Effect of organic fertilizers on CH$_4$ and N$_2$O production from organic paddy field

A Anshori$^{1,6}$, B H Sunarminto$^{2}$, E Haryono$^{3}$, A Pramono$^{4}$ and Mujiyo$^{5}$

$^1$Assessment Institute for Agricultural Technology of Yogyakarta. Karangsiari Wedomartani Ngemplak Sleman Special region of Yogyakarta Indonesia
$^2$Department of Soil Science, Faculty of Agriculture, UGM. Jl. Flora Bulaksumur Caturtunggal Depok Sleman Special Region of Yogyakarta Indonesia
$^3$Department of Environmental Geography, Faculty of Geography, UGM. Jl. Kaliurang Sekip Utara Bulaksumur Sleman Special Region of Yogyakarta Indonesia
$^4$Indonesian Agricultural Environment Research Institute. Jalan Raya Jakenan-Jaken Km 5 Pati Central Java Indonesia
$^5$Department of Soil Science, Faculty of Agriculture, UNS. Jl. Ir. Sutami No.36A Jebres Surakarta Central Java Indonesia
$^6$Corresponding author: arifanshori@yahoo.com

Abstract. Organic fertilizer potentially results in healthy soils and sustainable agriculture. Organic fertilizer is a nutrients source in organic farming. Organic fertilizer application affects CH$_4$ and N$_2$O production. CH$_4$ and N$_2$O production affect increasing greenhouse gas emission concentration, global warming and further climate change. This study aimed to determine organic fertilizers effect on CH$_4$ and N$_2$O production from organic paddy fields. Five types of organic fertilizer namely mixed compost (MC), cow manure (CM), cow manure compost (CMC), straw compost (SC) and solid biogas waste (SBW) were added to paddy soil and determined CH$_4$ and N$_2$O production. The result showed that CH$_4$ and N$_2$O production were affected by organic fertilizer addition. CH$_4$ production was 109.52 mg kg soil$^{-1}$ day$^{-1}$ and N$_2$O production was 1.70 mg kg soil$^{-1}$ day$^{-1}$. The lowest production of both gasses was in SBW treatment. CH$_4$ production was 177.21 mg kg soil$^{-1}$ day$^{-1}$ and N$_2$O production was 2.80 mg kg soil$^{-1}$ day$^{-1}$. The highest was in soil with cow manure (CM) treatment. CH$_4$ and N$_2$O production correlated positively with organic carbon and Carbon and Nitrogen ratio (C/N) of organic fertilizers (p < 0.05). Application of solid biogas waste (SBW) with drainage treatment on 10$^{th}$ day and composting are the best effort to mitigate CH$_4$ and N$_2$O production.

1. Introduction
Agriculture contributes to anthropogenic emissions of greenhouse gasses (GHGs), namely CH$_4$, N$_2$O and CO$_2$. The concentrations of CH$_4$ and N$_2$O are lower in the atmosphere, but the impact more adverse than CO$_2$ [1]. Management practices affect GHGs emissions [2]. CH$_4$ emissions are estimated of 506 Tg year$^{-1}$ (Tg = Teragram = $10^{12}$ grams), anthropogenic sources contribute of 306 Tg year$^{-1}$ [3]. CH$_4$ emissions from paddy field are around 26-51 Tg year$^{-1}$ [4]. Global N$_2$O emissions of 17.7 Tg N year$^{-1}$, 6.7 Tg N year$^{-1}$ from anthropogenic sources [5]. N$_2$O emissions are influenced by the use of synthetic chemical and organic fertilizers [6]. Agricultural production contributes a quarter of
anthropogenic GHGs emissions [7]. Cultivation practices determine GHGs emissions from paddy field [8]. Drainage reduces CH$_4$ emissions [9][10], but produces N$_2$O [11][12].

Organic matter increases soil productivity and health [13]. However, organic matter may be a substrate for methanogens in CH$_4$ production [14]. Organic matter stimulates respiration and growth of microorganisms and provides carbon for denitrification [15]. The growth of microorganisms increases oxygen consumption and anaerobic conditions for denitrification [16], which produces N$_2$O [17][18]. Organic paddy field uses organic materials in the production process [19]. Food and Agriculture Organization (FAO) introduced organic agriculture to reduce the contribution of GHGs in agricultural sector [20] and climate change adaptation [21]. Organic fertilizers affect the production of CH$_4$ and N$_2$O. Organic fertilizers are available under various conditions in fertilizer materials, manufacturing processes and fertilizer quality. This study aimed to determine the effect of organic fertilizers on CH$_4$ and N$_2$O production in organic paddy field.

