Nitrous Oxide Emission from Oil Palm Plantation – Why is it Important?

Norliyana Zin Zawawi*

ABSTRACT

Nitrous oxide (N_2O) emission from agriculture is one of the most important sources of greenhouse gases (GHG). Even though oil palm is the most widely cultivated agricultural crop in the tropics, we have relatively poor understanding of the range and magnitude of N_2O fluxes from oil palm. Due to the rapid nitrogen (N) cycling through microbial activities, tropical soils are likely to release large amounts of N_2O into the atmosphere, which is mainly associated with the fertiliser use in plantations. The spatial heterogeneity in oil palm ecosystems may also contribute to N_2O fluxes in tropical soils due to differences in ground disturbances and management levels. Despite the fact that N_2O fluxes from agricultural systems are strongly influenced by fertiliser application, data on oil palm plantations established on mineral or peat soils are still limited. Since N_2O emissions from fertiliser application account for more than 51% of total plantation emissions, this review aims to summarise the importance of N_2O studies for oil palm to obtain more accurate N_2O emissions data. This is to have a better understanding on the N dynamics of the oil palm, thus achieving the goal of sustainable palm oil.

ABSTRAK

Pelepasan gas nitrus oksida (N_2O) daripada pertanian merupakan sumber utama kepada gas rumah hijau. Walaupun tanaman sawit sangat meluas di negara-negara tropika, namun kita masih kekurangan data mengenai julat dan magnitud pelepasan gas N_2O daripada penanaman sawit. Tanah tropika berpotensi untuk melepaskan gas N_2O ke atmosfera kesan daripada kitaran nitrogen melalui aktiviti mikrob dalam tanah hasil daripada aktiviti pembajaan di dalam ladang. Kepelbagaian ekosistem di ladang sawit juga menyumbang kepada fluks gas N_2O bergantung kepada pengurusan tanah. Walaupun telah diketahui bahawa penggunaan baja di ladang mempengaruhi fluks gas N_2O, kita masih kekurangan data sama ada daripada penanaman di tanah mineral atau tanah gambut. Oleh sebab pelepasan gas N_2O mewakili 51% daripada jumlah keseluruhan pelepasan gas di ladang, artikel ini bertujuan untuk menekankan kepentingan kajian ke atas pelepasan gas N_2O dari penanaman sawit bagi mendapatkan data gas N_2O yang lebih tepat dan jitu bagi tujuan memahami kitaran nitrogen sawit untuk mencapai penghasilan minyak sawit yang lebih mampan.

Keywords: nitrous oxide, fertiliser, soil.

INTRODUCTION

Over the past 200 years, the concentration of greenhouse gases (GHG) in the atmosphere has increased due to human's activities. The increasing concentration of GHG not only has a harmful impact on the environment, but also has negative consequences for mankind, plants and animals. The United States Environmental Protection Agency (EPA) has concluded that agricultural activities are the primary human-related sources of nitrous oxide (N_2O). In Europe, the agriculture sector was identified as the second largest source of GHG contributing about 10% to the total amount of European anthropogenic GHG emissions (Neftel *et al*., 2006).

Nitrous oxide is a potent GHG and the third most important climate-forcing agent after carbon dioxide (CO_2) and methane (CH_4) (Snyder *et al*., 2009). Nitrous oxide has a global warming potential (GWP) of 298 times larger than an equal mass of CO_2 over a 100-year period (IPCC, 2006). It also catalyses the destruction of ozone in the stratosphere (Hergoualc'h *et al*., 2009) due its long lifespan, approximately 120 years. Gaseous emissions of N_2O, nitrogen oxides (NO_x) and nitrogen gas (N_2) are produced by soil microorganisms through nitrification and denitrification. Tropical soils are considered to be important sources of N_2O due to rapid nitrogen (N) cycling (Pardon *et al*., 2016). Nitrous oxide (N_2O) produced from anaerobic soil by denitrification, where the reduction of nitrate (NO_3^-) to N_2O or N_2 occurs primarily at 60%-70% water-filled pore space (WFPS) (Davidson, 1991; Bateman and Baggs, 2005), due to decreased oxygen supply and acidic soil conditions (Simek and Cooper, 2002). Nitrification is the aerobic oxidation of ammonium (NH_4^+) or ammonia (NH_3) to nitrite (NO_2^-) and

