Mitigating N$_2$O emission from chili plantation (*Capsicum annuum*) on the integrated pest management field school – case study in Rembang and Sukabumi Regencies, Indonesia

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Abstract. Agricultural activities such as an inorganic nitrogen fertilization and biomass burning contribute to increase the N$_2$O emissions from the agricultural sector. Integrated Pest Management Field School (IPM) in chili plantations using organic based fertiliser and the application of silver-black plastic mulch promote to reduce the N$_2$O emissions from agricultural sector. The purpose of this study was to investigate the reduction of N$_2$O emissions using organic based fertilizer and silver-black plastic mulch treatment on IPM school plots in Rembang and Sukabumi Regencies. The results showed that there was no significant different on N$_2$O emission from the organic based fertilizer and plastic mulch application to the control. However, treatment of organic based fertiliser and silver-black plastic mulch in IPM plots contribute to reduce the N$_2$O emissions of 14% in Sukabumi and 27% in Rembang compared to conventional farmers' technology without organic based fertiliser and plastic mulch treatments. Thus, the IPM on the chilli plantation contribute to N$_2$O mitigation.

1. Introduction

Nitrous oxide (N$_2$O), methane (CH$_4$) and carbon dioxide (CO$_2$) are the three major greenhouse gases from agricultural sector that contribute on the global warming. Nitrous oxide can potentially reduce the ozone thickness. Agricultural activities such as inorganic nitrogen fertiliser and biomass burning contribute to increase the atmospheric nitrous oxide emissions. Land management also influences the N$_2$O formation and its movement from the soil [1]. The N$_2$O movement from the soil into the atmosphere increase the nitrous oxide concentration in the atmosphere that contribute to accelerate the global warming.

Chili in Indonesia is a strategic fragile commodity in price due to low productivity and high demand. However, increasing demand contribute to promote the intensive chilli cropping systems that cause the environmental impacts due (e.g.) land use change, soil erosion, overexploitation of natural resources, pollution on the groundwater and the greenhouse gases emission [2]. Moreover, the agricultural systems are responsible up to 37% of the greenhouse gases emissions [3] especially from the production, transport and fertilizer usage as one of the main sources of the emissions from agricultural sector. In the case of the fertilization of agricultural practice, it contributes more than 70% of N$_2$O emissions [4]. The low chili production commenced due to the competition on chili planting.
period with the rice planting time especially during the rainy season, while the dry area is susceptible and high risk of failure for chilli plantation [5].

Integrated Pest Management Field School (IPM) in chili plantation has mandatory treatment through amendment of organic fertiliser and silver black plastic mulch application accompanied using appropriate pesticides that can reduce the attack of pests [6]. Environmentally friendly technology can be introduced to farmers through the Integrated Pest Management Field School (IPM) program by applying the technology to develop chili production and observe pests as learning for farmers while maintaining the environment. Increasing inorganic fertilizer on the intensive chilli plantation contribute to the environmental issue. Then, the aims of this research were to investigate the potential reduction of N₂O emissions using organic based fertilizer and silver-black plastic mulch treatment on IPM school plots in Rembang and Sukabumi Regencies.

2. Materials and methods
This research was conducted in the Integrated Pest Management Field School (IPM) plots and a conventional farmers management of chili in Central and West Java Provinces. The N₂O gas measurement locations were at Pengkol Village, Kaliiori District, Rembang Regency, Central Java Province, Indonesia, during the end of August 2013 until early December 2013. While the N₂O gas measurement on Pasir Datar Village, Caringin District, Sukabumi Regency, West Java Province was held during early September 2013 until end of November 2013. There was a rice field prior the chili plantation.

The basalt and supplementary fertilizers were used for the IPM area. The basalt fertilizers were applied at 5 Day After Showing (DAS) while supplementary fertilizers were given at 15 DAS, 35 DAS and 50 DAS with one third of the dose in each days of fertilising. The basis fertilizers used were manure with a dose of 15 t ha⁻¹, basalt fertiliser was nitrogen fertilizer of 100 kg N ha⁻¹, P fertilizer of 80 kg P₂O₅ ha⁻¹ and K fertilizer of 100 kg K₂O ha⁻¹. The supplementary fertilizer given is in the form of N fertilizer at a dose of 300 kg N ha⁻¹. Meanwhile, applying fertilizer to the conventional plots is following the farmers' habits and without applying organic based fertilizer.

