INTRODUCTION

Tropical peat soils accounted about 15 to 25 % from the total terrestrial N and C content although it was only covered 3.3 % of earth surface. The majority of tropical peat soils are located in Indonesia (around 21 Mha) and Malaysia with 2-2.5 Mha (Murdiyarso, Hergoualc'h, & Verchot, 2010). Thailand has approximately 45,000 ha and small areas can be found in Vietnam, Brunei and Philippines (Murdiyarso, Hergoualc'h, & Verchot, 2010). There are few studies can be found emphasized on soil nitrogen availability (Pett-Ridge, Petersen, Nuccio, & Firestone, 2013). In tropical peat soils, it is generally believed that nitrogen availability can be neglected because of the extremely acidic condition (pH water < 4.5). The acidic condition will decrease their growth and activity because they are unable to regulate their intracellular pH value when there are environmental changes in pH (Rousk et al., 2010). Moreover, natural tropical peat soils are in water saturated condition which suppressed aerobic microbial activity (Furukawa, Inubushi, Ali, Itang, & Tsuruta, 2005). However, in cultivated peat soils especially with oil palm, the water table is normally lowered to about 60 cm to allow oil palm roots well aerated (Mutert & Fairhurst, 1999). Therefore, added N source such as urea-based fertilizer could be one of the contributing factors of nitrogen availability in tropical peat soils cultivated with oil palm as it affects nitrifiers diversity.

Most of the peatlands are now converted for agriculture purposes and mainly planted with oil palm (Elaeis guineensis Jacq.) as well as other environmental impacts and social and economic aspects of the cultivation of oil palm on peat. Based on the available literature, the report presents conclusions

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ABSTRACT

Nitrogen release from soil is controlled by the soil moisture. Soil incubation was conducted to evaluate the effect of different moisture condition (75 %, 100 % and 150 %) on water holding capacity and fluctuating conditions between (150 % and 100 % water holding capacity) after application of urea and without urea addition. Ammonium and nitrate released were measured periodically over 70 days of incubation. Net mineralization and nitrification were measured at the end of the incubation period. Potential nitrification rate (PNR) was measured at the start and the end of incubation period. The results showed that the dynamics of NO3- did not show significant change with increased soil moisture without addition of urea. This results indicated nitrification in peat soil needed reactive N supply (urea) regardless of soil moisture conditions. Addition of urea increased the PNR ranging from 27.91 to 55.10 % compared to without urea. Fluctuating moisture condition with urea addition increased PNR by 21.82 % compared with a waterlogged condition. However, increasing soil moisture condition resulted in lower nitrate and PNR which reflect that soil moisture controlled the magnitude of PNR when urea was added.
on the gaps in knowledge, uncertainties and confusion in existing datasets. The palm oil sector has created in the past few decades millions of jobs. Over the next decade, the Indonesian government plans to double the annual production of palm oil, creating new jobs for an estimated 1.3 million households. Although the cultivation of oil palm on peatlands creates new income opportunities for many farmers in the short term, longer term economic implications remain uncertain. Transformation of tropical peat forest into plantations will lead to the loss of ecosystem services and biodiversity and will affect the social and cultural basis of forest dependant communities. Human health is affected negatively by haze resulting from forest and peat fires related to land preparation and drainage of the peat. There may be other negative ecological consequences linked to soil sub-sidence, which can lead to flooding and salt water intrusion when water tables reach levels and the land becomes undrainable. When peat is developed for agriculture, carbon is lost as CO2 because: 1. In oil palm cultivation under peat soils, drainage ditches are constructed so the water tables are lowered (Laiho, Vasander, Penttilä, & Laine, 2003). Drainage is necessary to provide O2 availability for the roots of the palm tree. Peat soils are primarily formed from partially decomposed organic matter rich with C and N which are preserved from decomposition because of the anaerobic condition. It can be considered that some of the organic matter exposed aerobically were decomposed and enhanced N cycling. Large amounts of NH4+ and NO3- and soluble organic N accumulated when the high organic soils exposed aerobically (Jumadi et al., 2008).

