in porewater and negatively correlated with sulfate concentration, suggesting the potential use of sulfate fertilizers to mitigate CH_4 release. Air temperature and humidity, plant biomass and concentration soil sulfate, available N, and dissolved organic carbon (DOC) together accounted for 92% of the variance in CH_4 emission, and Eh, pH, and the concentrations of available N and Fe^{3+}, leaf biomass, and air temperature 95% of the N_2O emission. Based on the positive correlations between CH_4 emission and DOC content and plant biomass the addition of a carbon substrate such as straw should be reduced and developing rice genotypes with smaller size but higher yield could be viable options for reducing the release of greenhouse gases from paddy fields [10].

Indonesia with a tropical climate is vulnerable to climate change. Climate change threatened food security [11]. This scenario inspired by the problem of methane emissions on paddy fields that occur in many regions both tropical, sub-tropical and so on, such as Latin and Central America, Africa and Southeast Asia. Facing the problem of efforts to increase high-quality rice production on the one hand, as well as efforts to overcome environmental damage due to pollution from the agricultural sector, on the other hand, is a dilemma, so it needs serious thinking to overcome the problem. An agricultural system is needed that can improve land productivity by not damaging the environment and is economically beneficial and socially acceptable to the community.

Organic farming was developed to improve food quality, especially on rice production. Farmers in Karanganyar Regency, utilize local organic materials to meet the nutritional needs of rice plants. However, the utilization of organic materials that have not been decomposed completely resulted in the increase of methane emissions in paddy fields. The decomposable organic matter is the main raw material for methanogenic bacteria in forming CH_4 in paddy fields. Therefore this research needs to be carried out to determine and analyze CH_4 emission dynamics for each stage of rice growth, the magnitude of seasonal CH_4 emissions, and the productivity of rice cultivated organically and conventionally in Alfisols and Andisols in Karanganyar Regency.

2. Materials and methods

This research was carried out with the survey method to measure methane gas emissions in paddy fields with conventional and organic farming management, in two types of soil, namely Alfisols and Andisols. Paddy field with soil type of Alfisols was located in Gentungan Village, Mojogedang Subdistrict with the coordinate of -7° 32' 48", 111° 00' 48", 293.9 m, 82° whereas paddy field with soil type of Andisols was in Ngadiluwih Village, Matesih Subdistrict, with coordinate -7° 38' 16", 111° 00' 26", 307.0 m, 82° District Karanganyar Regency, Indonesia, in the planting season of October 2017-April 2018.

The conventional farming management system on Alfisols was applied by using chemical fertilizer mixed with organic fertilizer from chicken manure, while, in Andisols only using chemical fertilizer. The organic farming management system both in Alfisols and Andisols were applied by using the organic material of cow manure.

Rice productivity was determined by calculating total yield 2.5 m^{-2} (Indonesian Statistical Bureau). CH_4 gas emission was measured 4 times (15, 35, 65, and 100 days after planting) in each location. CH_4 gas samples were taken with a box chamber, 50x50x100 cm^3, then analyzed by gas chromatography. The rate of methane production was measured using the equation as follows [11]:

$$E = (C_{24} - C_0) \cdot \frac{Vh}{20} \cdot \frac{mW}{mV} \cdot \frac{273,2}{(273,2 + T)} \quad (1)$$

Where
E : CH_4 production (mg. g $soil^{-1}$. day^{-1})
C_0 : initial CH_4 levels (ppm)
C_{24} : CH_4 levels after 24 hours of incubation (ppm)
Vh : headspace volume in an incubation cup (ml)
mW : CH_4 molecular weight (g)
mV : CH_4 molecular volume (22.41 l)
T : incubator average temperature (°C)

3. Results and discussion

This research was carried out during one rice growing season. The sampling site conditions and the treatment of conventional and organic farming management conducted in Andisols and Alfisols are presented in Table 1:

Table 1. The sampling site conditions and the treatment of conventional and organic farming management conducted in Andisols and Alfisols