2.1. Taking N₂O gas samples from the field
The sampling of N₂O gas was carried out in IPM and conventional plots. The area 500 m² area of investigation in each treatment and location. The age of the chili plants at the first sampling was 2 weeks after transplanting. Sampling was carried out until before harvest time, with chili plants aged ranging from 90 to 120 days after transplanting. Sampling was carried out in IPM and conventional chili plantation owned by the farmers. The IPM plots was covered by silver black plastic mulch. While the conventional was not covered by silver black plastic mulch. Then, the based for chamber was installed by making holes according to the size of the cross-section. Plastic mulch was opened at the time of sampling or chamber installation, after sampling, plastic mulch is closed again and then stuck with the duct tape.

There were 5 sampling points across 500 m² area in each treatment and location. Before sampling, the base of chamber was set up in each observation point to reduce gas leakage from cracked soil (Figure 1). The N₂O was captured by 40 cm length x 20 cm width x 30 cm height of closed chamber.

![Figure 1. Base for chamber observation](image-url)
Gas samples were taken after fertilization, with a sampling schedule at the 3 days after fertilization (hsp) and repeated every 3 weeks after during the harvest time. The sampling time is in the morning at 06.00 until 08.00 West Indonesia Time zone.

The syringe at 20 mL volume was used to take the gas sample from the chamber with 10’, 20’, 30’and 40’ gas sampling intervals. Then, the gas sample will be injected to the 10 mL of vacuum vials. The thermometer was used to monitor and recorded the temperature inside the chamber. The time sampling was monitored using the stopwatch. The gas sample is immediately taken to the GHG laboratory for analysis to determine the concentration of N\textsubscript{2}O gas.

2.2 Determination of N\textsubscript{2}O gas emissions in the laboratory
Gas samples were analysed using Greenhouse Gas (GHG) Chromatography type Varian 450 equipped by Electron Capture Detector (ECD) as N\textsubscript{2}O detector with Argon (Ar), Hydrogen (H\textsubscript{2}), Helium (He) and Nitrogen (N\textsubscript{2}) as the carrier gas.

The results of the gas sample analysis can be calculated to be N\textsubscript{2}O emission using the equation [8] below:

\[
F = \frac{dc}{dt} \times \frac{Vch}{Ach} \times \frac{mW}{mV} \times \frac{273.2}{273.2+T}
\]

Where:
- \(F\) : Flux of N\textsubscript{2}O (\(\mu g \text{ m}^{-2} \text{ minute}^{-1}\))
- \(dc/dt\) : Difference in N\textsubscript{2}O concentration per time sampling (ppb minute\(^{-1}\))
- \(Vch\) : Chamber volume (m\(^3\))
- \(Ach\) : Chamber area cover (m\(^2\))
- \(mW\) : Molecular weight of N\textsubscript{2}O (g)
- \(mV\) : Volume of N\textsubscript{2}O molecules (22.41 l)
- \(T\) : Average temperature during gas sampling (\(^\circ\text{C}\))

2.3 Statistical analysis
RStudio (ver.3.2.1) was used to analyse the data. The normality distribution and homogeneity of the parametric data were tested using the Shaprio-Wilk and Levene tests. Then, the ANOVA was used to analyse the N\textsubscript{2}O emissions to the treatment.

3. Results and discussion
According to the Statistical Institute (Rembang and Sukabumi) [9, 10], Rembang Regency covers about 11,973 hectares at an altitude of 0 to 7 m above sea level (asl), 56,197 hectares at an altitude of 8 to 100 m asl, 28,688 hectares at an altitude of 101 to 500 m asl and 3,112 hectares at an altitude of more than 500 m asl with an average rainfall is below 1,000 mm year\(^{-1}\). While, the altitude of the Sukabumi Regency varies between 0 to 2,958 m with an average rainfall is 2,000 to 4,000 mm year\(^{-1}\). Flat areas are generally found in coastal areas and in the foothills of the mountains, which are mostly rice fields. There are two different rainfall area between Rembang and Sukabumi as a research location.

