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Nitrous oxide emission from nitrogen fertiliser application in oil palm plantation of different stages

Faradiella Mohd Kusin*

Department of Environmental Sciences,
Faculty of Environmental Studies,
Universiti Putra Malaysia,
43400 UPM Serdang, Malaysia
and
Environmental Forensics Research Centre,
Faculty of Environmental Studies,
Universiti Putra Malaysia,
43400 UPM Serdang, Malaysia
E-mail: faradiella@upm.edu.my
*Corresponding author

Nurul Izzati Mat Akhir and
Ferdaus Mohamat-Yusuff

Department of Environmental Sciences,
Faculty of Environmental Studies,
Universiti Putra Malaysia,
43400 UPM Serdang, Malaysia
E-mail: nurulizzatimatakhir@gmail.com
E-mail: ferdius@upm.edu.my

Muhamad Awang

SEGi University, Kota Damansara,
47810 Petaling Jaya, Selangor, Malaysia
E-mail: muhamad@segi.edu.my

Abstract: The release of nitrous oxide (N_2O) from agricultural activities contributes to the increase of greenhouse gases in the atmosphere. In this study, the amount of nitrogen fertiliser used in an oil palm plantation of different stages (immature and mature) was estimated. Data of fertilising scheme at the oil palm plantation for oil palms varying in age (planted between 1986 and 2009) was used. Estimation of nitrous oxide emissions and the resulting CO_2-equivalent (CO_2-eq) emissions were calculated for each category of the oil palm. The amounts of N-fertiliser applied were between 102–137 kg N/ha. The resulting N_2O emissions were between 19.07–22.10 kg N_2O-N/ha, which corresponds to CO_2-eq of between 2223.53–2700.42 kg CO_2-eq/ha. It was also estimated that about 29.87–34.63 g CO_2 were emitted per MJ crop. The N_2O emission per ha oil palm was found to decrease from immature stage until maturely-developed stage spanning 20 years. The CO_2-eq amount decreased only after ten years of oil palm development. The results were also compared for synthetic nitrogen fertiliser-induced emissions within tropical regions.

Keywords: nitrous oxide emission; CO_2-equivalent; N-fertiliser; greenhouse gases; GHGs; global warming; oil palm plantation.

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Biographical notes: Faradiella Mohd Kusin is a Lecturer in the Department of Environmental Sciences, Universiti Putra Malaysia (UPM) and an associate member of Environmental Forensics Research Centre (ENFORCE), Faculty of Environmental Studies, UPM. She completed her PhD in Newcastle University, UK in the field of Environmental Engineering in 2011.

Nurul Izzati Mat Akhir is a postgraduate student in the Department of Environmental Sciences, Faculty of Environmental Studies, Universiti Putra Malaysia. She is currently completing her Master's degree in Environmental Pollution and Control Technology.

Ferdaus Mohamat-Yusuff is a Lecturer in the Department of Environmental Sciences, Faculty of Environmental Studies, Universiti Putra Malaysia. She is also an associate member of ENFORCE, UPM. She received her PhD from The University of Tokyo in 2011 and her field of specialisation is environmental ecotoxicology.

Muhamad Awang received his PhD specialising in air pollution and vegetation from the University of Sheffield, the UK in 1979. He was a Professor of Environmental Sciences at the Faculty of Environmental Studies, Universiti Putra Malaysia (UPM) until 7 April 2005. He has conducted numerous researches and published papers, and he is best known for his teaching and research on Air Pollution and Tropical Ecosystem Physiology and Environmental Science Management. He was a recipient of Anugerah Langkawi and was conferred the title Emeritus by UPM on 9 September 2009.

1 Introduction

Agricultural activities can contribute to the increasing nitrous oxide (N_2O) in the atmosphere. N_2O is primarily emitted as a by-product of nitrification and denitrification in both agricultural landscapes and natural ecosystems (Schrier-Uijl et al., 2013). One of the factors that contribute to the increase of N_2O concentration includes fertilised soil in agro-industrialisation (Hewitt et al., 2009). Emissions from fertiliser application represent more than 51% of the overall plantation emission (Castanheira et al., 2014). The amount of fertiliser used in oil palm plantation may result in high N_2O emission into the atmosphere, ultimately leading to significant global warming. In fact, more than half of the fertiliser use in Malaysia is utilised in palm oil industry (Corley and Tinker, 2003). The production of palm oil-based biodiesel has now been initiated in Malaysia in line with the effort to reduce the country's dependency on fossil fuel. Additionally, the use of biodiesel as an alternative source of fuel may reduce the emissions of multiple air pollutants (Palit et al., 2011). Pleanjai et al. (2009) found that the greenhouse gas (GHG) emissions from the use of palm oil-based biofuel were 79% less than that from conventional diesel and will therefore contribute to reducing global warming potential.