Treatment	Andisols C	Alfisols C	Andisols O	Alfisols O
Plot size of sampling location	3000 m^2	1000 m^2	3000 m^2	2000 m^2
Irrigation system	Technical	Technical	Technical	Technical
Variety	Mentik	Ciherang	Gloutinous Rice	*Cempo* Black Rice
Seedling age	15 Day After Seedling	25 Day After Seedling	15 Day After Seedling	15 Day After Seedling
Planting distance	20x20 cm	20x20 cm	20x20 cm	20x20 cm
Nutrition	Chemical fertilizer: Phonska (: 0,1 $tons.ha^{-1}$, TSP: 0,1 $tons.ha^{-1}$, and Urea: 0.5 $tons.ha^{-1}$	Chemical fertilizer: Phonska: 0.4 tons ha^{-1}, TSP: 0.3 tons ha^{-1}, Urea: 0.3 tons ha^{-1}, and chicken manure: 1.6 $tons.ha^{-1}$	Organic fertilizer: Cow manure: 3 $tons.ha^{-1}$	Organic fertilizer: Cow manure: 7.5 $tons.ha^{-1}$

Andisols C: Andisols with Conventional Farming Management), Alfisols C: Alfisols with Conventional Farming Management, Andisols O: Andisols with Organic Farming Management, Alfisols O: Alfisols with Organic Farming Management

Information:

Phonska contain	: 15% Nitrogen, 15% P_2O_5, 15% K_2O, 9 % Sulfur, and 2000 ppm Zinc
TSP contain	: 45% P_2O_5, and 15% Calcium
Urea contain	: 46% Nitrogen

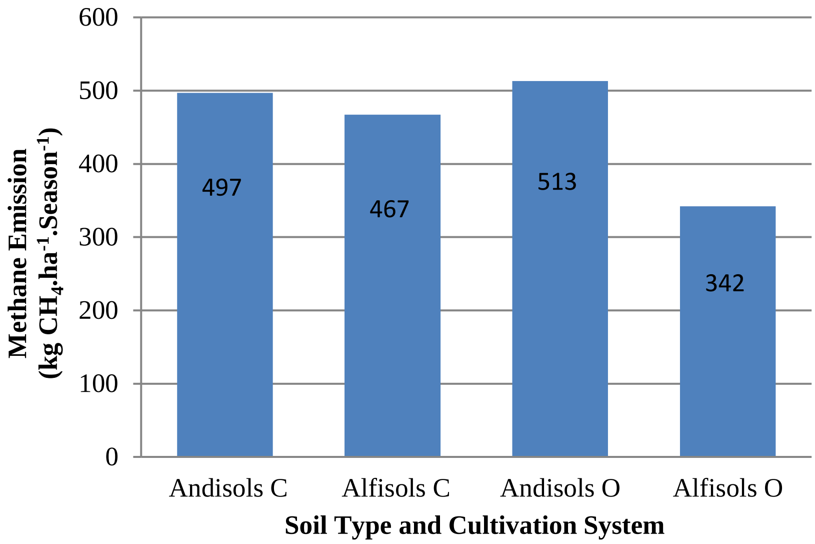

Figure 1. Total methane emission in paddy fields in one planting season period.
Andisols C: Andisols with Conventional Farming Management), Alfisols C: Alfisols with Conventional Farming Management, Andisols O: Andisols with Organic Farming Management, Alfisols O: Alfisols with Organic Farming Management

Figure 1 presented total methane emission fluctuations in paddy fields in one planting period. From the results of the observations, it is known that the highest methane gas emissions were produced by organic rice cultivation in Andisols and the lowest was at organic Alfisols. Organic matter used at organic andisols field was estimated still on the decomposing process, in anaerobic conditions the emission produce estimated to be higher.

