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Nitrous Oxide Emission from different Land Use Changes Associated with Oil Palm Plantation

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Abstract

The amount of nitrous oxide emission from syntheticfertilizer use in different scenarios of land use changes associated with oil palm plantation has been estimated.The plantations include two transformed land use estates (large and small-scale) and a logged-over forest converted into oil palm plantation. Field-determined data of soil N, P, K content at the oil palm plantations for oil palms varying in age were investigated (immature and mature palms). The amount of N-fertilizer applied ranged between 99.41-155.94 kg N/ha that results in19.11-22.35 kg N_2O-N/ha. This corresponds with 1027.29-1430.31 kg CO_2-eq/ha for the three different estates. The CO_2-eq emission released per MJ crop produced was between 29.93-35.02 g CO_2-eq. Generally, the amount of N_2O emissions were slightly higher for oil palms aged < 5 years (immature) for all categories of land use changes compared to more mature palms > 5 years.However, the highest CO_2-eq emission was found from the logged-over forest for oil palms aged > 20 years. The variations in the resulting CO_2-eq emission were found related with the carbon stock changes of the different land use transformation of the oil palm plantations.

Keywords: Nitrous oxide emission; CO_2-eq emission; N-fertilizer; greenhouse gases; climate change; oil palm plantation

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1. Introduction

Nitrous oxide 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 fertilized soil in agro-industrialization (e.g. Hadi et al., 2005; Melling et al., 2007; Hewitta et al., 2009; Millar et al., 2010; Goa et al., 2014). Emissions from fertilizer application represent more than 51% of the overall plantation emission (Castanheira et al., 2014). The amount of fertilizer used in oil palm plantation may result in high N_2O emission into the atmosphere, ultimately leading to significant global warming (Zhang et al., 2014). In fact, more than half of the fertilizer use in Malaysia is utilized in palm oil industry (Corley and Tinker, 2003;Chase and Henson, 2010). 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 greenhouse gases (Schmidt, 2010). Therefore, application of N-fertilizer during the agricultural stage of palm oil production may contribute to the emission of greenhouse gases (GHG). Castanheira et al. (2014) found that the highest GHG emissions were obtained when ammonium nitrate (synthetic N-fertilizer) was applied as fertilizer in oil palm plantation compared to the use of organic fertilizer such as poultry manure.

1.1 Importance of Study

Most of previous works in this regard relied upon secondary data provided elsewhere around their scope of study(e.g. Henson, 2004; Schmidt, 2007; Germer and Sauerborn, 2008; Siangjaeo et al., 2011; Castanheira et al., 2014) and hence extensive analysis can be presented using numerous existing available data. However, field-determined data may help strengthen the detailed analysis with higher degree of confidence. The data may also be useful for evaluation of site-specific emission for area of concern. In this study, we focused on the emissions arising fromthe agricultural stage of palm oil production (primarily due to synthetic fertilizer application) by experimentally determining the contribution of N-related emissions.

In this case, we measured the N, P, K contents of the soil associated with the application of synthetic fertilizer to evaluate the impact of known amount of applied N-fertilizer on GHGs emission in oil palm plantations of different categories (immature and mature), and based on different land use changes of the oil palm plantation.

Further to this, future research may look into the contributions from other GHGs emitted during the agricultural stage of palm oil production alongside the N_2O so that the impact on global warming may be well understood.

2. Materials and Methods

2.1 Study Sites

The study was undertaken at three different sites according to the land use changes of the oil palm plantation. The soil samples were collected from Kempas Estate (transformed land use, large-scale), UPM oil palm plantation (transformed land use, small-scale) andChepor Estate(logger-over forest). The Kempas Estate and UPM plantation used to be the area of grassland prior to development of oil palm plantation. The highly degraded grassland area of Kempas Estate has a total area of 1700 ha.The UPM plantation is a small-scale degraded area of 40 ha and the Chepor Estate has a total area of 982 ha. The sampling was performed according to the age of the palms, i.e.< 5 years (immature), 5-20 years (mature) and > 21 years (mature).

