Journal of Environmental Science and Technology

ISSN 1994-7887

science alert

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Journal of Environmental Science and Technology

ISSN 1994-7887
DOI: 10.3923/jest.2017.206.214

Research Article
Triangle Graphs Development for Estimating Methane and Nitrous Oxide Gases Emission from the System of Rice Intensification (SRI)

[1]Nur Aini Iswati Hasanah, [2]Budi Indra Setiawan, [3]Masaru Mizoguchi, [4]Gary Robert Sands, [2]Chusnul Arif and [1]Slamet Widodo

[1]Department of Mechanical and Biosystem Engineering, Bogor Agricultural University, 16680 Bogor, Indonesia
[2]Department of Civil and Environmental Engineering, Bogor Agricultural University, 16680 Bogor, Indonesia
[3]Department of Global Agricultural Sciences, The University of Tokyo, 113-8657, Tokyo, Japan
[4]Department of Bioproducts and Biosystems Engineering, University of Minnesota, 55108 Saint Paul, USA

Abstract

Background and Objective: SRI paddy field occasionally experiences aerobic soil conditions that emit complicated greenhouse gases due to biophysical processes. Understanding these emission patterns, as well as the amount, is important to determine the proper mitigation action to take. This study was carried out to produce a simple method to estimate CH_4 and N_2O using easily measure environmental parameters that might be used to simulate the mitigation of non-CO_2 emissions. **Materials and Methods:** Two Artificial Neural Network (ANN) models were developed to estimate methane (CH_4) and nitrous oxide (N_2O) fluxes based on three selected variables. Based on the models, patterns of CH_4 and N_2O emissions in SRI paddy fields were presented in the form of a triangle graph that can be used to estimate emissions from the easily measured soil pH, soil moisture and air temperature. A sensitivity test (Spearman's correlation test) was used to statistically analyze data. **Results:** ANN models were developed to estimate emission fluxes based on three selected variables of soil pH, soil moisture and air temperature that could produce R^2 0.96 and 0.82 for CH_4 and N_2O, respectively. CH_4 emission in the SRI paddy field increased with air temperature but decreased when soil moisture decreased, while N_2O emissions were mostly stable at all times regardless of changes in soil moisture and air temperature. In general, a higher soil pH produced higher CH_4 and N_2O emissions. The triangle graph shows that in SRI paddy field with soil pH, soil moisture and air temperature range 4.30-5.30, 0.354-0.524 m^3 m^{-3}, 29.0-32.5°C, respectively; it could be a sink or emission of methane until more than 45 mg m^{-2} day^{-1} and be able to emit nitrous oxide to more than 6 µg m^{-2} day^{-1}. **Conclusion:** SRI paddy field can be emission source of CH_4 and N_2O. The graphs can be used to identify mitigation action that can be implemented to lower emissions by showing the set-point value of soil moisture. For example, in an air temperature of 29.4°C and soil pH condition of 4.8, to minimize the emission of CH_4 and N_2O, the soil moisture should be less than 0.418 m^3 m^{-3}.

Key words: Artificial neural network, emission estimation graphs, mitigation, soil moisture, system of rice intensification

Received: February 09, 2017 Accepted: April 24, 2017 Published: June 15, 2017

Citation: Nur Aini Iswati Hasanah, Budi Indra Setiawan, Masaru Mizoguchi, Gary Robert Sands, Chusnul Arif and Slamet Widodo, 2017. Triangle graphs development for estimating methane and nitrous oxide gases emission from the System of Rice Intensification (SRI). J. Environ. Sci. Technol., 10: 206-214.

Corresponding Author: Nur Aini Iswati Hasanah, Department of Mechanical and Biosystem Engineering, Bogor Agricultural University, 16680 Bogor, Indonesia Tel: +622518425583

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The System of Rice Intensification, or SRI, is a set of alternative agricultural practices to increase rice production by changing the management of plants, soil, water and nutrients. In water management, SRI recommends intermittent irrigation (as opposed to permanent flooding in a conventionally managed production system). This process is carried out to improve soil aeration and root development and activity[1]. The drying period creates aerobic conditions that have the potential to reduce emissions of CH_4, which is a potent, non-CO_2 greenhouse gas. While the emission rate is much lower than CO_2, it has more effect per molecule in a period of 100 years (23 times eq-CO_2). However, this benefit may be offset by increased nitrous oxide (N_2O) emission, which has a much higher effect than CH_4 with 296 times eq-CO_2[2].

CH_4 and N_2O are byproducts of microbial survival, which are characterized by a transfer of electrons in the redox reaction[3]. Its emission from a paddy field depends on the source and sink process that is related to soil Eh, which is a major factor controlling the redox processes and showing the aerobic-anaerobic condition of soil. Some studies report that the amount of non-CO_2 emissions from SRI paddy fields are less than half as much in conventional rice production[4]. The average emission of CH_4 and N_2O of SRI paddy cultivation in Indonesia is 2.22 ton ha^{-1} [5]. The contribution of CH_4 to Global Warming Potential (GWP) is very significant, exceeding 87% compared to a 3% contribution from N_2O[6]. The peak of the emissions of CH_4 and N_2O depend on many environmental factors, such as air temperature, soil moisture, soil temperature, EC, soil pH and soil Eh due to their influence on gas production and consumption.