2. Material and methods 

2.1. Soils sample

Soil samples were taken from organic paddy field in Jayan, Kebonagung, Imogiri, Bantul, Special Region of Yogyakarta, Indonesia, at 7°56’01.22”N, 110°22’18.87”E. Soil was classified as Inceptisols [22] and has characteristics of loamy texture, pH of 6.26, organic carbon of 2.27%, particle density of 1.72 g cm$^{-3}$, bulk density of 1.16 g cm$^{-3}$, soil permeability of 4.31 cm hour$^{-1}$ [23] and total nitrogen of 0.11%. Samples of topsoil were taken to determine CH$_4$ and N$_2$O production.

2.2. Organic fertilizers

The research used 5 types of organic fertilizers, namely mixed compost (or MC = 1.20% N), cow manure (or CM = 1.21% N), cow manure compost (or CMC = 1.28% N), straw compost (or SC = 1.31% N) and solid biogas waste (or SBW = 1.36% N). Organic paddy soil was added with organic fertilizer win the same nitrogen dose. The difference of C/N value results in a different amount of organic carbon input. The rate of organic fertilizers was determined based on the nitrogen content in the soil and organic fertilizers. The nitrogen rate refers to Sanchez [24] for lowland rice, filled with soil nitrogen and organic fertilizers. In this study, all nitrogen was added from organic fertilizers.

2.3. Production of CH$_4$ and N$_2$O

Production of CH$_4$ and N$_2$O was determined under flooding conditions in the laboratory. According to nitrogen content, twenty grams of soil and organic fertilizer were dissolved in 40 ml of distilled water, then incubated. Gas samples were taken with 5 ml syringe for laboratory analysis. The production of CH$_4$ and N$_2$O were measured by gas chromatography, CH$_4$ using Flame Ionization Detector (FID) and N$_2$O using Electron Capture Detector (ECD), and calculated with the formula as follow [25]:

$$\text{Production of CH}_4 \text{ or N}_2\text{O} = (\text{CB} - \text{CA}) \times \frac{Vh}{Ws} \times \frac{Wm}{Vm} \times \frac{Ts}{(Ts_c + T)}$$

Where: $CA =$ CH$_4$ or N$_2$O concentration at hour A (ppm); $CB =$ CH$_4$ or N$_2$O concentration at hour B (ppm); $Vh =$ volume of headspace (ml); $Ws =$ weight of soil sample (g); $Wm =$ weight of molecule CH$_4$ and N$_2$O (g); $Vm =$ volume of CH$_4$ and N$_2$O at standard conditions (273.2 K); $Ts =$ temperature standard conditions (273.2 K); $T =$ air temperature of incubation (°C).

2.4. Statistical Analysis.

Correlation analysis was used to determine the relationship between CH$_4$ and N$_2$O production and organic fertilizers’ properties [26].
3. Results and Discussion

3.1. Production of CH$_4$ and N$_2$O.

The pattern of CH$_4$ production was the same (Figure 1), as in Mujiyo et al [27]. The maximum production occurred on 15$^{th}$ day. The pattern of CH$_4$ production in soil plus CM was slightly different, still high on 22$^{nd}$ day. Organic carbon input was of CM (higher C/N) so that CH$_4$ production was still high on 22$^{nd}$ day. Composting increases carbon loss as CO$_2$ [28][29] so CM (without composting) has higher carbon content that leads to higher CH$_4$ production. The additions of compost to soil enhance the quality and quantity of soil organic matter [30], also as source of nutrients [31]. Production of N$_2$O showed a similar pattern (Figure 1). N$_2$O production was low on day 1, increased and reached a maximum on 15$^{th}$ day, then decreased. Production of CH$_4$ and N$_2$O reached a maximum on 15$^{th}$ day. CH$_4$ and N$_2$O production did not reach the maximum as a mitigation option. The 10$^{th}$ day of drainage will reduce CH$_4$ production because before 15$^{th}$ day, CO$_2$ and CH$_4$ mainly lose carbon through organic matter mineralization, but we must pay attention to N$_2$O production. Nitrogen is lost through NH$_3$ volatilization and N$_2$O emission from nitrification and denitrification [32].