2.2 Soil sampling and Analysis

Thesoil samplingwasconductedforthethreeestatesaccording to the age of the palms.Soil samples were collected for analysis of N, P, K contents and soil organic carbon. The soil samples were collected as triplicatestoadepth of 25cm due to theaccumulationofmajornutrientsonthesurface soil (Sierra et al., 2007). About 20kg of total soilwascollectedfrom each sampling occasion andthey werestored in zipped plasticbags and were labeled according to the age of palm. Samples were kept cool during transportation and brought back to laboratory for further analysis. Samples were storedin the refrigerator to prevent moistureloss and composition changes as the biologicalactivityslowsatlow temperature. In the laboratory, the soil samples were air dried at room temperature in adustandfume-free place.

After drying,soil aggre gates were pulverizedusing mortar and pestleto reduce particle size so as to pass through 0.25 mm sieve. The soil samples were screened througha 0.25mm sieve. Afterscreening,soilisthoroughlymixed and put ina plastic pot tillanalysis. Extraction of soil samples werec arried out using 0.01M $CaCl_2$.

10 gram of airdriedsoil sample wasshaken for two hours at 20°Cwith 100 mL of $CaCl_2$solution. Later, the suspension was centrifuged in the supernatant liquid and the nutrient contents (N, P, K) were analyzed using Auto-Analyzer instrument.

2.3 Estimation of Nitrous Oxideemission and CO_2-eq

The amount of nitrogen fertilizer applied was used to calculate direct N_2O emission based on the model described in the Intergovernmental Panel on Climate Change (IPCC) incorporating peat soil which is the most encountered type of soil in Malaysia (Schmidt, 2007). This is based on the fact that most Malaysian oil palm plantation soil is composed of peat (Henson, 2004; Schmidt, 2007). Additionally, 50% of new plantations in Malaysia and Indonesia are on peat soils (Wetland International, 2007) 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):

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

Where F_{SN} is the annual amount of synthetic fertilizer nitrogen 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} isthe 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 theemission 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).

$CO_{2\text{-}}$equivalent (CO_2-eq) is the conversion of other gases to equivalent amount of carbon dioxide based on the Global Warming Potential (GWP). In order to calculate the $CO_{2\text{-}}$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 N-related emissions were converted into CO_2-equsing the Global Warming Potential of the gas. According to IPCC (2006), the equation is given as:

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

Where F_{SN} represents the amount of synthetic fertilizer N 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 Global Warming Potential of N_2O (t CO_2-eq). The applied GWP of N_2O relative to CO_2 is 298 (IPCC, 2007).

3. Results and Discussion

The N_2O emission from N-fertilizer application was calculated for oil palms of different ages at the three different plantation estates (according to the land use changes prior to development of oil palm plantation). Table 1 shows the amount of N-fertilizer applied, and the resultingN_2O emission and CO_2-equivalent (CO_2-eq) emission at the threeestates. For transformed land use, TLU (large-scale), i.e. at Kempas Estate, the amount of N-applied ranged from 108.15-133.76 kg N/ha. The resulting N_2O emission was between 19.11-22.18 kg N_2O/ha which corresponds to 1052.25-1209.50 kg CO_2-eq/ha. For small-scale transformed land use at UPM plantation, 122.24-126.67 kg N have been applied per ha plantation. This corresponds to about 19.16-22.35 kg N_2O/ha and between 1098.64-1284.36 kg CO_2-eq/ha. For the logged-over forest converted into oil palm plantation, i.e. at Chepor Estate, the applied N- was about 99.41-155.94 kg N/ha which corresponds to 1027.29-1430.31 kg CO_2-eq/ha.For TLU large-scale, about 29-34 g CO_2-eq emission have been emitted per MJ crop produced. For TLU small-scale, about 30-35 g CO_2-eq/MJ crop were released and about 30-34 g CO_2-eq/MJ crop emitted from the logged-over forest.