Biogenic CH_4 is formed by methanogens under strictly anaerobic conditions where soil Eh <150 mV. In a paddy field under aerobic soil condition where the soil pores are not completely filled with water, CH_4 is produced likely in saturated soil zones and escapes from the soil to the atmosphere by means of the diffusion process through aerated microsites[7]. Meanwhile, N_2O is a byproduct from two biological processes, namely nitrification and denitrification. In aerobic soil conditions in which O_2 concentration is relatively high, nitrification is the main mechanism to produce N_2O. Mostly, N_2O is produced through nitrate reduction when the soil moisture moderately reduces, or when the nitrate diffuses into a zone that is less oxidized[8]. N_2O emission begins from light textured soils when Eh >400 mV but <400 mV for heavily textured soils[9].

CH_4 and N_2O emissions from SRI paddy fields under aerobic condition are indeed very dynamic and simultaneous processes that are difficult to control, like for the sake of mitigation strategies. However, since these processes involve environmental parameters that are easy to measure, it would be possible to find out what the parameters are that play a significant role in the production of emission. This research aimed to examine environmental parameters that contribute to the release of CH_4 and N_2O emission in paddy fields under aerobic conditions with these objectives: (1) To find such parameters and their sensitivities, (2) To come up with CH_4 and N_2O emission patterns based on the parameters; and (3) To produce a simple method to estimate both emissions that might be used to simulate the mitigation of non-CO_2 emissions.

MATERIALS AND METHODS

Experimental site and data collection: Field experiments were conducted in an experimental site belonging to Bogor Agricultural University, Bogor Regency, West Java Province of Indonesia, located at S 6°33' 48.78"; E 106°43'38.09" with an elevation of 183.4 m above sea level. At this location, there are some plots of paddy fields mainly used for field practices and outdoor experiments. Based on Schmidt-Ferguson Climate Classification[10], this location belongs to A rainfall type (very wet) with the average annual and monthly rainfall being 4046 and 329.7 mm, respectively. In general, the rainy season occurs from September to February. This experiment was conducted between March 10 and June 20, 2015 within one cultivation period using the SRI method (one young seedling of Ciherang variety with 30×30 cm space).

This study used a modeled SRI paddy field in the form of a box made mainly from wood, Fig. 1. This was primarily used to obtain the SRI method. The modeled field was constructed in such a way that the water level could be easily controlled. The box consists of cultivation space having 90 cm length, 60 cm width and 50 cm depth, along with circumference canal that having a water inlet and outlet equipped with solenoid valves and e-Tape water level sensor (Milone Technologies, USA) installed in the canal. A micro-controller was used to detect the water level and subsequently issue commands to each solenoid valve whether to open or close in order to maintain the desired water level in the canal.

In this research, the irrigation water that was used for cultivation, stored in surface irrigation-drainage channel than pass porous media. The porous media has a different conductivity with soil so that water can pass through this media. Water table control is water management that is implemented in this SRI paddy field. The purpose of the system is to control soil moisture in the range that is suitable

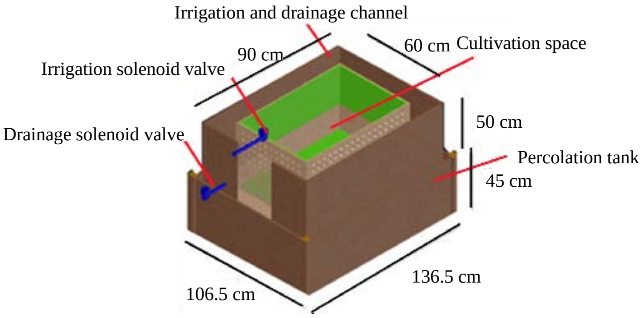


Fig. 1: Experimental box for paddy cultivation

for plant growth to get a high yield. The water table is then controlled according to the desired set point (0 and +2 cm from soil surface during normal and flooding time, respectively).

A weather monitoring station was installed on-site. Air temperature was measured every 30 min by EHT sensors (Decagon Devices, Inc., USA). Soil moisture, soil temperature and EC were measured using 5-TE sensor (Decagon Devices, Inc., USA) that was placed 5 cm under the soil surface every 30 min. Meanwhile, soil pH (pH 3310 SET 2 incl. SenTix®41, Germany) and soil Eh (WTW SenTix, Germany) were measured every week when gas sampling was conducted.

CH_4 and N_2O fluxes were analyzed in the laboratory using two gas samples that were captured each week. The static (closed) chamber method was used for gas sampling. This method is normally used extensively in various ecosystems including paddy fields because of its low cost and simple application.

Gas samples were collected at 0, 10, 20 and 30 min after the chamber top placement and 15 mL of the sample was injected into a gas bottle sample. The CH_4 and N_2O concentrations of the samples were measured by a Gas Chromatograph (GC). The gas flux was calculated to see the fluctuation of CH_4 and N_2O concentration, using Eq. 1[11]:

$$E = \frac{\delta C}{\delta t} \times h_{ch} \times \frac{mW}{mV} \times \frac{273.2}{273.2 + T} \quad (1)$$

Where:

E = CH_4 or N_2O flux (mg m^{-2} min^{-1})
δC = The difference concentration between t_0 and t_c (ppm)
δt = The time interval (minutes)
h_{ch} = Height of the chamber (m),
mW = Molecular weight (g)
mV = Mole volume (22.41 L)
T = Sampling temperature (°C)

The physical properties of textures, porosity, densities, permeability, as well as water retention, were obtained through laboratory analysis. The soil texture is silty clay loam (8% sand, 62% silt and 30% clay) with bulk density 0.90 g cc^{-1} and particle density 2.35 g cc^{-1}. Soil moistures at Field Capacity (FC) and Permanent Wilting Point (PWP) were 45.1 and 27.7%, respectively. The Water Retention Curve (WRC) conformed to the Van Genuchten model with a coefficient correlation (R^2) near unity, whereas the saturated soil moisture was 59.19%, the residual water content was 20.0%, the Air-Entry Value (AEV) was 98.1 cm H_2O and the n and m parameters were 1.3 and 0.2, respectively.