Furthermore, the use of non-fossil energy options can reduce the emissions of GHGs and are important to combat climate change (Rosen, 2009). It is believed that the most significant contribution to global warming from oil palm plantation is from the agricultural stage (i.e., cultivating, clearing and replanting) whereby N_2O contributes to more than 50% compared to other GHGs (Schmidt, 2010). Therefore, application of nitrogen fertiliser (N-fertiliser) during the agricultural stage of palm oil production may contribute to the emissions GHG. Castanheira et al. (2014) found that the highest GHG emissions were obtained when ammonium nitrate (synthetic N-fertiliser) was applied as fertiliser in oil palm plantation compared to the use of organic fertiliser such as poultry manure.

Artificial fertiliser that contains N is an important source of nutrient that is essential in controlling the growth of plant (Sawan et al., 2001). The direct N_2O emission occurs from direct addition of N-fertiliser on the soil whereas indirect N_2O emission may be results from processes such as N-deposition from the atmosphere, N-fixation by legumes and decomposition of biomass residues (Schmidt, 2007; Millar et al., 2010). Schmidt (2007) reported that the type of N-fertiliser used in Malaysia is of 73% of ammonia sulphate and 27% of urea. According to Intergovernmental Panel on Climate Change (IPCC) report, 1% of N_2O is emitted to the atmosphere from the total of N applied during the application of fertiliser, and that the Global Warming Potential (GWP) of N_2O is 296 times stronger than CO_2.

Further, N-fertiliser from palm oil-related activities may have impact on various environmental aspects through N_2O emissions (Kim and Dale, 2008). The increase in available mineral N in the most managed soil will eventually enhance the formation and emission of N_2O through the process of nitrification and denitrification to the atmosphere (Hewitt et al., 2009). Therefore, the input of either organic or inorganic N will lead to escalation of N_2O. In addition, the high demand of N-fertiliser from synthetic sources in palm oil industry had been related to the rise of global N_2O emission. For example, the operations such as transportation, fresh fruit bunches processing and use of palm oil-derived products may increase N_2O emissions to the atmosphere (Klaarenbeeksingel, 2009). It was reported that the calculated annual N_2O emissions for average oil palm plantation soil in Malaysia is between 24.1–24.5 kg N_2O/ha for oil palm aged 1–2 years (immature), and between 19.0–20.2 kg N_2O/ha for 3–25 years (mature), respectively (Schmidt, 2007).

On the other hand, high N_2O concentration will affect human health, plant growth and also environment. For instance, production of industrial agricultural products contributes to 75% of global N_2O emissions that can cause significant global warming and also contributes to air pollution (Vandermeer et al., 2009). In agricultural industry, fertilisers are widely used for the growth of plantation. N-fertilisers can lead to loss of species composition and biodiversity, which can also disturb the ecosystem. For example, human and wildlife can be exposed to the risk of diseases and infections through alteration of nitrogen from fertiliser (Bernhard, 2012). In aquatic ecosystem, excess nitrogen may lead to the increase of acidification. In this study, we attempt to evaluate on the amount of N_2O emissions from the N-fertiliser application specifically in oil palm plantation of different stages (i.e., immature and mature palms). While many studies have been focusing on field measurements of N_2O, i.e., closed-chamber measurement techniques for various land covers, much could be gain from such investigations particularly on the temporal variability of N_2O emissions (e.g., Hadi et al., 2005; Furukawa et al., 2005;

Melling et al., 2007; Zhang et al., 2014; Gao et al., 2014). The findings from this study would be of some contributions to site-specific N_2O emission of oil palm plantation-related activities and how it may have impact on the global warming in general. Other inputs of GHG emissions during the agricultural stage of oil palm plantation were also assessed and are reserved in other publications, e.g., carbon dioxide, methane and P-related emissions.