* Malaysian Palm Oil Board, 6, Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia.
E-mail: norliyanazz@mpob.gov.my

nitrate (NO_3^-), with N_2O production occurring under oxic or anoxic (nitrifier denitrification) conditions at 35%-60% of WFPS (Bateman and Baggs, 2005). Oxic denitrification normally occurs in the top few millimetres of the soil when the soils are at relatively low to moderate soil moisture (Skiba *et al.*, 2012; Davidson, 1991). The emission factor (EF), the ratio of N_2O-N emission to input of N fertiliser, is often estimated using the default Intergovernmental Panel on Climate Change (IPCC) value as 1% for mineral soil and 16% for tropical organic soil (peat soils) (IPCC 2006). However, there are large variations in EF due to differences in environment, crops, and management.

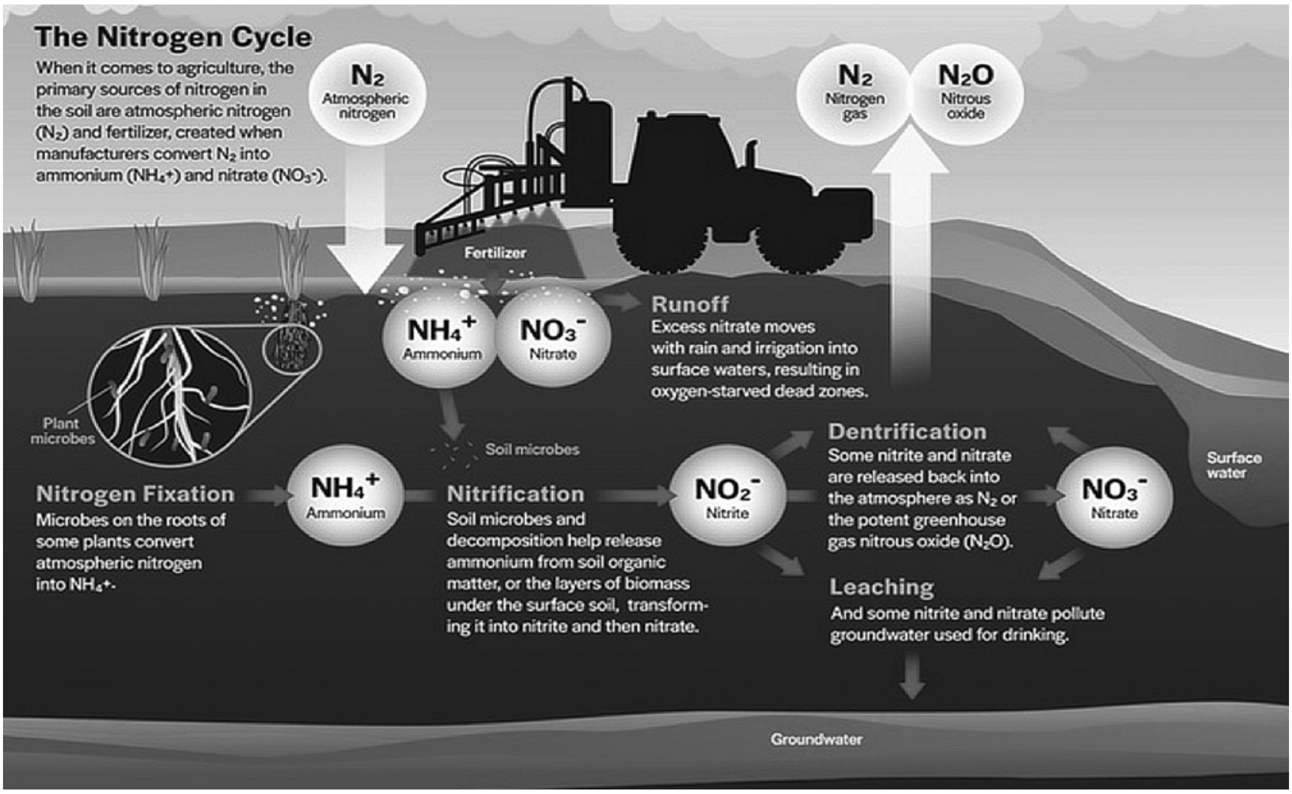
In oil palm plantations, the addition of fertilisers (*Figure 1*) is a common practice to increase the yield potential of the crop due to the inadequate nutrient supply from organic sources. Fertiliser application constitutes 46% to 85% of the field costs in a plantation (Caliman *et al.*, 2001; Goh and Po, 2005; Silalertruksa *et al.*, 2012; Goh and Härdter, 2003). In 2008 alone, the commercial plantation in Malaysia consumed 1.29 million tonnes of N fertilisers (Law *et al.*, 2012). The main nutrients present in fertiliser are nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg), which can be applied to promote plant growth and maximise fruit production. As the N fertiliser is the most common limiting nutrient for crop production, the use of synthetic N fertilisers (such as urea) and inorganic sources (such as ammonium sulphate and ammonium nitrate) is expanding globally to satisfy the demand in the agricultural industry, especially the growing demand from palm oil industry.