Statistical analysis: A sensitivity test (Spearman's correlation test) was used as statistical analysis to analyze data from six parameters (soil pH, soil Eh, air temperature, soil moisture, soil temperature and EC). It was conducted by using the Analyse-it add-in for Microsoft Excel Professional Plus 2013 (Microsoft, USA) to find out the most sensitive factors for CH_4 and N_2O gases emissions from the SRI paddy field.

Spearman's correlation coefficient (r_s) can satisfactorily show if there is any relationship between variables[12]. The best three parameters that have higher r_s were used as input parameters in the estimation model.

Emission estimation model: Two ANN models were developed with the multi-layer network to estimate CH_4 and N_2O gas emission, separately. Each ANN model consisted of three layers: input layer (three input nodes), hidden layer (three hidden nodes with 1 bias) and output layer (one output node). The learning method used for this ANN model is back propagation. A sigmoid function was selected as the activation.

Weekly fluctuations of input parameters and greenhouse gas emissions could be determined by plotting the average value in gas sampling time. The general relationship between each input parameter and gas emission were analyzed by making a trend line of scattered graphs. The strange trend data were ignored and not used as inputs in the estimation model.

The comparison between CH_4 or N_2O fluxes were observed and estimated values conducted for evaluating the ANN model. The indicators for evaluation used are RMSE and coefficient of determination (R^2).

Simple method for emission calculation: A simple method was proposed to easily calculate CH_4 and N_2O emission in the SRI paddy field. In the proposed new method, emission graphs built using modified ternary-contour diagram in Origin 2017 (OriginLab, USA) were used. The triangle shows CH_4 and N_2O emission contour in various environmental conditions in the form of a two-dimensional plot. Each of the three axes represents crucial environmental parameter values that are pre-determined using a sensitivity test.

The emissions data that are capable of representing variations in environmental conditions are needed to create a good contour in the CH_4 and N_2O emission graphs. Since actual measured data were not able to represent the whole variety of environmental conditions, generated simulation data under previous ANN models were needed.

The use of the triangular emission graphs can serve to quickly represent certain phenomena, such as emitted or sink of CH_4 and N_2O from the SRI paddy field. It was good to determine the mitigation action, by changing the value of an environmental parameter.

RESULTS

Sensitivity analysis of input parameter estimation models: CH_4 and N_2O fluxes in a paddy field are related to some biophysics parameters. Some are more sensitive than others in forming CH_4 and N_2O. The selection of input parameter is very crucial. In the model development, input parameters' sensitivity can be related to the predicting result and model typology[13].

The result of sensitivity analysis tests in several input parameters are shown in Table 1. The correlation coefficient (r_s) varies. If the r_s is a positive value, the CH_4 and N_2O fluxes will tend to increase while the input parameter also increases. Inversely, if r_s is a negative value, the CH_4 and N_2O fluxes will tend to increase while the input parameter decreases.

The result shows that CH_4 and N_2O fluxes in SRI paddy field are related to all input parameters because $r_s \neq 0$. The higher the r_s in sensitivity analysis is, the more influential the parameter is Gajev *et al.*[14]. Based on the sensitivity analysis result, air temperature, soil moisture and soil pH are the most influential to CH_4 and N_2O flux. Other parameters were less influential or uninfluential and could be neglected as input parameters of the estimation model.

Table 1: Sensitivity analysis result of input parameters in estimation model

	r_s	
Parameters	CH_4	N_2O
Soil moisture (m^3 m^{-3})	0.104^3	-0.250^1
Soil temperature (°C)	-0.046^5	0.181^3
EC (dS m^{-1})	0.078^4	0.073^4
Air temperature (°C)	0.187^2	0.033^5
Soil pH	0.250^1	-0.171^2
Soil Eh (mV)	-0.030^6	0.052^6

*r_s value is the correlation coefficient, number index in r_s value showed the rank of sensitivity

ANN estimation models of methane and nitrous oxide gas emission: The average daily air temperature during cultivation season at sites is 27.3°C, while in gas sampling, it ranged from 29-33.8°C with an average of 31.8°C. The ripening phase and heavy precipitation had effects on soil moisture. A water table that is properly controlled in this paddy field makes soil moisture conditions suitable for crop growth, which ranged from 0.278-0.524 m^3 m^{-3} in gas sampling. Meanwhile, the average soil pH in this study is 4.9 with a range value from 4.1-5.6. All of the environmental biophysical conditions resulted in fluctuations in CH_4 and N_2O fluxes emissions. The emission and sinks of methane occur during the growing season, with maximum 422.4 sink and 590.9 mg m^{-2} day^{-1} emit. In the meantime, N_2O sink did not occur at all with average emissions at 3.4 μg m^{-2} day^{-1}. Detailed weekly fluctuations of these parameters are shown in Fig. 2.

The general relationship between the air temperature, soil moisture and soil pH to the CH_4 and N_2O flux are shown in Fig. 3. All of those relationships were non-linear relations. This result shows that the ANN model, rather than having the capability to capture the non-linearity of a system, can be a solution to making a model of CH_4 and N_2O flux emission in a SRI paddy field.