![Figure 1. CH$_4$ and N$_2$O production pattern during 29 days of incubation](image)

CH$_4$ production in soil with CM treatment was 177.21 mg CH$_4$ kg soil$^{-1}$ day$^{-1}$. CH$_4$ production in soil with MC treatment was 21.33% lower than soil plus CM. Meanwhile, soil with CMC treatment reduced CH$_4$ production by 25.82%, soil with SC treatment by 32.45% and soil with SBW treatment 38.20% compared to soil with CM treatment (Figure 2). CH$_4$ production in the soil without organic fertilizer of 79.53 mg CH$_4$ kg soil$^{-1}$ day$^{-1}$ [33] was lower than plus organic fertilizers. N$_2$O production on CM treatment was 2.80 mg N$_2$O kg soil$^{-1}$ day$^{-1}$. The addition of SBW reduced N$_2$O production up to 39.24% compared to soil with CM treatment. Meanwhile, soil with SC treatment reduced N$_2$O production by 28.48%, CMC 24.18% and MC 12.58% compared to soil with CM treatment (Figure 2). Referring to the results obtained by Anshori et al [33], organic fertilizers increased N$_2$O production. The addition of SBW to organic paddy soil gave the lowest CH$_4$ and N$_2$O production. Amendments with fine organic matter, like SBW, negligibly increase methane production and emission. Application of composted material, which has a higher degree of humification, only slightly increases methane formation and fluxes [34]. We proved that SBW is the best alternative for mitigation of CH$_4$ and N$_2$O production.
Figure 2. CH$_4$ and N$_2$O production after 29 days of incubation

3.2. The correlation of CH$_4$ and N$_2$O production with organic fertilizer properties.

The difference in CH$_4$ and N$_2$O production occurred due to differences in organic fertilizers’ properties, such as carbon (C) and C/N fertilizers. There was positive correlation between C, C/N, phosphorus (P) and potassium (K) organic fertilizers with CH$_4$ and N$_2$O production. The negative correlations occurred in sulfur (S), iron (Fe), manganese (Mn) and copper (Cu) with CH$_4$ and N$_2$O production (Table 1). Organic carbon positively correlated with CH$_4$ production, as in Mujiyo et al and Anshori et al [27] [33], organic carbon is a methanogen substrate in producing CH$_4$ [14][34]. Organic fertilizers significantly increased CH$_4$ emissions [27][35][36][37]. Composting reduces fertilizer C/N. Fertilizer C/N has a positive correlation with CH$_4$ production (Table 1). Methanogenic bacteria are thought to be more active at high fertilizers C/N. According to Kim et al [38] composting can reduce CH$_4$ emissions. P and K of organic fertilizers positively correlated with CH$_4$ production, while negatively correlated to S, Fe and Mn. Wihardjaka et al [39] also found a positive relationship between soil P$_2$O$_5$ and K$_2$O with CH$_4$ production and negative to SO$_4$, Fe and Mn. These soil properties parameters affect the reduction-oxidation and soil pH [40]. Organic fertilizers application with high C/N tends to increase the production of CH$_4$. Efforts to mitigate CH$_4$ emissions can be done by reducing C/N of organic fertilizers through composting.

Table 1. Correlation of CH$_4$ and N$_2$O production with organic fertilizers parameter

| Parameters | CH$_4$ | N$_2$O |
|------------|--------|--------|
| C-organik  | 0.94** | 0.84*  |
| C/N        | 0.99** | 0.94** |
| S          | -0.67  | -0.62  |
| P          | 0.69   | 0.60   |
| K          | 0.29   | 0.17   |
| Fe         | -0.86* | -0.75* |
| Mn         | -0.05  | -0.18  |

** significance at 1% level;   * significance at 5% level

Soil organic carbon has a positive correlation with N$_2$O production because it is denitrification substrate [41]. Nitrification-denitrification is a source of N$_2$O emission [42]. Organic carbon increases the nitrification-denitrification, resulting in higher N$_2$O production. However, C/N of organic fertilizer has a positive correlation with N$_2$O production. C/N ratio is the main indicator of composting stability and final product maturity [43]. Organic materials which high C/N contain high organic carbon, nitrification-denitrification is more active, so that the production of N$_2$O is higher. According to Addo et al [44], organic carbon is a source of energy for denitrification, positively correlating with N$_2$O.
emissions [45]. N$_2$O production is positively correlated with P and K of organic fertilizer and negatively with S, Fe and Mn. Ions play a role in the production of N$_2$O through the nitrification-denitrification process [46][47][48][49]. Application high C/N of organic fertilizers tends to increase the production of N$_2$O. Similar to CH$_4$ mitigation above, mitigation of N$_2$O emissions can be done also by composting to reduce C/N of organic fertilizers.

4. Conclusion
Organic fertilizers application increased CH$_4$ and N$_2$O production in organic paddy field. CH$_4$ and N$_2$O production with organic fertilizers application and flooded condition reached a maximum on the 15$^{th}$ day, and the lowest was on soil with soil biogas waste (SBW) treatment. SBW application and treatment drainage on 10$^{th}$ day was the best treatment to mitigate CH$_4$ and N$_2$O production in this study. Positive correlation between CH$_4$ and N$_2$O production from soil treated with organic carbon and C/N of organic fertilizers also provides an alternative to mitigate CH$_4$ and N$_2$O through composting.