Figure 1. Examples of compound fertiliser used in oil palm plantation.

Even though the use of N fertilisers is essential in the agricultural production of oil palm, without a proper management, their usage can lead to negative impacts to the environment. Nitrogen application is widely recognised to be a key factor in controlling N_2O emissions (Baumert *et al.*, 2005; Aini, *et al.*, 2015) as the application of N to the palm circle will result in strong localised production of N_2O due to substrate (NO_3^-) supply. The combination of temporal variability, warm temperatures, frequent rainfall in tropical climates, N fertiliser and high levels of organic matter in soil may enhance N_2O production through nitrification and denitrification (Tiedje, 1994; Bouwman, 1996; Bremner, 1997; Toma *et al.*, 2011), regardless of soil type and the amount of N fertiliser application. The example of the N budget in oil palm plantations and the N fertiliser cycle are shown in *Figure 2*.

KNOWLEDGE GAPS

Although existing measurements have been carried out over the past 50 years, the input of N cycling in oil palm plantations and the impact of environmental conditions and management practices on N losses have not yet been fully studied (Pardon *et al.*, 2016). The N budgets (balances) have been a valuable tool in expanding our knowledge of the N cycle. However, in order to accurately estimate the net loss and to ascribe this loss to a particular process, all other major N-transformations must be considered. Therefore, N budgets are of inestimable value in contributing to our understanding on the processes of mineralisation, immobilisation, plant assimilation, leaching, and nitrate reduction (*e.g.* denitrification). Addressing the above areas of concern requires more detailed and in-depth studies. While many studies have been performed on GHG emissions in tropical soils, most studies have focused on the C balance and C dynamics, while N_2O emissions remain poorly documented. While few studies have documented the N_2O fluxes



(Source: DISCOVER: Tracking Nitrogen through the Soil to Reduce Pollution from Agriculture from July/August 2013 Issue).

Figure 2. The N fertiliser cycle.

from the oil palm plantation (Fowler *et al*., 2011; Ishizuka *et al*., 2005; Bouwman *et al*., 2002; Kusin *et al*., 2016) the amount of nitrogen fertiliser used in an oil palm plantation of different stages (immature and mature), very few researches have been done on peat soil (Melling *et al*., 2007; Toma *et al*., 2011; Sakata *et al*., 2015).

Previous studies have shown that the application of fertilisers as nitrogen input is likely to be a key factor in controlling N_2O emissions in managed tropical soils. Even though the N_2O flux magnitudes reported by various studies vary widely, an increase in N_2O fluxes post-fertiliser application is commonly observed, regardless of soil type and the amount of N fertiliser applied. In agriculture, high N fertiliser inputs are widely recognised as the major driver of N_2O emissions (Baumert *et al*., 2005; Aini *et al*., 2015). The Tier 1 emission factor (IPCC, 2006) approach assumes a linear relationship between N input and N_2O emission. Although N_2O fluxes are expected to increase in response to the fertiliser treatment, the timing and magnitude of the N_2O emissions can vary substantially between the two fertilisers at the same dose, mainly due to the high variation in field environmental factors. The N_2O emissions depend on concomitant factors, such as plant demand and uptake, climatic conditions during and post fertiliser application, fertiliser type, application method, soil properties and the cultivated crops present (Corre *et al*., 1995; MacKenzie *et al*., 1998; Nagano *et al*., 2012). The combination of vegetational differences with warm temperatures, frequent rainfall in tropical climates, application of N fertiliser and high levels of organic matter in soil have a major impact on the production and emission of N_2O from soil through nitrification and denitrification (Tiedje, 1994; Bouwman, 1996; Bremner, 1997).