The soil Eh data fluctuated during crop season. After it was corrected with pH, it ranged from 237.7-699.0 mV with an average of 480.5 mV. However, it never had a negative value because the Eh measurement and gas sampling were not conducted at the time of flooding; this field also uses intermittent irrigation with very short flooding time. Most of the soil data showed values of more than 300 mV, which is categorized in aerated (oxid) conditions, except in week 12 and 13. Therefore, the data in those weeks were not used as input in ANN models.

Environmental conditions in 0 week after transplantation were not yet stable (seen from the different soil moistures), which resulted in the data for that week being ignored and not used as input model. CH_4 flux values that were very

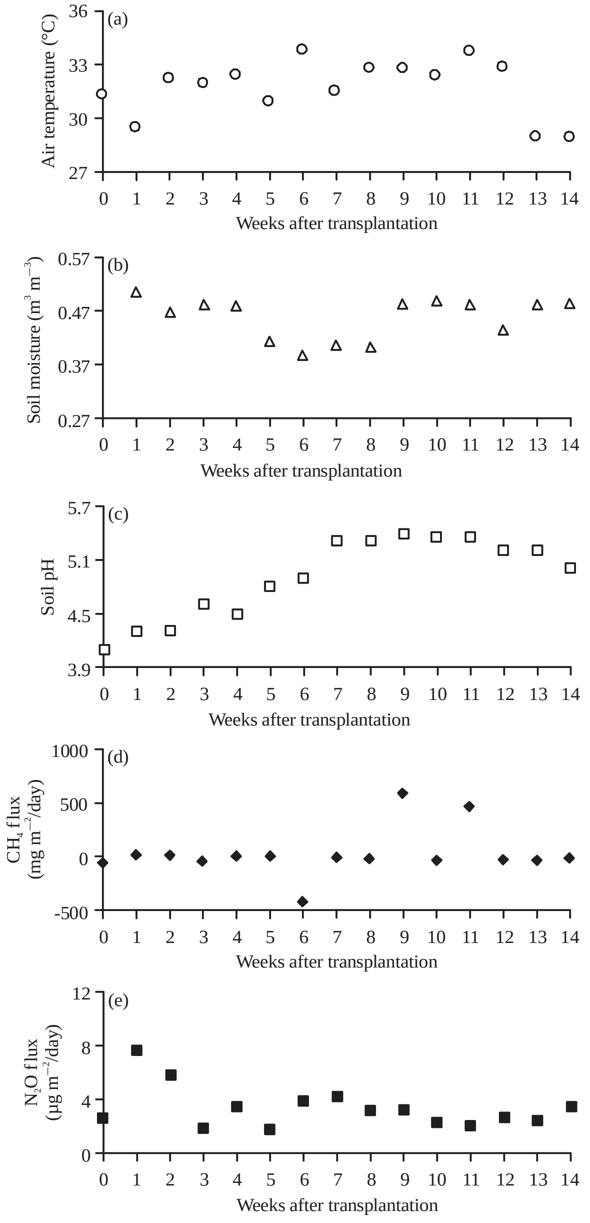


Fig. 2: Value of (a) Air temperature, (b) Soil moisture, (c) Soil pH (d) CH_4 and (e) N_2O flux

different suddenly occurred in 6, 9 and 11 weeks after transplantation. Data from those weeks were also discharged as inputs in the CH_4 ANN model. The neglected data from 1 and 2 weeks after transplantation were performed at the N_2O estimation ANN model due to sudden high fluctuation. Under and over measure emissions could have happened because of the effects of turbulence and pressure disturbances in the chamber and also leakages in the chamber or bottle sample, leading to contamination from ambient air and error in GC analysis which is as a result of the injection system[15–17].

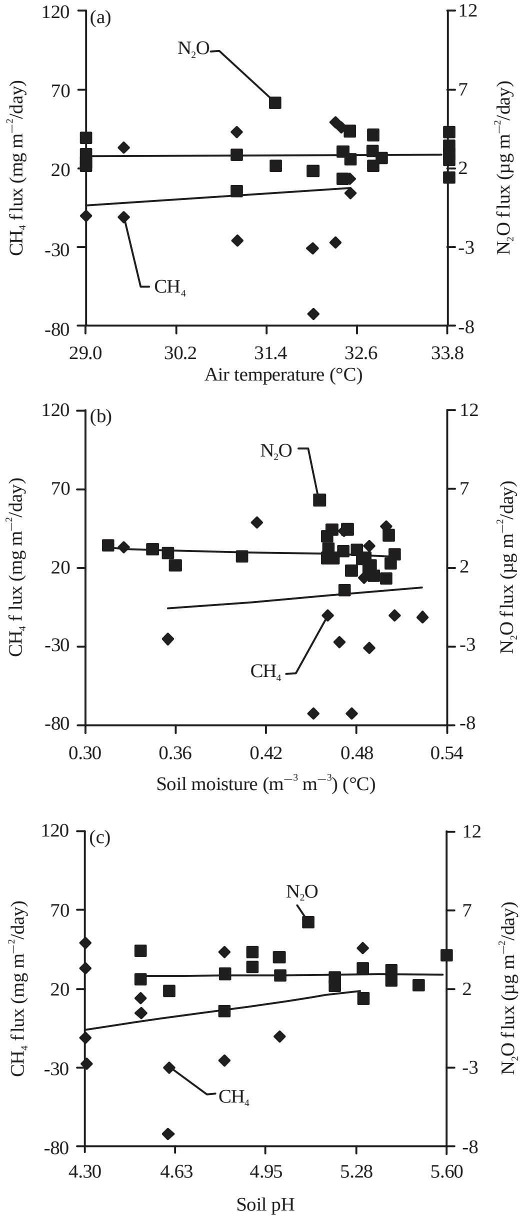


Fig. 3: Relationship between CH_4 and N_2O flux in aerobic paddy field with (a) Air temperature (b) Soil moisture and (c) Soil pH