References
[1] Rodhe H, “A comparison of the contribution of various gases to the greenhouse effect,” Science (80-. ), vol. 248, pp. 1217–1219, 1990.
[2] Minamikawa K and Sakai N, “The practical use of water management based on soil redox potential for decreasing methane emission from a paddy field in Japan,” Agric. Ecosyst. Environ., vol. 116, pp. 181–188, 2006.
[3] Sass RL, Fisher FM, Ding A and Huang Y, “Exchange of methane from rice fields national, regional and global budgets..” J. Geophys. Res., vol. 104, no. D21, pp. 26943–26951, 1999.
[4] Thangarajan R, Bolan NS, Tian G, Naidu R and Kunhikhirisnan A, “Role of organic amendment application on greenhouse gas emission from soil,” Sci. Total Environ., vol. 465, pp. 72–96, 2013.
[5] Wang JS, Logan JA and McElroy MB, “A 3-D model analysis of the slowdown and interannual variability in the methane growth rate from 1988 to 1997,” Glob. Biogeochem. Cycles., vol. 18, p. 30p, 2004.
[6] Denman KL, Brasseur Chidthaisong Ciais Cox Dickinson Hauglustaine Heinzle Holland Jacob Lohmann Ramachandran da Silva Dias Wofsy and Zhang X, “Couplings Between Changes in the Climate System and Biogeochemistry..” in Climate Change : The Physical Science Basis., 2007, pp. 499–587.
[7] Mosier AR, Duxbury JM, Freney JR, Heinemeyer O, Minami K and Johnson DE, “Mitigating agricultural emissions of methane,” Clim. Chang., vol. 40, pp. 39–80, 1998.
[8] Zou J, Huang Y, Jiang J, Zheng X and Sass RL, “A 3-year field measurement of methane and nitrous oxide emissions from rice paddies in China: Effects of water regime, crop residue, and fertilizer application,” Glob. Biogeochem. Cycles., vol. 19, p. 9p, 2005.
[9] Diba F, Shimizu M and Hatano R, “Effects of soil aggregate size, moisture content and fertilizer management on nitrous oxide production in a volcanic ash soil,” Soil Sci. Plant Nutr., vol. 57, p. 733—747, 2011.
[10] Farquharson R and Baldock J, “Concepts in modelling N2O emissions from land use..” Plant Soil., vol. 309, pp. 147–167, 2008.
[11] Turmuktini T, Kantikowati E, Natalie B, Setiawati M, Yuwariah Y, Joy B and Simarmata T, “Restoring the Health of Paddy Soil by Using Straw compost and Biofertilizers to Increase Fertilizer efficiency and Rice Production with Sobari (System of Organic Based aerobic Rice Intensification) Technology,” Asian J. Agric. Rural Dev., vol. 2, no. 4, pp. 519–526, 2012.
[14] Hou F, Li G, Wang S, Jin X, Yang Y, Chen X, Ding C, Liu Z and Ding Y, “Methane emissions from rice fields under continuous straw return in the middle-lower reaches of the Yangtze River,” J. Environ. Sci., vol. 25, no. 9, pp. 1874–1881, 2013.

[15] Cameron KC, Di HJ and Moir JL, “Nitrogen losses from the soil/plant system : a review.,” Ann. Appl. Biol., vol. 162, no. 2, pp. 145-173., 2013.

[16] Signor D and Cerri CEP, “Nitrous oxide emissions in agricultural soils : a review.,” Pesq. Agropec. Trop., Goiânia, vol. 43, no. 3, pp. 322–338, 2013.

[17] Cleemput OV, “Nitrogen transformation in soil, ozone depletion and the greenhouse effect.,” 1994.

[18] Mulvaney RL, Khan SA and Mulvaney CS, “Nitrogen fertilizers promote denitrification.,” Biol. Fertil. Soils, vol. 24 : 211–2, 1997.

[19] Sutanto R, “Pertanian organik : Menuju pertanian alternatif dan berkelanjutan,” Penerbit Kanisius. Yogyakarta., 2002.

[20] FAO, Organic agriculture, environment and food security. 2002.

[21] FAO, “FAO profile for climate change. FAO. Rome.,” 2009.

[22] Steel RGD and Torrie JH, “Principles and procedures of statistics : Biometrical Approach,” Mac Graw Hill Inc. B. Co. Tokyo., 1978.