THE SIGNIFICANCE OF N_2O STUDIES

In order to achieve the goal of sustainable palm oil, it is necessary to understand the root cause of the issue by studying the N dynamics of oil palm. To assess the N budgets of an oil palm plantation, it is important to have every detail on the N transformations involved. The N_2O studies will provide a more accurate estimation of N_2O fluxes released from the soil and strengthen the current understanding of how soil N_2O emissions are affected by environmental conditions. More precise data on N_2O emission can contribute to other on-going research, particularly in understanding the relationship between emissions and the common agricultural practices, such as the application of fertiliser. This will aid researchers, managers and policy makers in developing the best agricultural practices and alternatives that reduce N_2O emissions from oil palm and hence mitigate the climate change.

TABLE 1. STUDIES ON N_2O EMISSIONS FROM VARIOUS TYPES OF SOIL AND CROP

Soil type	Crops	Range of N_2O (kg N ha^{-1} yr^{-1})	Reference
Boreal peatland	Barley and grass	8.3 - 11	Maljanen *et al*. (2003)
Boreal peatland	Grass, barley, potatoes	2.6 - 24.1	Regina *et al*. (2004)
	Fallow	3.8 - 37	
Mineral soils	Oil palm	0.9 - 6.4	Bouwman *et al*. (2002)
Mineral soils	Oil palm	4.4	Skiba *et al*. (2012)
Mineral soils	Oil palm	4.4	Fowler *et al*. (2011)
Tropical peatland	Oil palm	1.2	Melling *et al*. (2007)
Tropical peatland	Cassava, maize and vegetables	12.6 - 698	Toma *et al*. (2011)
Tropical peatland	Maize, spinach and cassava	21 - 259	Takakai *et al*. (2006)

FUTURE RECOMMENDATION

In order to meet the growing demand for vegetable oils and biofuels, oil palm planting is rapidly expanding, and the industry has a responsibility to mitigate and improve environmental degradation due to mismanagement of natural resources and energy (Kushairi *et al.,* 2018). While meeting the global demand for oil palm production, one way to optimise the usage of N fertiliser is to implement intensive crop management practices, using the principle of ecological intensification to enhance nutrient absorption efficiency while achieving high yields. Efficient utilisation is the key to the solution of problems concerned with high crop production, minimal pollution, and energy conservation. There is still a need to establish the best management practices that limit atmospheric impacts without reducing productivity of oil palm. To this end, the most appropriate experimental design is to concomitantly monitor palm production and N_2O emissions under varying N-input rates.

At present, there are few studies on N_2O emissions from oil palm plantation on tropical soils, especially peat soils. During the establishment of oil palm cultivations on peat soil, a large amount of N_2O may be continuously emitted. There is a scarcity of information on the spatial and temporal variability of N_2O fluxes in oil palm plantations. Moreover, it is strongly influenced by soil and vegetation management practices, such as fertiliser and pesticide application, weeding, variation in vegetation and cover crop, and the level of disturbance of the soil. Consequently, it is difficult to derive accurate area-weighted N_2O flux estimates or predict the impact of N_2O fluxes on vegetation or soil management practices. For example, Melling *et al*. (2007) estimated N_2O emission in the Malaysian oil palm plantation to be 566 kg CO_2-eq ha^{-1} yr^{-1}; however, uncertainties were large and data were too limited to distinguish the background emissions from event-based emissions due to fertiliser application. Therefore, it is necessary to study N_2O emissions in tropical agricultural soils in order to provide more accurate emission factor values for oil palm cultivation, its uncertainty, and determine the factors that influence its changes.

CONCLUSION

As N_2O is the highest contributor of GHG from agriculture sector with a global warming potential (GWP) of 298 times greater than an equal mass of CO_2, it is important to have accurate estimation of N_2O fluxes released from the soil to understand the relationship between emissions and the common agricultural practices, such as the application of fertiliser. The variability and pattern of emissions observed can be used to comprehend the entire process and develop measures to mitigate adverse environmental impacts, thereby reducing the negative perspectives of palm oil for a better future. Due to the limited research on N_2O emissions from oil palm in Southeast Asia, the results could serve as a benchmark for the industry as well as to improve their environmental performance. From here, good-practice guidelines and greener methods could be developed by researchers and conducted by the planters to achieve an eco-friendly and sustainable palm oil product.