Two ANN models were developed for estimating CH_4 and N_2O gas emissions from crucial environmental parameter data in SRI paddy cultivation during various conditions. The ANN models each have three input nodes (input parameters that passed a sensitivity analysis test) and one output node (CH_4 and N_2O flux, separately). During the training process, the weight is adjusted in order to make the actual outputs (prediction) close to the target (measured data) output during the iterations to minimize the error of estimation. As a result, the RMSE values of the ANN models were 0.40 and 0.19.

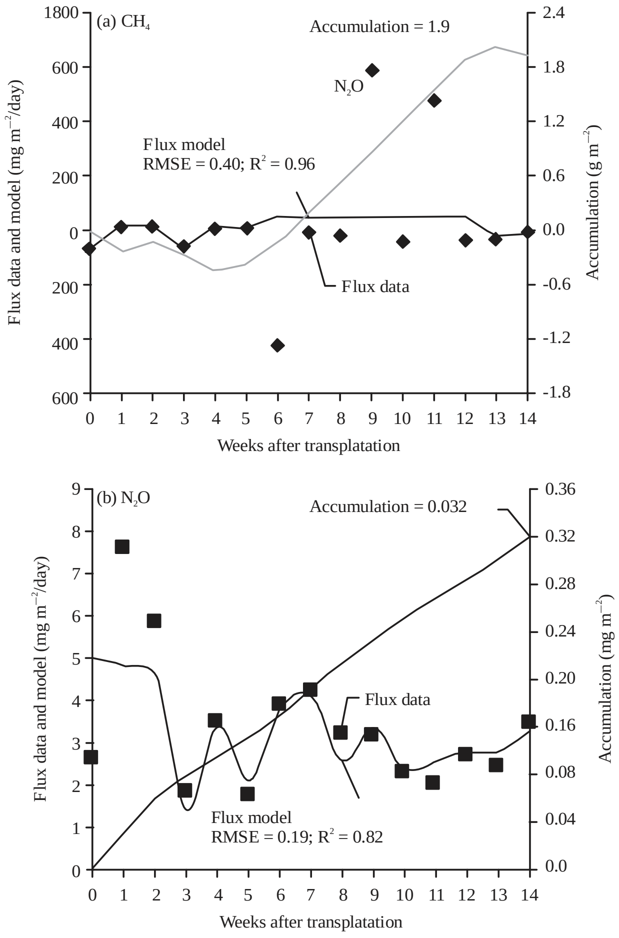


Fig. 4: ANN model and validation curve of (a) CH_4 and (b) N_2O emission

Moreover, the coefficient determination(R^2) values were 0.96 and 0.82 for CH_4 and N_2O, respectively, as shown in Fig. 4. That result showed that this model could be accepted as a suggested method to estimate CH_4 and N_2O fluxes in a SRI paddy field with only three parameters in the input layer.

Quick emission estimation using develop triangle graph: ANN models were used in this study to simulate non-CO_2 greenhouse gas emissions in various environmental conditions. The generated emissions data were then used as inputs in contour mapping in the estimation graph making, as well as in the estimation graphs shown in Fig. 5.

The graphs correlate three independent input parameters to provide easy readable CH_4 and N_2O gas emission estimation, reading instructions shown in Fig. 6. These graphs clearly show the characteristics of greenhouse gas emissions in various environmental conditions in a SRI paddy field.

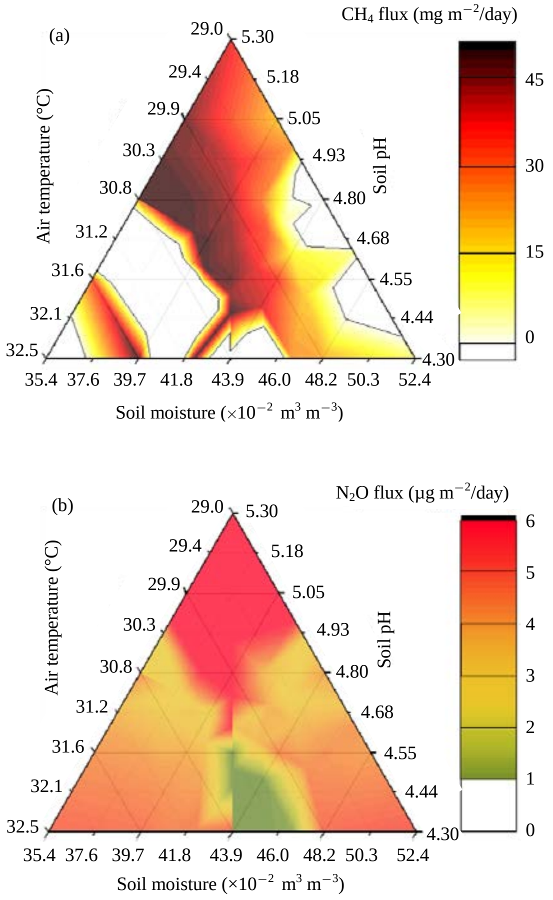
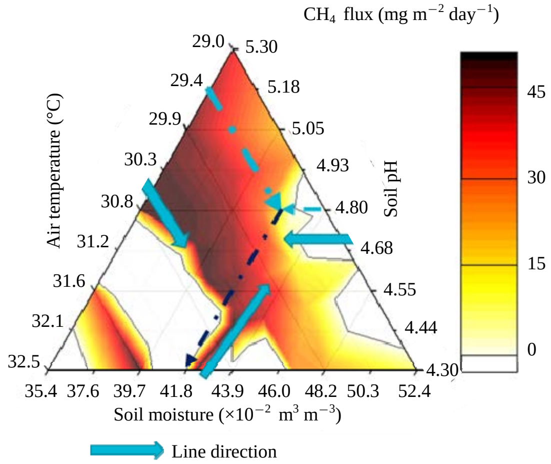