2 Methods

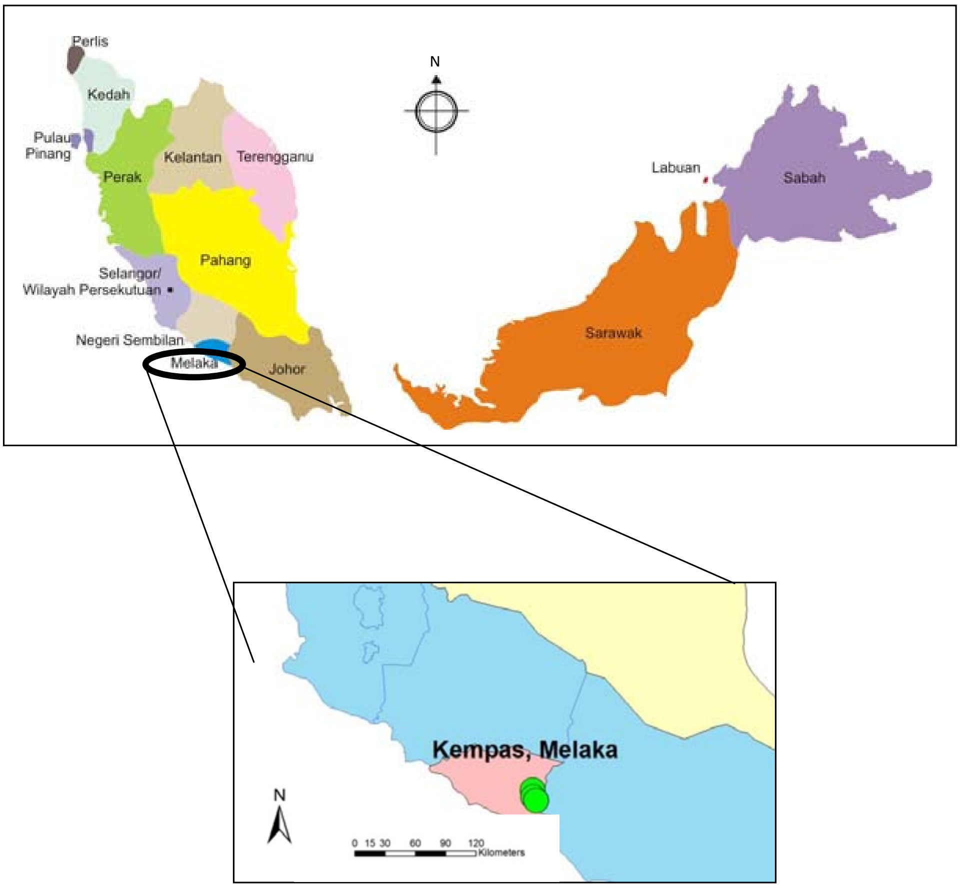
2.1 Site description

Kempas Estate (2°15'9"N 102°27'6"E) is located in Jasin district, Malacca at the western coast of Peninsular Malaysia (Figure 1) and is approximately 150 kilometres from Kuala Lumpur. It is bordered by the Straits of Malacca to the west, state of Negeri Sembilan to the north and state of Johor to the south. The oil palm plantation covers an area of 1,700 hectare and is currently managed and operated by the Sime Darby Plantation Malaysia. The Kempas Estate operates within an organisational structure of Strategic Operating Units, adopting Best Agricultural Management Practices and planting of high yielding palms. The estate is located in Malacca/Johor North zone with fresh fruit bunch (FFB) total yield breakdown of 24.11 Mt/ha, believed to be one of the zones of highest FFB yield in Malaysia. The average FFB yield in Malaysia is 18.87 t/ha (Schmidt, 2007), which is nearly the amount of FFB yield in Colombia i.e., 19.5 t/ha (Castanheira et al., 2014).

2.2 Data

In this study, we used the actual amount of applied N-fertiliser as utilised in the scheduled fertilisation scheme to estimate the resulting amount of N_2O emissions. Data of fertilising scheme at the Kempas Estate from 1986 to 2009 was used to estimate the annual N_2O emissions over the years. The data was collected from four series of fertilisation scheme (conducted by the estate operator) yearly and the average values are presented. The rainfall data was obtained from the Malaysian Meteorological Department to relate the meteorological factor and the variation of N_2O emissions. Emission Database for Global Atmospheric Research (EDGAR) was retrieved for comparison of the N_2O emissions, i.e., gridded emissions for the region. For further analysis of the data, the N_2O emissions were analysed against the age of the oil palms for a particular year, i.e., as observed in 2012. The oil palms were classified as immature (less than five years) and mature (> 5 years) after planting. Chase and Henson (2010) stated that typical life cycle of oil palm is around 25–30 years before replanting of new palms. The applied fertiliser was of 28% ammonium nitrate, 14% phosphate, 53% potash and 7% MgO (Corley and Tinker, 2003). The amount of N-fertiliser applied may vary between plantations and the average values reported by Schmidt (2007) are 90 kg N/ha and 106 kg N/ha for immature and mature oil palms in Malaysia, respectively. Generally, one average ha of oil palm plantation consists of 8% immature and 92% of mature palms (Schmidt, 2007), whilst in Kempas Estate it is estimated that about 5% of the plantation is considered immature up to 2012, i.e., replanted palms in 2009.