The relationship between total methane emissions and organic matter in the soil shown in Figure 2. The decomposable organic matter is the main raw material for methanogenic archaea in forming CH_4 in paddy fields [12]. Whereas chemical fertilizers without organic mixing, produce lower CH_4 emissions because of the raw materials for methane produce is limited. Chemical fertilizer compounds directly absorbed by plants or evaporate, some carried by water flow. In soils containing high Fe such as Alfisols tend not to support the occurrence of methane gas emissions. In this soil, there are Fe reducing bacteria that compete with archaeal methanogens that produce methane in utilizing subtract or energy sources available in the soil (organic compounds). Competition between the two bacteria in obtaining energy sources causes inhibited CH_4 formation. Cultivation treatments on organic Alfisols produce low methane gas emissions because from observations, organic fertilizers used by farmers have been well decomposed, so the decomposition process when applying in paddy fields is low. The relationship between organic materials and methane emissions is as follows:

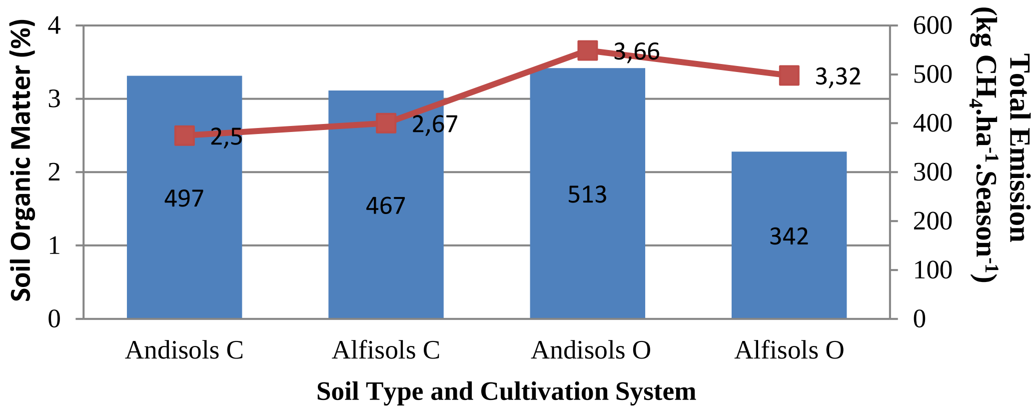

Figure 2. Relationship of total CH_4 emissions with soil organic materials.
Andisols C: Andisols with Conventional Farming Management), Alfisols C: Alfisols with Conventional Farming Management, Andisols O: Andisols with Organic Farming Management, Alfisols O: Alfisols with Organic Farming Management

Methane emission measured 4 times during the growing season, at 15 DAP (vegetative phase), 35 DAP (active tillering phase), 65 DAP (generative phase), 100 DAP (ripening phase). Different planting phases give different emissions. The methane gas emissions fluctuation in paddy fields in one planting season period can be seen in Figure 3.