Fig. 5(a-b): Triangle estimation graph of (a) CH_4 and (b) N_2O flux



Example:

Air temperature = 29.4°C
Soil pH = 4.8

Air moisture set-point = 0.418 $m^3 m^{-3}$
Mitigation:
Reduce soil moisture = 0.418 $m^3 m^{-3}$

Fig. 6: Reading instruction and mitigation strategy

DISCUSSION

Air temperature, soil moisture and soil pH are founded as the most influential to CH_4 and N_2O flux. The findings result agree in general with most previous studies. Both of CH_4 and N_2O fluxes tended to increase at higher air temperature[18-19]. In wet soil (high soil moisture), the oxygen diffusion rates are low. This condition triggers the oxidation of CH_4 because the availability of oxygen is the major factor limiting methanotroph, which results in higher methane emission by reason of high un-oxidized methane. Less CH_4 occurred in lower pH because more methanogens (that produce methane) started to appear when pH increased. Aerobic methane oxidation, MO, requires both oxygen and methane. N_2O emission is different, as it will decrease at that condition due to the decrease in nitrification rates[20]. It will be higher at lower pH because the nitrate accumulation was higher[21] but it could be different in acid conditions because an inhibition of nitrite production could happen[22].

The estimation graphs were made to easily know the character of emissions in various environmental conditions. To make the contours of the emissions in graphs, CH_4 and N_2O emission data in various environmental conditions were needed. In terms of that, several observations from the field were required to collect such data. It should be noted that CH_4 and N_2O flux observations from the field were not easily conducted. It requires high cost, time and trained human resources[23]. An easy way of knowing the actual CH_4 and N_2O fluxes to indicate gas emission was highly needed.

In this study, a greenhouse gas emission estimation model was built based on SRI paddy field experimental data in aerobic conditions. The ANN models in this study used three input nodes (air temperature, soil moisture and soil pH) and one output node (CH_4 and N_2O flux, separately). The coefficient determination (R^2) values were 0.96 and 0.82 for CH_4 and N_2O respectively, while in another study, a greenhouse gas emission estimation model was also built based on paddy field experimental data in aerobic and anaerobic conditions using different parameter inputs. ANN models achieved reasonable predictive power, producing R^2 of 0.72 and 0.70 for CH_4 and N_2O, respectively in Setiawan *et al.*[6] using soil moisture, air temperature and soil pH input. Higher R^2 levels from a greenhouse gas prediction ANN model found in Arif *et al.*[23] are 0.93 and 0.73 for CH_4 and N_2O, using soil moisture, soil temperature and EC inputs.

The CH_4 emission from the SRI paddy field based on this study generally increased when the air temperature increased, which is the same as with Jugold *et al.*[24]. However, it should be noted that in higher air temperature, the soil moisture decreased. This leads to the increase of oxygen availability in the soil, thus allowing it to oxidize and sink more methane, as mentioned before. The higher emissions occur in higher pH. Benstead and King[25] showed that methane uptake by methanotroph occurred over a wide pH range (3.5-7.5); however, methanogen is more sensitive. Increasing pH will increase fermentative activity and generally the availability of acetate (and presumably H_2); furthermore this increase in methanogenic substrates is likely partially responsible for the increase in CH_4 production at higher pH[19,26].

N_2O emission decreases at lower pH; the same condition appears in Mosier *et al.*[22]. As previously mentioned, nitrification (NO to N_2O) mostly controls the N_2O emission in oxid conditions[8]. NO was produced through the chemical decomposition of nitrite, which in turn was a product of biological nitrification. Although NO formation is likely due to the chemical decomposition of nitrite at low pH, nitrite is produced in large part by biological processes; as such, an inhibition of nitrite production could happen[22]. The N_2O emission is not big, as founded at Meijide *et al.*[27]. It occurs almost in all soil moisture and air temperature conditions. The emission decreases when air temperature increases due to the decrease in nitrates rates, it was the same with conditions of Benoit *et al.*[18].

The CH_4 and N_2O flux estimation graphs were helpful in knowing the amount of non-CO_2 greenhouse gases that occur from a SRI paddy field in quick time. It can be used to identify mitigation action that can be implemented to lower emissions. Based on the non-CO_2 gas emission pattern in the SRI paddy field, maintaining soil moisture will be a great way to mitigate greenhouse gas emission. Soil moisture is easier to control than air temperature and soil pH. For example, in an air temperature of 29.4°C and soil pH condition of 4.8, to minimize the emission of CH_4 and N_2O, the soil moisture should be less than 0.418 (Fig. 6).