Figure 1 Site location (see online version for colours)



2.3 *Estimation of N_2O direct emission and CO_2-equivalent (CO_2-eq)*

The amount of nitrogen fertiliser applied in Kempas plantation was used to calculate direct N_2O emission based on the model described in the IPCC incorporating peat soil which is relevant in Malaysia and Indonesia (Schmidt, 2007). This is based on the fact that most Malaysian oil palm plantation soil is composed of peat (Henson, 2004; Schmidt, 2007; Adon et al., 2012). Additionally, 50% of new plantations in Malaysia and Indonesia are on peat soils and that the area cultivated with peat is getting higher nowadays (Hergoualc'h and Verchot, 2013). However, it is presumed that cultivation on peat soil may increase the contribution to global warming significantly (Schmidt, 2010). The equation for estimating the N_2O emission is given as follows (IPCC, 2006):

$$\ln(\mathrm{kg\ N_2O - N / ha}) = \left[\left(F_{SN} + F_{AM} + F_{BN} + F_{CR}\right). EF_1\right] + \left(F_{OS} + EF_2\right)$$

where F_{SN} is the annual amount of synthetic N-fertiliser applied to soils (kg N ha^{-1}), F_{AM} is the annual amount of animal manure nitrogen intentionally applied (kg N ha^{-1}), F_{BN} is the amount of nitrogen fixed by N-fixing crops cultivated annually (kg N ha^{-1}), F_{CR} is the amount of nitrogen in crop residues returned to soils annually (kg N ha^{-1}), F_{OS} is the area of organic soils cultivated annually (ha), EF_1 is the emission factor for emissions from N inputs (kg N_2O–N/kg N input), EF_2 is the emission factor for emissions from organic soil cultivation (kg N_2O–N/ha-yr).

CO_2-equivalent (CO_2-eq) is the conversion of other gases such as nitrogen gases to equivalent amount of carbon dioxide based on the GWP. In order to calculate the CO_2-eq, standard ratios are used to convert the various gases into equivalent amounts of CO_2 that describes its total warming impact relative to CO_2 over a set period. The emissions were converted into CO_2-eq using the GWP of the gases. According to IPCC (2006), the equation is given as:

$$CO_{2-eq} = \left(F_{SN} * F_{E1}\right) * \left(44/28\right) * \left(GWP\ N_2O/1000\right)$$