[23] Dewi WS, Wahyuningsih GI, Syamsiyah J and Mujiyo, “Dynamic of N-NH4+, N-NO3 -, and total soil nitrogen in paddy field with azolla and biochar,” IOP Conf. Ser. Earth Environ. Sci. 142, 2018.

[24] Yuan J, Chadwick D, Zhang D, Li G, Chen S, Luo W, Du L, He S and Peng S, “Effect of aeration rate on maturity and gaseous emissions during sewage sludge composting,” Waste Manag, vol. 56, pp. 403–410, 2016.

[25] Yagi K and Minami K, “Effect of organic matter application of methane emission from some Japanese paddy fields,” Soil Sci. Plant Nutr., vol. 36, pp. 599–610, 1990.

[26] Qin YM, Liu SW, Guo YQ, Liu QH and Zou JW, “Methane and nitrous oxide emissions from organic and conventional rice cropping systems in Southeast China.,” Biol. Fertil. Soils., vol. 46, pp. 825–834, 2010.

[27] Singh A, Singh RS, Upadhyay SN, Joshi CG, Tripathi AK and Dubey SK, “Community
structure of methanogenic archaea and methane production associated with compost-treated tropical rice-field soil.” *Fems Microbiol. Ecol.*, vol. 82 : 118–1, 2012.

[37] Mujiyo, Sunarminto BH, Hanudin E, Widada J and Syamsiyah J, “Methane emission on organic rice experiment using azolla,” *Int. J. Appl. Environ. Sci.*, vol. 11, pp. 295–308, 2016.

[38] Kim SY, Pramanik P, Gutierrez J, Hwang HY and Kim PJ, “Comparison of methane emission characteristics in air-dried and composted cattle anure amended paddy soil during rice cultivation.” *Agric. Ecosyst. Environ.*, vol. 197 : 60–6, 2014.

[39] Wihardjaka A, Susilowati HL and Whyuni S, “Potensi produksi gas metana pada tanah sawah tadah hujan di Jawa Timur.,” 2008.

[40] Setyanto P, Rosenani AB, Makarim AK, Che Fauziah I, Bidin A and Suharsih, “Soil controlling factor of methane gas production from flooded rice fields in Pati District, Central Java.,” *Indones. J. Agric. Sci.*, vol. 3(1) 1-11., 2002.

[41] Vilain G, Garnier J, Decuq C and Lugnot M, “Nitrous oxide production from soil experiments : denitrification prevails over nitrification,” *Nutr. Cycl. Agroecosyst.*, vol. 98, pp. 169–186, 2014.

[42] Wagner-Riddle C, Furon A, McLaughlin NL, Lee I, Barbeau J, Jayasundara S, Parkin G, Bertoldi PV and Warland J, “Intensive measurement of nitrous oxide emissions from a corn–soybean–wheat rotation under two contrasting management systems over 5 years.,” *Glob. Chang. Biol.*, vol. 13, pp. 1722–1736, 2007.

[43] Chan M, Selvam A and Wong JWC, “Reducing nitrogen loss and salinity during ‘struvite’ food waste composting by zeolite amendment,” *Bioresour. Technol.*, vol. 200, pp. 838–844, 2016.

[44] Addo JS, Lee HC and Baggs EM, “Nitrous oxide emissions after application of inorganic fertilizer and incorporation of green manure residues.,” *Soil Use Manag.*, vol. 19 : 331–3, 2003.

[45] Chen H, Li X ,Hu F and Shi W, “Soil nitrous oxide emissions following crop residue addition : a meta-analysis.,” *Glob. Chang. Biol.*, vol. 19 : 2956-, 2013.

[46] Kampschreur MJ, Kleerebezem R, de Vet WWJM and van Loosdrecht MCM, “Reduced iron induced nitric oxide and nitrous oxide emission,” *Water Res.*, vol. 45, no. 5949–5952, 2011.

[47] Liu Y, Ngo AH, Guo W, Zhou J, Peng L, Wang D, Chen X, Sun J and Ni BJ, “Optimizing sulfur-driven mixotrophic denitrification process: System performance and nitrous oxide emission,” *Chem. Eng. Sci.*, vol. 172, pp. 414–422, 2017.

[48] Susilawati HL, Setyanto P, Makarim AK, Ariani M, Ito K and Inubushi K, “Effects of steel slag applications on CH4, N2O and the yields of Indonesian rice fields: a case study during two consecutive rice-growing seasons at two sites,” *Soil Sci. Plant Nutr.*, vol. 61, pp. 704–718, 2015.

[49] Velthof GL and Rietra RPJJ, “Nitrous oxide emission from agricultural soils,” *Wageningen Environ. Res.*, 2018.