However, maintaining soil moisture in crop production only in the range between FC and PWP is a way to lower greenhouse gas emission without interfering with plant growth. Deciding the best soil moisture set-point in cultivation for mitigating greenhouse gas emission also needs be based on the kind of crop that is cultivated by the farmer. The impact of it on the crop yield needs to be considered.

It was clear that the SRI method in paddy cultivation can reduce CH_4 emission and emit small amounts of N_2O emission. Nevertheless, we noticed from this cultivation that controlling the water level in SRI to get good soil moisture also has a potential to reduce the non-CO_2 greenhouse gases while still giving a good yield, as seen in Table 2. The average paddy height, total and productive tiller numbers are 132 cm, 72 and

Table 2: Resume of GHG emission during ideal SRI paddy cultivation

Items	Value
Yields (kg m^{-2})	1.64
Straws (kg m^{-2})	3.70
Roots (kg m^{-2})	6.09
Biomass (kg m^{-2})	11.44
Carbon (kg m^{-2})	5.94
CH_4 (kg-CO_2 m^{-2})	0.04
N_2O (kg-CO_2 m^{-2})	0.00001
GHG Emission-non CO_2 (kg-CO_2 m^{-2})	0.04
Emission factor (kg-CO_2 kg^{-1} yields)	0.03

47 tillers, respectively in harvesting time with 1.64 kg m^{-2} yields. The aerobic condition during the cultivation is able to make the GHG emission only 0.04 kg-CO_2 m^{-2}.

In real paddy fields, it is not easy to apply the SRI elements, particularly in water management[28]. That is the reason why the emission factor that is reported from real fields in Indonesia (0.295-0.343) is much higher than this study (0.03)[5]. It was indicated that better water management in a SRI paddy field will not only influence the efficiency of water use but will also lower the global warming potential. Thus, management of soil moisture in a SRI paddy field based on the estimation graph presented will lower the emission factor from the SRI cultivation practice.

CONCLUSION

From the modeled paddy field experiment, it found that a SRI paddy field has the potential to emit CH_4 and N_2O; it was also found that some environmental parameters (air temperature, soil moisture and soil pH) are influential to this emission. The CH_4 emission tended to increase when the air temperature increased and soil moisture decreased and generally at higher pH. The N_2O emission occurs almost in all soil moisture and air temperature conditions but decreases at lower pH. The CH_4 and N_2O emissions in a SRI paddy field can be estimated accurately using triangle graph that developed by using generated data from ANN model. The simple triangle graphs can be used to easily estimate soil moisture set-point which is expected to lower emissions. From the emission graphs, we conclude that soil moisture control is the best way to mitigate greenhouse gas emissions.

SIGNIFICANCE STATEMENTS

This study discovers the possible easy calculation of CH_4 and N_2O fluxes emission in the SRI paddy field using triangle graphs that can be beneficial for making mitigation action. It will help the researcher to uncover the critical areas of non-CO_2 emission pattern from SRI paddy field that many researchers were not able to explore. This work emphasized on a new theory of CH_4 and N_2O source and sink process from SRI paddy field that mostly having aerobic condition.

ACKNOWLEDGMENTS

This work was supported by grant numbers 081/SP2H/PL/Dit.Litabmas/VI/2014, 157/SP2H/ PL/Dit. Litabmas/II/2015 and 180/SP2H/PL/Dit.Litabmas/II/2016 under PMDSU research project "Automation of Irrigation and Drainage to Improve the Productivity of Land and Water and Reduce Greenhouse Gas Emissions Factor" from the Ministry of Research, Technology and Higher Education, Indonesia. Paperwork was supported by the same ministry, especially by Directorate General of Resources for Science, Technology and Higher Education through PKPI scholarship. We greatly appreciate the warm reception from Department of Bioproducts and Biosystems Engineering, University of Minnesota and Department of Global Agricultural Sciences, The University of Tokyo during paperwork activity. I would additionally like to thank Prof. K. Noborio (Meiji University) for his scientific advice and discussion about greenhouse gases emission from agricultural soil.

REFERENCES

1. Uphoff, N., A. Kassam and A. Thakur, 2013. Challenges of increasing water saving and water productivity in the rice sector: Introduction to the system of rice intensification (SRI) and this issue. Taiwan Water Conserv., 61: 1-13.
2. Ramaswamy, V., O. Boucher, J. Haigh, D. Hauglustaine and J. Haywood *et al*., 2001. Radiative Forcing of Climate Change. In: Climate Change 2001: The Scientific Basis, Joos, F. and J. Srinivasan (Eds.). Cambridge University Press, Cambridge, UK., pp: 349-416.
3. Li, C.S., 2007. Quantifying greenhouse gas emissions from soils: Scientific basis and modeling approach. Soil Sci. Plant Nutr., 53: 344-352.
4. Gathorne-Hardy, A., D.N. Reddy, M. Venkatanarayana and B. Harriss-White, 2013. A Life Cycle Assessment (LCA) of greenhouse gas emissions from Sri and flooded rice production in SE India. Taiwan Water Conserv., 61: 110-125.
5. Setiawan, B.I., A. Imansyah, C. Arif, T. Watanabe, M. Mizoguchi and H. Kato, 2014. SRI paddy growth and GHG emissions at various groundwater levels. Irrigation Drainage, 63: 612-620.
6. Setiawan, B.I., A. Irmansyah, C. Arif, T. Watanabe, M. Mizoguchi and H. Kato, 2013. Effects of groundwater level on CH_4 and N_2O emissions under SRI paddy management in Indonesia. Taiwan Water Conserv., 61: 135-146.