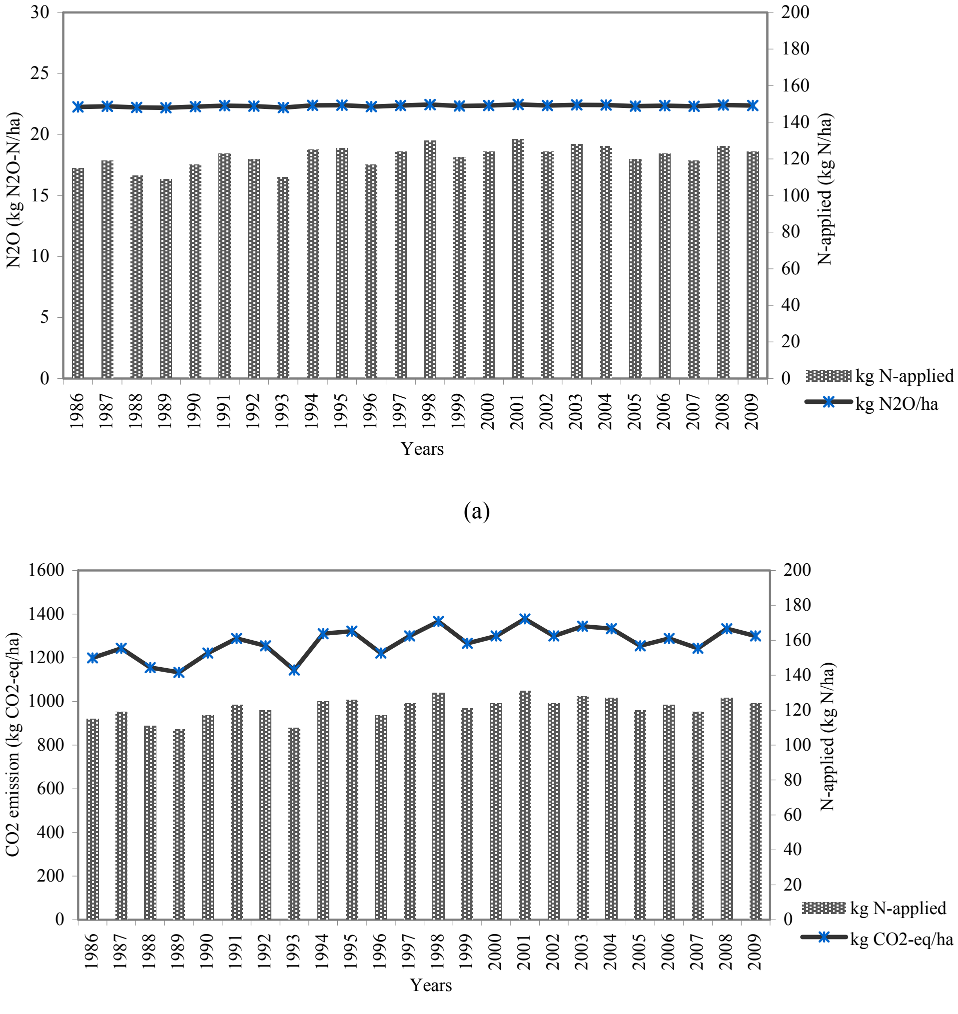
where F_{SN} represents the amount of synthetic N-fertiliser applied to soils (kg N yr^{-1}), F_{E1} represents emission factor for N_2O emissions from N inputs (kg N_2O–N kg N $input^{-1}$), 44/28 is a conversion of N_2O–N emissions to N_2O emissions, and GWP represents GWP of N_2O (t CO_2-eq).

3 Results and discussion

The amount of N-fertiliser applied at the oil palm plantation for 20 years beginning 1986 to 2009 and the calculated N_2O and CO_2-eq emissions are presented in Figures 2(a) and 2(b). The amount of the applied N-fertiliser was fairly consistent over the years and only a little variation in N_2O emission was observed. The resulting CO_2-eq emission closely followed the variation of the applied N-fertiliser. On the other hand, the yearly average rainfall data over the years are illustrated in Figure 3(a). Generally, in most of the years the estate receives < 200 mm of average rainfall yearly, the fact that the state of Malacca is one of the areas that receives the least amount of rainfall in Malaysia year round. The lowest amount of rainfall received was in 1997 (108 mm) and the highest were in 2000 and 2003 (241 mm). However, there is no clear relationship between N_2O and CO_2-eq emissions and the variation of the rainfall over the years studied [Figures 3(b) and 3(c)]. In addition, the N_2O emissions were also compared to the EDGAR data for Southeast Asia region and specifically for Malaysian N_2O emission from agricultural sector. Generally, the N_2O emission from Kempas plantation contributes to about 0.2% of the total annual N_2O emissions from agricultural-related activities across Malaysia (Figure 4). For Southeast Asia region, the recorded N_2O emissions were between 106–147 million tonnes CO_2-eq from 1990–2010. In Kempas Estate, the N_2O emissions were found between 1,944,041–2,342,551 kg CO_2-eq from 1986–2009.

Further analysis was performed to assess whether there is any relationship between N_2O emissions and the age of oil palm. The N_2O emissions from N-fertiliser application was analysed for oil palms of different category of age at the estate for a selected year. Table 1 shows the mean data of N-fertiliser applied, and the calculated N_2O emissions and CO_2-equivalent (CO_2-eq) emission of the oil palms. For oil palms aged less than five years (< 5) (replanted between 2007–2009), the mean N-fertiliser applied is 102 kg/ha, followed by the oil palms aged between 5 to 10 years (planted between 2001–2005), whereby the mean is 137 kg/ha. Whilst, the oil palms with the age between 11 to 20 years (planted in 1991–2000), the mean N-fertiliser applied is 132 kg/ha and the lowest mean was recorded at 115 kg/ha for oil palms aged between 21 to 30 years (planted between 1986–1990).