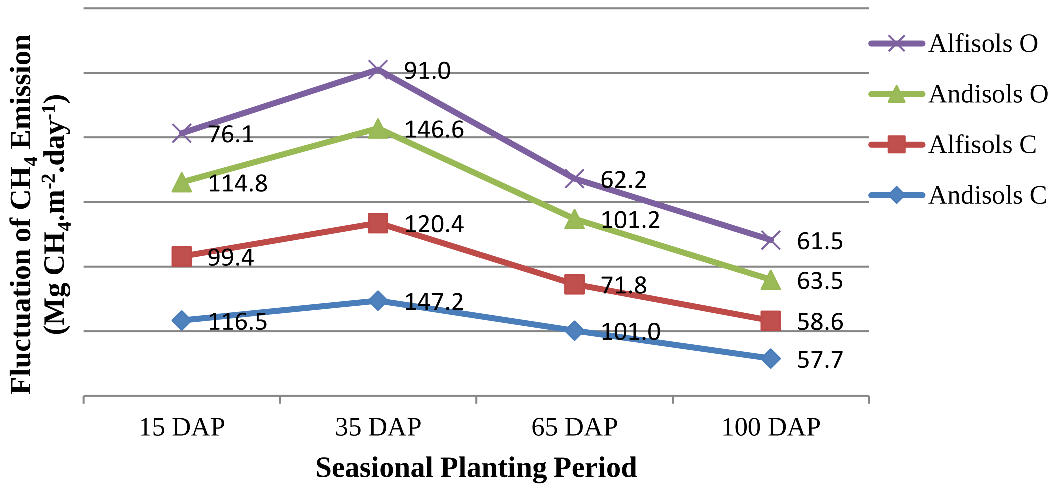

Figure 3. The methane emissions fluctuation in paddy fields in one planting season period.
Andisols C: Andisols with Conventional Farming Management), Alfisols C: Alfisols with Conventional Farming Management, Andisols O: Andisols with Organic Farming Management, Alfisols O: Alfisols with Organic Farming Management. DAP (Day After Planting)

Based on the graph above, in all research locations, the highest methane emissions were obtained from the active tillering phase (35 DAP). In this phase, the farmers will inundate the paddy fields to meet the water needs for the plants to increase the number of rice tiller. The inundation method causes the decrease of soil Eh, the pH value approaches neutral, and anaerobic decomposition of organic matter takes place which causes the formation of CH_4 gas. Frenzel and Karofeld [13] reported that 80-99% of the CH_4 produced in paddy soil was oxidized. In the rhizosphere, Jia et al. [14] reported that an average of 36.3-54.7% of the CH_4 produced was oxidized in paddy soils.

The data of paddy rice productivity was taken at the harvest time, by a 5 x 5 m tile method. The results are as follows:

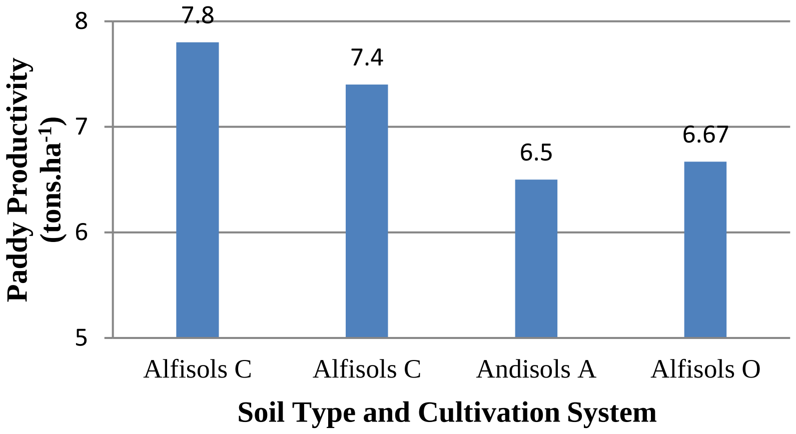

Figure 4. Paddy productivity.
Andisols C: Andisols with Conventional Farming Management), Alfisols C: Alfisols with Conventional Farming Management, Andisols O: Andisols with Organic Farming Management, Alfisols O: Alfisols with Organic Farming Management

From the observations result, it can be seen that productivity from conventional rice cultivation is higher than the organic one. Conventional farming management applies chemical fertilizers that are more easily absorbed by plants, spraying pesticides to control pests and diseases due to that action no pest attacks and plant nutrients are sufficient so that plant productivity will be high. Whereas in organic cultivation, the soil is only given organic fertilizer made by farmers, without the addition of chemical fertilizers and spraying of chemical pesticides, so that the adequacy of plant nutrients is less compared to rice fields that given chemical fertilizers. Organic farming management is a better choice compared to conventional farming management, it is because of the high income with not so large production differences, the higher selling prices, and lower environmental damage. Niggli et al. [15] stated that the potential for global warming of organic farming management is much smaller than conventional or integrated systems when calculated per land area.

4. Conclusions

The treatment of Andisols C (Andisols with Conventional Farming Management) in the highest CH_4 emission in paddy fields for one planting season. This result due to the decomposition process of the organic matter followed by the anaerobic condition at paddy fields participate in the increase the CH_4 production. The highest CH_4 emissions were obtained at the active tillering phase (35 DAP), since the effect of flooded conditions. For both Andisols and Alfisols conventional farming management resulted in higher rice productivity, whereas organic farming management results in better economically and in preserving the environment.

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