The results are illustrated in Figure 1 for the different types of land use and according to the age of the oil palms (i.e. < 5 years, 5-20 years and > 5 years). The results are plotted on the same scale for ease of comparison. The amount of N_2O emission released per ha plantation did not vary significantly between different land use changes. However, it was noted that the amount of N_2O emissions were slightly higher for oil palms aged < 5 years (immature) for all categories of land use changes, compared to mature palms > 5 years.

The relatively higher N_2O emission during the immature stage may be attributed to several factors. According to Sawan et al. (2001), the N rate is significantly increased due to the seed protein content and protein yield per ha.

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). 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).

Despite high N_2O emission during early stage of palm development, the resulting CO_2-eq emissions were not consistently high for immature palms. For instance, relatively higher CO_2-eq emissions were observed for mature palms at TLU (large scale) and logged-over forest. Note that the variations in the amount of CO_2-eq are reflected by the amount of N-applied and the resulting N_2O emission; whereby the N-related emissions are attributed to many indirect N-parameters that differ between mature and immature stages. Notwithstanding this, the highest CO_2-eq emission was found from the logged-over forest for oil palms aged > 20 years. This could be associated with the carbon stock changes from the different land use transformation. The previous tropical forest when transformed into oil palm plantation may result in reduced carbon stocks over the entire plantation operation, and hence increased CO_2-eq emission.

Table 1: Nitrous Oxide and CO_2-eq Emissions for different Land use Changes

Kempas Estate				
(transformed land use (TLU)-large scale)	N-applied (kg N/ha)	N_2O emission[a] (kg N_2O-N/ha)	CO_2-eq.[a] (kg CO_2-eq/ha)	CO_2-eq. (g CO_2-eq/MJ crop)
Age of palm (year)				
<5 (immature)	108.15	22.18	1123.15	34.74
5-20 (mature)	133.76	19.31	1209.50	30.25
>20 (mature)	117.6	19.11	1052.25	29.93
UPM plantation				
(transformed land use (TLU)-small scale)	N-applied (kg N/ha)	N_2O emission[a] (kg N_2O-N/ha)	CO_2-eq.[a] (kg CO_2-eq/ha)	CO_2-eq. (g CO_2-eq/MJ crop)
Age of palm (year)				
<5 (immature)	122.67	22.35	1284.36	35.02
5-20 (mature)	126.27	19.21	1136.24	30.10
>20 (mature)	122.4	19.16	1098.64	30.02
Chepor Estate				
(logged-over forest)	N-applied (kg N/ha)	N_2O emission[a] (kg N_2O-N/ha)	CO_2-eq.[a] (kg CO_2-eq/ha)	CO_2-eq. (g CO_2-eq/MJ crop)
Age of palm (year)				
<5 (immature)	99.41	22.06	1027.29	34.57
5-20 (mature)	152.49	19.54	1395.58	30.61
>20 (mature)	155.94	19.58	1430.31	30.68