The result showed that there was no significant interaction between different location and the different management (Integrated Pest Management Field School and conventional farming system) on N\textsubscript{2}O emissions (\(F = 0.017\); \(df = 1\); \(P = 0.9\)). Meanwhile, based on the statistical test (ANOVA), the different location between Rembang and Sukabumi on the research site has no significant effect on N\textsubscript{2}O emissions (\(F = 1.14\); \(df = 1\); \(P = 0.3\)). The different management system between Integrated Pest Management Field School and conventional farming system also has no significant difference on N\textsubscript{2}O emissions (\(F = 2.93\); \(df = 1\); \(P = 0.1\)) (Figure 2.)
Figure 2. Boxplot ANOVA of the N$_2$O emission from conventional and the Integrated Pest Management Field School at Rembang and Sukabumi.

The conventional farming practices for chilli plantation in Rembang and Sukabumi gain a high N$_2$O flux compared to that of Integrated Pest management Field School (Figure 3). The N$_2$O flux from conventional management practice in Rembang and Sukabumi was at 1,242.5 µg N$_2$O m$^{-2}$ d$^{-1}$ and 1,279.9 µg N$_2$O m$^{-2}$ d$^{-1}$ respectively. While, the N$_2$O flux from Integrated Pest management Field School management practice in Rembang and Sukabumi was at 903.9 µg N$_2$O m$^{-2}$ d$^{-1}$ and 1,099 µg N$_2$O m$^{-2}$ d$^{-1}$.

Figure 3. Bar diagram of the N$_2$O fluxes from conventional and the Integrated Pest Management Field School at Rembang and Sukabumi.

This research shows that the low rainfall area tends to contribute high N$_2$O flux compared to high rainfall area. Rembang regency has below 1,000 mm year$^{-1}$ rainfall in average while Sukabumi regency has between 2,000 to 4,000 mm year$^{-1}$ rainfall in average. The low N$_2$O flux from high rainfall area commence due to the high nitrate leaching [11]. The rainfall that influence the amount of water that percolates is important in determining the nitrate leaching amount [12]. The nitrogen was leached by the rain before its form is changes into the gas and flush to the atmosphere.
The treatment of organic based fertiliser promotes soil porosity that affects better soil drainage, then, it contributes to low N$_2$O emissions [13]. It shows that the research with Integrated Pest Management Field School in both location Rembang and Sukabumi with organic based fertiliser amendment obtain lower N$_2$O emissions than that in the conventional management by the farmers. Moreover, organic based fertiliser might fill the nitrogen needs by plant, but also reduce the environmental impact such as GHG emissions abatement and enhancing the soil carbon stock [14].

Then, estimation of soil C increase up to 0.13 Mg ha$^{-1}$ yr$^{-1}$ (total SOC accumulation of 10 Tg C after 100 years) if the all agricultural land area were amended with available, underutilized exogenous organic materials (EOM) (urban waste and composted agro-industrial by-products) case in the Mediterranean coastal regions of Spain [15]. Application of plastic mulches on the IPM contribute to inhibit the N$_2$O formation, then it promotes on reducing N$_2$O emission to the atmosphere [16, 17]. The high temperature under plastic mulches [18] tent as the lead to reduce the N$_2$O production.

4. Conclusions
The IPM which applied organic based fertilizer and silver black plastic mulch have no significant effect on N$_2$O emission. The different average of rainfall amount annually also had a no significant on N$_2$O fluxes. However, organic based fertiliser and silver black plastic mulch contribute to reduce N$_2$O emissions from chilli plantation. Then, the high rainfall area tends to have low N$_2$O emissions. Even there was no significant on the IPM and conventional practices.