REFERENCES

Aini, F K; Hergoualc'h, K; Smith, J U and Verchot, L (2015). Nitrous oxide emissions along a gradient of tropical forest disturbance on mineral soils in Sumatra. *Agriculture, Ecosystems & Environment*, *214*: 107-117.

Bateman, E J and Baggs, E M (2005). Contributions of nitrification and denitrification to N_2O emissions from soils at different water-filled pore space. *Biology and Fertility of Soils*, *41(6)*: 379-388.

Baumert, K; Herzog, T and Pershing, J (2005). Navigating the Numbers: Greenhouse Gas Data and International Climate Policy. World Resources Institute (WRI), USA.

Bouwman, A F (1996). Direct emission of nitrous oxide from agricultural soils. *Nutrient Cycling in Agroecosystem.* 46: 53-70.

Bouwman, A F; Boumans, L J M and Batjes, N H (2002). Emissions of N_2O and NO from fertilized fields: summary of available measurement data. *Glob. Biogeochem. Cycles*, *16*: 1058-1070.

Bremner, J M (1997). Sources of nitrous oxide in soils. *Nutr. Cycling Agroecosys*, *49*: 7-16.

Caliman, J P; Hardianto, J and Ng, M (2001). Strategy for fertilizer management during low commodity price. Cutting edge technologies for sustained competitiveness: *Proc. of the PIPOC International Palm Oil Congress - Agriculture Conference.* MPOB, Bangi. p. 295-312.

Corre, M D; van Kessel, K C; Pennock, D J and Solohub, M P (1995). Ambient nitrous oxide emissions from different landform complexes as affected by simulated rain-fall. *Commun. Soil Sci. Plant Analysis*, *26*: 2279-2293.

Davidson, E A (1991). Fluxes of nitrous oxide and nitric oxide from terrestrial ecosystems. A global inventory of nitric oxide emissions from soils. *Microbial production and consumption of greenhouse gases: Methane, nitrogen oxides and halomethanes* (Rogers J E, Whitman W B eds.). Washington, DC. p. 219-235.

Fowler, D; Nemitz, E; Misztal, P; Di Marco, C; Skiba, U; Ryder, J; Helfter, C; Cape, J N; Owen, S; Dorsey, J; Gallagher, M W; Coyle, M; Philips, G; Davison, B; Langford, B; MacKenzie, R; Muller, J; Siong, J; Dari-Salisburgo, C; Carlo, P D; Aruffo, E; Giammaria, F; Pyle, J A and Hewitt, C N (2011). Effects of land use on surface-atmosphere exchanges of trace gases and energy in Borneo: Comparing fluxes over oil palm plantations and a rainforest. *Philosophical Transactions of the Royal Society B: Biol Sciences*, *366(1582)*: 3196-3209.

Goh, K J and Härdter, R (2003). General oil palm nutrition. *Oil Palm Management for Large and Sustainable Yields* (Fairhurst Härdter ed.). IPNI, Singapore. p. 191-230.

Goh, K J and Po, S B (2005). Fertilizer recommendation systems for oil palm: Estimating the fertilizer rates. *Proc. of MOSTA 2004 Best Practices Workshops-Agronomy and Crop Management.* MOSTA, Petaling Jaya.

Hergoualc'h, K; Harmand, J M; Cannavo, P; Skiba, U; Oliver, R and Henault, C (2009). The utility of process-based models for simulating N_2O emissions from soils: A case study based on Costa Rican coffee plantations. *Soil Biology & Biochemistry*, *41*: 2343-2355.

IPCC (2006). Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD/IEA, Paris, France.

Ishizuka, S; Iswandi, A; Nakajima, Y; Yonemura, S; Sudo, S; Tsruta, H and Murdiyarso, D (2005). The variation of greenhouse gas emissions from soils of various land-use/cover types in Jambi province, Indonesia. *Nutr Cycl Agroecosystems*, *71*: 17-32.

Kushairi, A; Soh, K L; Azman, I; Hishamuddin, E; Ong-Abdullah, M; Izuddin, Z B M N; Razmah, G; Sundram, S and Parveez, G K A (2018). Oil palm economic performance in Malaysia and R&D progress in 2017. *J. Oil Palm Res.*, *30(2)*: 163-195.