[a]Calculated using IPCC (2006) equations

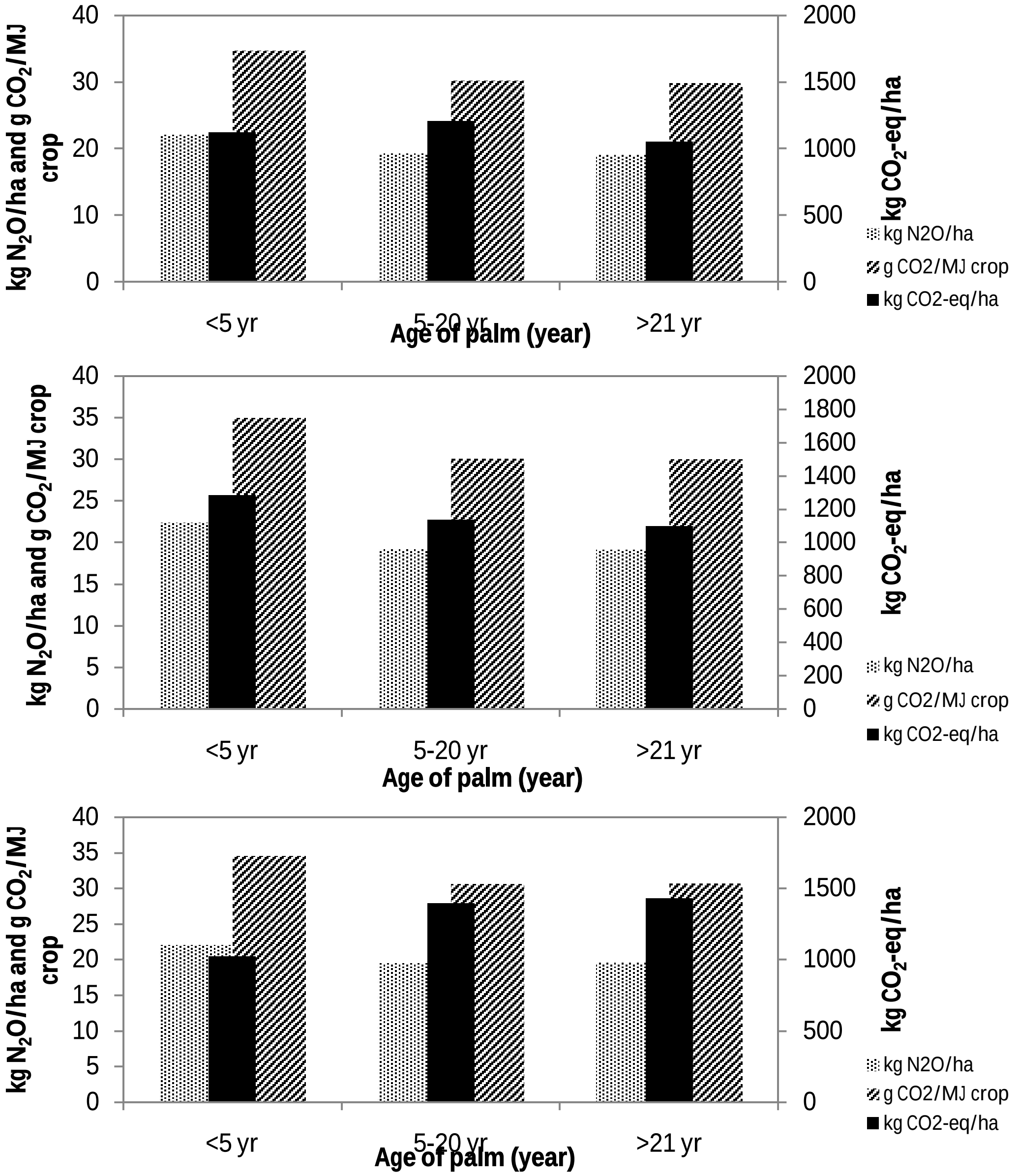

Figure 2: N_2O Emission for different Types of Land use Changes (a) TLU-Large Scale (b) TLU-Small Scale (c) Logged-Over Forest

4. Conclusion

Generally, the application of inorganic N-fertilizer greatly influences the contribution of agriculture to the greenhouse effect especially by potentially increase the emission of N_2O, CO_2 and CH_4 from soil.An increase in N-fertilizer 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, fertilization was not only potential for the increase of N_2O emission but also strongly influences the carbon dioxide emissions (Treseder, 2008).N-fertilizer 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. On the other hand, use of organic fertilizer is believed to release a significantly low N_2O emission compared to inorganic fertilizer and may be useful to minimize 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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