Figure 2 Variation of N_2O and CO_2-eq emissions with regard to applied N-fertiliser (see online version for colours)



(a)

(b)

Figure 3 (a) Yearly average rainfall in Kempas Estate (b) Rainfall with respect to N_2O (c) CO_2-eq emissions (see online version for colours)

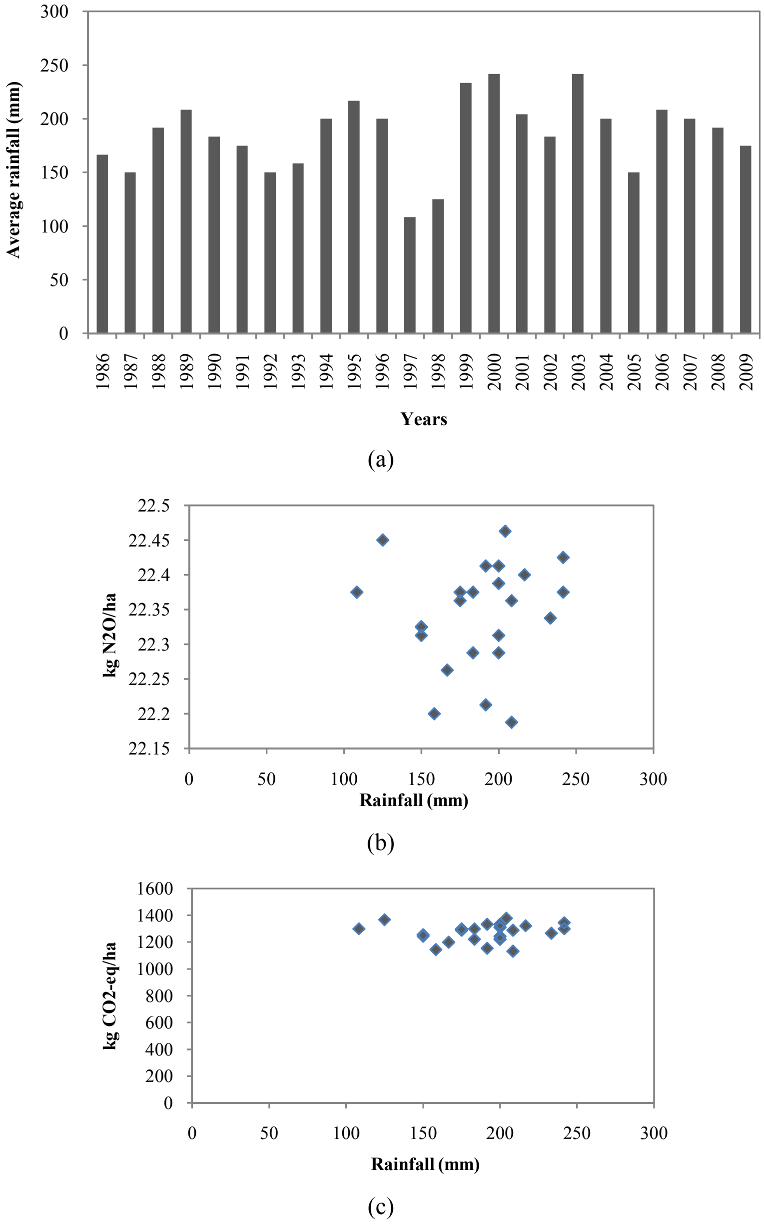


Figure 4 N_2O emissions from agricultural sector in Malaysia

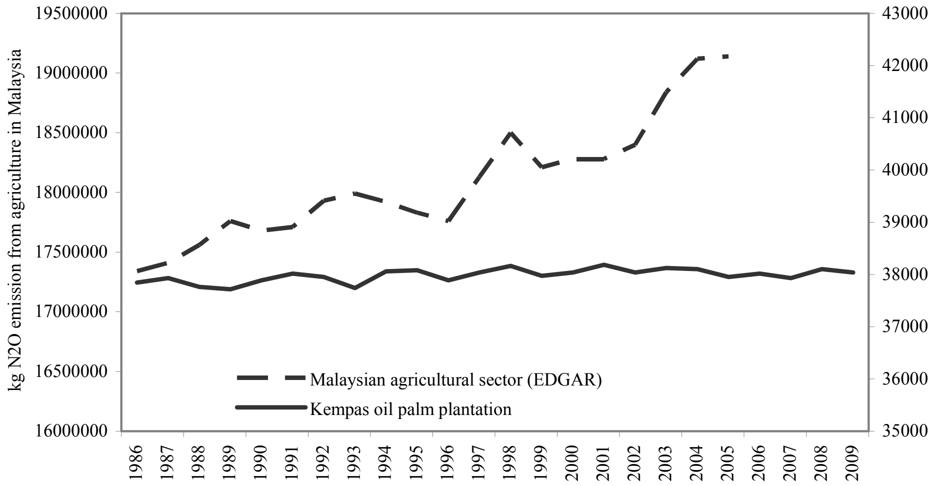


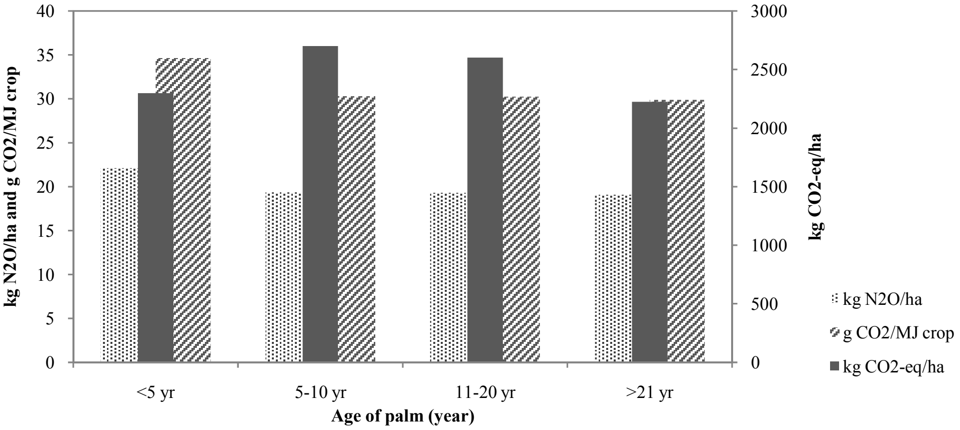
Table 1 Mean data of N-fertiliser applied, calculated N_2O and CO_2-eq emissions in Kempas Estate

	N-applied (kg N/ha)	*N_2O emission (kg N_2O-N/ha)*	*CO_2-eq. (kg CO_2-eq/ha)*	*CO_2-eq. (g CO_2-eq/MJ crop)*
Age of palm (year)				
<5 (immature)	102	22.10	2,297.66	34.63
5–10 (mature)	137	19.35	2,700.42	30.32
11–20 (mature)	132	19.29	2,602.04	30.23
21–30 (mature)	115	19.07	2,223.53	29.87

For the N_2O emissions in Kempas Estate, the results (Table 1) show 22.10 kg N_2O-N/ha in plantation aged < 5 years, 19.35 kg N_2O-N/ha (aged between 5–10 years), 19.29 kg N_2O-N/ha (aged between 11–20 years) and 19.07 kg N_2O-N/ha (aged between 21–30 years) were released. It seems that there is only a little variation in the amount of N_2O emitted at different stages. In addition, the calculated emission given as CO_2-eq in Kempas Estate is 2,297.66 kg CO_2-eq/ha for oil palms aged < 5 years, 2,700.42 kg CO_2-eq/ha for oil palms aged 5–10 years, 2,602.04 kg CO_2-eq/ha (aged between 11–20 years) and for oil palms between 21 to 30 years the emission is calculated as 2,223.53 kg CO_2-eq/ha.

The results show that the N_2O emissions per ha palm plantation decreases from immature stage until maturely developed to more than 21 years (Figure 5). The relatively higher N_2O emissions during the immature stage may be attributed to several factors. Note that the N_2O emissions in this context are mainly attributable to the amount of N-fertiliser applied. According to Sawan et al. (2001), the N rate is significantly increased due to the seed protein content and protein yield per ha. Hence, high concentration of N-fertiliser is very important for the growth of oil palm. Additionally, nitrogen is required at the early stage of oil palm growth because it is also a component of nucleic acids that holds the genetic code and for the formation of DNA (Sawan et al., 2001). This process is essential at juvenile stage of oil palm to catalyse the rapid growth of the palm. Thus, N-fertiliser is widely used for high yield in the palm oil industry. Therefore, generally the high N content during the early stage of palm development is attributed to N-fixation, return of nitrogen in crop residues and decomposition of biomass (Schmidt, 2007).