At the same time, this aerobic condition also went through different moisture levels and fluctuating moisture condition because of the wet and dry season. During the rainy season (October to December with average around 250 mm rainfall), the water table is high and mostly the surface planted area is flooded (Mohammed, Megat Mohd. Noor, & Ghazali, 2006). However, during the dry season (May to September with average less than 110 mm rainfall) the surfaces of the planted area are dry (Lung, 2016). The previous study in tropical soils indicated that substantial potential nitrification (0.96-1.58 μg N/g soil) despite low pH (3.9) and limited O2 (3-13 %) occurred for extended periods (38 weeks) due to fluctuating redox regimes (Pett-Ridge, Petersen, Nuccio, & Firestone, 2013). An increase in O2 availability during the dry season may lead to enhanced peat decomposition and N mineralization. Whereas during the wet season, studies have shown that N2O emission was high.

In addition, oil palm cultivation on peat soils with the application of N fertilization can expedite the peat decomposition and mineralization (Jauhiainen et al., 2012; Toma et al., 2011). An increasing amount of reactive N into this ecosystem can shift the balance of N cycling with implication for aboveground and belowground assimilation. When reactive N exceeds palm demand for N, the additional mineral N may be used by soil microbes especially nitrifiers and denitrifiers. In more acidic conditions, another set of microbes may dominate (Lu et al., 2012). Field and laboratory measurements in tropical soils indicated substantial gross nitrification rates despite low pH and limited O2 availability. In general, very few studies focus on peat soil planted with oil palm. In this study, NH4+, NO3-, N, and PNR were measured under different moisture levels and fluctuating moisture conditions with and without the addition of urea.

Large amounts of NH4+ and NO3- and soluble organic N accumulated when the peat soils exposed aerobically (Hadi et al., 2000). The aerobic condition also went through different moisture levels contributed to change on nitrogen cycle. The objective of this study was to understand the impact of moisture changes on N cycling in tropical peat soils with oil palm cultivation.

**MATERIALS AND METHODS**

Soil samples were collected on 2015-2016 at Ladang Sg. Samak, Malaysian Palm Oil Board (MPOB) Research Station in Teluk Intan, Perak, Malaysia (3.49° N, 101.06° S). The site has mean annual temperature ranging from 25 to 32 °C and the annual rainfall are between 1,219 to 2,128 mm with the driest month is in July (< 100 mm) and the wettest is in November 2015 until 2016. The total annual rain days ranged between 96 to 229 days. The soil was classified as Penor Series, Terric Sulfsaprist (Paramananthan, 2000). The study area is flat, receives a moderately high and uniformly distributed rainfall and has a high soil water table which was kept 60 cm from the surface. Conventional fertilization has been carried out in WC zone which received 1 kg urea, 1 kg Christmas Island rock phosphate (CIRP) and 5 kg muriate of potash (MOP) per palm per year since 2007 divided
three times per year. The palm age was 6-years-old at sampling time. The peat soil used in this study was collected from topsoil (0-10 cm). The soil samples were placed in a container with ice and immediately transported to the laboratory for analysis.

The soil samples were analyzed for pH (10 g) (1:10 w/w) (Saunders & Metson, 1971) moisture content (50 g) (24 hour oven dried at 60 °C); total carbon (TC) and total nitrogen (TN) (5 g) (LECO TruMac CNS Analyzer, USA). The NH₄⁺, NO₃⁻, and NO₂⁻ were extracted using 10 g of soil with 2 M KCl using a 1:10 soil-extractant ratio and a 1 hour end-over-end shake followed by filtration (Keeney & Nelson, 1982). Concentrations of NH₄⁺, NO₃⁻, and NO₂⁻ in solution were measured using auto analyzer with Cadmium-Copper reduction column (Lachat Part No. 50277). The summation of NH₄⁺ and NO₂⁻ was referred to as N. Net mineralization/nitrification is equaled the final concentration of NH₄⁺/NO₃⁻ minus initial concentration of NH₄⁺/NO₃⁻ (Hart, Stark, Davidson, & Firestone, 1994) For examples;

Net nitrification for soil that has been incubated for 7 days:

\[ \text{NN} = (\text{NO}_3^- 1) - (\text{NO}_3^- 0) \]  \[ \text{1) } \]

Remarks:

NN: Net nitrification (µg N/soil/day)
NO₃⁻1: NO₃⁻ concentration at day 7
NO₃⁻0: NO₃⁻ concentration at day 0