7. Peyron, M., C. Bertora, S. Pelissetti, D. Said-Pullicino and L. Celi *et al*., 2016. Greenhouse gas emissions as affected by different water management practices in temperate rice paddies. Agric. Ecosyst. Environ., 232: 17-28.
8. Hou, A.X., G.X. Chen, Z.P. Wang, O. van Cleemput and W.H. Patrick, 2000. Methane and nitrous oxide emissions from a rice field in relation to soil redox and microbiological processes. Soil Sci. Soc. Am. J., 64: 2180-2186.
9. Wlodarczyk, T., Z. Stepniewska and M. Brzezinska, 2003. Denitrification, organic matter and redox potential transformations in cambisols. Int. Agrophys., 17: 219-227.
10. Pratiwi, E., E. Santoso and M. Turjaman, 2010. [Habitat characteristics of gaharu inducing tree species (*Aquilaria* spp.) in several forest plantations in West Java]. Info Hutan, 7: 129-139.
11. IAEA., 1992. Manual on measurement of methane and nitrous oxide emisssions from agriculture. AEA TECDOC No. 674, International Atomic Energy Agency, Vienna, AT., pp: 57.
12. Bolboaca, S.D. and L. Jantschi, 2006. Pearson versus Spearman, Kendall's Tau correlation analysis on structure-activity relationships of biologic active compounds. Leonardo J. Sci., 9: 179-200.
13. Vilimek, M., 2014. An artificial neural network approach and sensitivity analysis in predicting skeletal muscle forces. Acta Bioeng. Biomech., 16: 119-127.
14. Gajev, I., W. Ma and T. Kozlowski, 2014. Sensitivity analysis of input uncertain parameters on BWR stability using TRACE/PARCS. Ann. Nucl. Energy, 67: 49-58.
15. Kutzbach, L., J. Schneider, T. Sachs, M. Giebels and H. Nykanen *et al*., 2007. CO_2 flux determination by closed-chamber methods can be seriously biased by inappropriate application of linear regression. Biogeosciences, 4: 1005-1025.
16. Hutchinson, G.L. and G.P. Livingston, 2001. Vents and seals in non-steady-state chambers used for measuring gas exchange between soil and the atmosphere. Eur. J. Soil Sci., 52: 675-682.
17. Barwick, V.J., 1999. Sources of uncertainty in gas chromatography and high-performance liquid chromatography. J. Chromatogr. A, 849: 13-33.
18. Benoit, M., J. Garnier and G. Billen, 2015. Temperature dependence of nitrous oxide production of a luvisolic soil in batch experiments. Process Biochem., 50: 79-85.
19. Kumar, A., A.K. Nayak, S. Mohanty and B.S. Das, 2016. Greenhouse gas emission from direct seeded paddy fields under different soil water potentials in Eastern India. Agric. Ecosyst. Environ., 228: 111-123.
20. Huang, Y., J. Zou, X. Zheng, Y. Wang and X. Xu, 2004. Nitrous oxide emissions as influenced by amendment of plant residues with different C:N ratios. Soil Biol. Biochem., 36: 973-981.
21. Martikainen, P.J., M. Lehtonen, K. Lang, W. de Boer and A. Ferm, 1993. Nitrification and nitrous oxide production potentials in aerobic soil samples from the soil profile of a finnish coniferous site receiving high ammonium deposition. FEMS Microbiol. Ecol., 13: 113-121.
22. Mosier, A.R., J.A. Delgado and M. Keller, 1998. Methane and nitrous oxide fluxes in an acid oxisol in Western Puerto Rico: Effects of tillage, liming and fertilization. Soil Biol. Biochem., 30: 2087-2098.
23. Arif, C., B.I. Setiawan, S. Widodo, Rudiyanto, N.A.I. Hasanah and M. Mizoguchi, 2015. [Development of artificial neural network to predict greenhouse gas emissions from rice fields with different water regimes]. J. Irigasi, 10: 1-10.
24. Jugold, A., F. Althoff, M. Hurkuck, M. Greule, K. Lenhart, J. Lelieveld and F. Keppler, 2012. Non-microbial methane formation in oxic soils. Biogeosciences, 9: 5291-5301.
25. Benstead, J. and G.M. King, 2001. The effect of soil acidification on atmospheric methane uptake by a maine forest soil. FEMS Microbiol. Ecol., 34: 207-212.
26. Ye, R., Q. Jin, B. Bohannan, J.K. Keller, S.A. McAllister and S.D. Bridgham, 2012. pH controls over anaerobic carbon mineralization, the efficiency of methane production and methanogenic pathways in peatlands across an Ombrotrophic-minerotrophic gradient. Soil Biol. Biochem., 54: 36-47.
27. Meijide, A., C. Gruening, I. Goded, G. Seufert and A. Cescatti, 2017. Water management reduces greenhouse gas emissions in a mediterranean rice paddy field. Agric. Ecosyst. Environ., 238: 168-178.
28. Arif, C., K. Toriyama, B.D.A. Nugroho and M. Mizoguchi, 2015. Crop coefficient and water productivity in conventional and System of Rice Intensification (SRI) irrigation regimes of terrace rice fields in Indonesia. J. Teknol., 75: 97-102.