Figure 5 N_2O emissions (kg N_2O-N/ha) from N-fertiliser application for oil palms of different ages



The amount of the resulting CO_2-eq emission per ha oil palm plantation were found increased during five to ten years of oil palm development. This was reflected by the greater amount of N-fertiliser being applied, coupled with the portion of the N_2O contribution. The CO_2-eq emission then decreased in the following years of plantation establishment. Apart from the emission released per ha plantation, the amount of CO_2 emitted when taking into account of the heating value of feedstock from dry organic matter fraction of harvested product was also determined using methods from GNOC (2013). The estimated CO_2-eq emissions per MJ oil palm were between 29.87–34.63 g, the values of which decrease over the years of oil palm development.

The results from this study are comparable to some other values reported by various authors (Table 2). The N_2O emissions from fertiliser use found in this study (in the range of 19.07–22.10 kg N_2O-N/ha) is within the values reported by Schmidt (2007) for Malaysian oil palm plantation in general (i.e., in the range 19.0–24.5 kg N_2O-N/ha). The values reported in their study were calculated based on the estimation of the average 105 kg N-fertiliser being applied per ha plantation. The emission is higher than the N_2O emissions reported by Germer and Sauerborn (2008) i.e., 4.1 ± 5.5 kg N_2O-N/ha, and also higher than the emission found in Melling et al. (2007) i.e., 1.2 kg/ha. Germer and Sauerborn (2008) have estimated the resulting GHG fluxes in response to oil palm plantation establishment with specific estimation of peat decomposition that emits N_2O. Melling et al. (2007) did a one year (monthly) measurements of N_2O emissions using a closed-chamber technique in three ecosystems including oil palm ecosystem. Nevertheless, the calculated N_2O emission in this study is greater than the default value for synthetic fertiliser-induced emissions for tropical regions i.e., 10 kg N_2O-N/ha per year as suggested by IPCC (2006). While it seems that this is greatly attributed to the use of synthetic N-fertiliser, contribution of peat (cultivation of crop on peat soil) cannot be ruled out.

Table 2 Estimation of N_2O and CO_2-eq emissions in oil palm plantation from various authors

N_2O emission (kg N_2O-N/ha)	*CO_2-eq (kg CO_2-eq-/ha)*	*Reference*
19–24.5	nr	Schmidt (2007)
nr	566	Melling et al. (2005)
nr	55,000	Fargione et al. (2008)*
4.1 ± 5.5	33,000 ± 16,000	Germer and Sauerborn (2008)*
nr	36,700–55,000	Reijnders and Huijbregts (2008)*
8	42,700	Wicke et al. (2008)*
nr	19,200	Koh et al (2010)*
1.2	nr	Melling et al. (2007)
[a]10		IPCC (2006)

Notes: *Adapted from Page et al. (2011)
[a]Default value for synthetic nitrogen fertiliser-induced emissions for tropical regions
nr – not reported

Generally, the application of inorganic N-fertilisers greatly influences the contribution of agriculture to the greenhouse effect especially by potentially increasing the emission N_2O, CO_2 and CH_4 from soil (Inselsbacher et al., 2011). An increase in N-fertiliser in soil directly enhances the nitrification and denitrification processes. Hence, the production of N_2O also increases because N_2O is produced naturally in soils through the process of nitrification and denitrification (IPCC, 2006). Moreover, Mosquera et al. (2007) stated that the production and consumption of both N_2O and CH_4 from soils occurs as a result of different microbial process which in turn is controlled by factors that influence the growth of microorganism such as soil oxygen (O_2) content, soil temperature, mineral N content in organic matter and pH. Furthermore, fertilisation not only leads to the increase of N_2O emission but also strongly influences the carbon dioxide emissions (Treseder, 2008). N-fertiliser was also applied to enhance the root respiration for rapid plant growth and generally will lead to the increasing of total CO_2 emission in the atmosphere.

4 Conclusions

Agricultural activities during early cultivation through to maturely-developed oil palms contributed to high N_2O emissions in the atmosphere, ultimately leading to the increase of GHGs contributing to global warming. It is worth noting that in this study, we only assessed the amount of N_2O emitted as a direct result of N-fertiliser while it is known that there are other multiple emissions related to N balance i.e., indirect from ammonia and nitrate. Further work will aim at assessing the amount of N_2O while taking into account of other indirect emissions related to N balance. On the other hand, use of organic fertiliser is believed to release a significantly low N_2O compared to inorganic fertiliser and may be useful to minimise the emission from agricultural activities. While it is known that peat soil may also contribute to the increase of nitrous oxide, future plantation may look into integrating the type of soil for such agricultural activities.

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