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References
[1] Jacinthe P A, Dick W A 1997 Soil management and nitrous oxide emissions from cultivated fields in southern Ohio Soil and Tillage Research. 41(3-4): 221-235.
[2] Mattsson B, Cederberg C, Blix L 2000 Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops Journal of cleaner production. 8(4): 283-292.
[3] IPCC 2019 Summary for policymakers. In: Arneth A. (Ed.) Climate Change and Land. An IPCC special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems, Available at: https://www.ipcc.ch/site/assets/uploads/2019/08/4.SPM_Approved_Microsite_FINAL. pdf. Accessed date: 1 October 2019
[4] Sutton M A, Howard C M, Erisman J W, Billen G, Bleeker A, Grønnefelt P, Grinsven H V and Grizzetti B (Eds.) 2011 The European nitrogen assessment: sources, effects and policy perspectives. Cambridge University Press.
[5] Jawal A S, April L S, Aditia M K, Hilman Y 2015 Production Dynamics and Price Volatility of Chili: Anticipation Strategy and Development Policy. Pengembangan Inovasi Pertanian. 8(1): 33-42.
[6] Uhan T S, Nurtika N 1995 The effect of mulches, manure and pesticides to the pests, diseases and yield on the chili plantation. J. Hort. 5(3): 5-15.
[7] Hervani A, Kartikawati R, Ariani M, Setyanto P 2018 N$_2$O Emissions from Rainfed Sugarcane Plantation Bulletin Tanaman Tembakau, Serat & Minyak Industri. 9(1): 10-14.
[8] Khalil M A K, Rasmussen R A, Wang M X, Ren L 1991 Methane Emission from Rice Fields in China Environment Science Technology 25: 979-981.
[9] Badan Pusat Statistik 2019 Kabupaten Rembang dalam Angka (in Bahasa). Retrieved from https://rembangkab.bps.go.id/
[10] Badan Pusat Statistik 2020 Kabupaten Sukabumi dalam Angka (in Bahasa). Retrieved from https://sukabumikab.bps.go.id/

[11] Wang H, Ju X, Wei Y, Li B, Zhao L, Hu K 2010 Simulation of bromide and nitrate leaching under heavy rainfall and high-intensity irrigation rates in North China Plain *Agricultural Water Management*. 97(10): 1646-1654.

[12] Williams J R, Kissel D E 1991 Water percolation: An indicator of nitrogen-leaching potential *Managing nitrogen for groundwater quality and farm profitability*. 59-83.

[13] Schwenke G D, Haigh B M 2016 The interaction of seasonal rainfall and nitrogen fertiliser rate on soil N₂O emission, total N loss and crop yield of dryland sorghum and sunflower grown on sub-tropical Vertosols *Soil Research*. 54(5): 604-618.

[14] Vico A, Sáez J A, Pérez-Murcia M D, Martinez-Tomé J, Andreu-Rodríguez J, Agulló E, ... & Moral R 2020 Production of spinach in intensive Mediterranean horticultural systems can be sustained by organic-based fertilizers without yield penalties and with low environmental impacts *Agricultural Systems*. 178, 102765.

[15] Pardo G, Del Prado A, Martínez-Mena M, Bustamante M A, Martín J R, Álvaro-Fuentes J, Moral R 2017 Orchard and horticulture systems in Spanish Mediterranean coastal areas: Is there a real possibility to contribute to C sequestration? *Agriculture, Ecosystems & Environment*. 238: 153-167.

[16] Ni X, Hao Q J, Chen S J, Li X X, Shi X J and Jiang C S 2019 Effects of plastic film mulching and nitrogen fertilizer application on N₂O emissions from a vegetable field *Huan Jing ke Xue= Huanjing Kexue*. 40(2): 893-903.

[17] Feng D, Hao Q J, Zhang K L, Shi J L, Shi X J and Jiang C S 2017 Effects of plastic film mulching on nitrous oxide emissions from a vegetable field *Huan jing ke xue= Huanjing kexue*. 38(10): 4380-4389.

[18] Berger S, Kim Y, Kettering J and Gebauer G 2013 Plastic mulching in agriculture—friend or foe of N₂O emissions? *Agriculture, ecosystems & environment*. 167: 43-51.