Kusin, F M; Akhir, N I M; Mohamat-Yusuff, F and Awang, M (2016). Nitrous oxide emission from nitrogen fertiliser application in oil palm plantation of different stages. *International J. of Global Warming*, *9(4)*: 529-541.

Law, C C; Zaharah, A R; Husni, M H A and Akmar, A S N (2012). Evaluation of nitrogen uptake efficiency of different oil palm genotypes using N-15 isotope labelling method. *Pertanika J. of Tropical Agricultural Science*, *35(4)*: 743-753.

MacKenzie, A F; Fan, M X and Cadrin, F (1998). Nitrous oxide emission in three years as affected by tillage, corn-soybean-alfalfa rotations and nitrogen fertilization. *J. Environ. Qual.*, *27*: 698-703.

Maljanen, M; Liikanen, A; Silvola, J and Martikaine, P J (2003). Nitrous oxide emissions from boreal organic soil under different land-use. *Soil Biol. Biochem.*, *35*: 689-700.

Melling, L; Hatano, R and Goh, K J (2007). Nitrous oxide emissions from three ecosystems in tropical peatland of Sarawak, Malaysia. *Soil Science and Plant Nutrition*, *53*: 792-805.

Nagano, H; Kato, S; Ohkubo, S and Inubushi, K (2012). Emissions of carbon dioxide, methane, and nitrous oxide from short- and long-term organic farming Andosols in central Japan. *Soil Sci. Plant Nutr.*, *58*: 793-801.

Neftel, A; Fischer, C and Flechard, C H (2006). Measurement of greenhouse gas fluxes from agriculture, *International Congress Series*, *1293*: 3-12.

Pardon, L; Bessou, C; Nelson, P N; Dubos, B; Ollivier, J; Marichal, R; Caliman, J-P and Gabrielle, B (2016). Key unknowns in nitrogen budget for oil palm plantations. A review. *Agronomy for Sustainable Development*, *36(1)*: 1-21.

Regina, K; Syvasalo, E; Hannukkala, A and Esala, M (2004). Flux of N_2O from farmed peat soils in Finland. *Eur. J. Soil Sci.*, *55*: 591-599.

Sakata, R; Shimada, S; Arai, H; Yoshioka, N; Yoshioka, R; Aoki, H; Kimoto, N; Sakamoto, A; Melling, L and Inubushi, K (2015). Effect of soil types and nitrogen fertilizer on nitrous oxide and carbon dioxide emissions in oil palm plantations. *Soil Sci. Plant Nutr.*, *61*: 48-60.

Silalertruksa, T; Bonnet, S and Gheewala, S H (2012). Life cycle costing and externalities of palm oil biodiesel in Thailand. *J. Clean Prod., 28*: 225-232.

Simek, M and Cooper, J E (2002). The influence of soil pH on denitrification: Progress towards the understanding of this interaction over the last 50 years. *European J. Soil Science, 53*: 345-354.

Skiba, U; Rees, R; Siong, J and Sentian, J (2012). Non CO_2 greenhouse gas sources from managed and natural soils - fluxes and mitigation. *J. Oil Palm and the Environment*, *3(11)*: 107-113.

Snyder, C S; Bruulsema, T W; Jensen, T L and Fixen, P E (2009). Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems and Environment*, *133*: 247-266.

Takakai, F; Morishita, T; Hashidoko, Y; Darung, U; Kuramochi, K; Dohong, S; Limin, S H and Hatano, R (2006). Effects of agricultural land-use change and forest fire on N_2O emission from tropical peatlands, central Kalimantan, Indonesia. *Soil Sci. Plant Nutr., 52*: 662-674.

Tiedje, J M (1994). Denitrifiers. *Methods of Soil Analysis. Part 2.* (Weaver RW ed.). Madison, MI. p. 245-257.

Toma, Y; Takakai, F; Darung, U; Kuramochi, K; Limin, S H; Dohong, S and Hatano, R (2011). Nitrous oxide emission derived from soil organic matter decomposition from tropical agricultural peat soil in central Kalimantan, Indonesia. *Soil Science and Plant Nutrition*, *57(3)*: 436-451.