Potential nitrification rate (PNR) was determined by shaking 15 g of field-moist soil sample with 100 mL working solution containing 1.5 mM NH₄⁺ and 1 mM PO₄³⁻ (pH 7.20) (Hart, Stark, Davidson, & Firestone, 1994). The slurry was collected at 2, 6, 20 and 24 h; filtered and analyzed for NH₄⁺ and NO₃⁻ concentration using auto analyzer with Cadmium-Copper reduction column (Lachat Part No. 50277). Potential nitrification rate was determined before and after incubation, whereas soil pH was determined at initial incubation (day 0) and final day of incubation (day 60). Selected soil physicochemical properties of the soil used are presented in Table 1.

The soil samples (108 % WHC) used in the incubation experiment were air-dried and adjusted to 75, 100 and 150 % water holding capacity (WHC) before they were pre-incubated for one week. Next, soil samples (250 g) were placed in a plastic container with four moisture conditions (75 %, 100 % and 150 % WHC maintained under lab and fluctuating conditions between 150 % WHC and 100 % WHC- Each for 12 days). Another set was established with additional urea addition at 0.11 g N and mixed thoroughly. Deionized water was added to adjust the required soil moisture. The entire container were covered with punctured cap to maintain aerobic condition and incubated at 25 ± 2 °C for 70 days. Any water loss from evaporation was replaced using deionized water every three days. Soils were sub-sampled at 0, 7, 14, 21, 28, 35, 42, 49, 56, 63 and 70 days for NH₄⁺ and NO₃⁻. There were three replicates for each treatment with control unfertilized. Initial sampling (day 0) were done three hours after the soil was mixed. The soils were then analyzed for pH (day 0 and day 60). After 60 days of incubation, the soil samples were removed from the cup and PNR was determined.

The experiment was set-up in lab using container in completely random design (CRD). The data were analysis using SAS 9.4 statistical analysis package (SAS Institute, 2007). Analysis of variance (ANOVA) was done to test treatment effect using Tukey’s Test at p < 0.05. Pearson correlation analysis was carried out for all parameters at p < 0.05.

### Table 1. Selected soil physicochemical properties before incubation

| Soil Physicochemical Properties | Value |
|--------------------------------|-------|
| pH                             | 3.96  |
| Soil moisture (%)              | 48.81 |
| Total C (%)                    | 49.22 |
| Total N (%)                    | 1.22  |
| C/N Ratio                      | 40.45 |
| NH₄⁺ (µg/g)                    | 1.71  |
| NO₃⁻ (µg/g)                    | 0.36  |
| N (µg/g)                       | 2.07  |
| Potential nitrification rate   | 0.48  |

## RESULTS AND DISCUSSION

Different moisture level and fluctuating moisture condition without any urea addition resulted in erratic fluctuation in NH₄⁺ throughout the incubation period (Fig. 1). The NH₄⁺ fluctuation ranged from 0.52 to 4.46 µg/g soil. All the treatments were unable to fit any trend curve. It can be considered that mineralization or NH₄⁺ is very low without urea addition and moisture level and fluctuating moisture condition have little effects on NH₄⁺ availability.

In the treatments with urea addition, the results indicated that increasing soil moisture reduced NH₄⁺ content (Fig. 2). Fluctuating moisture condition (M4) enhanced NH₄⁺ release compared to...
150 % WHC (M3). M4 showed linear trend in $\text{NH}_4^+$ release throughout the incubation period, whereas, M3 showed quadratic curve and the $\text{NH}_4^+$ content peaked at day 47 with 207 µg/g soil of $\text{NH}_4^+$. In contrast, M1 and M2 showed irregular fluctuation of $\text{NH}_4^+$ throughout incubation period.

**Fig. 1.** Dynamic of soil $\text{NH}_4^+$ content during the incubation with different moisture level and fluctuating moisture condition (without urea)

**Fig. 2.** Dynamic of soil $\text{NH}_4^+$ contents during the incubation with different moisture level and fluctuating moisture condition (with urea)

Remarks: T1 = without urea addition; M1 = 80 % WHC, M2 = 100 % WHC, M3 = 150 % WHC and M4 = fluctuation between 150 % WHC and 100 % WHC (each for 12 days)

Remarks: T2 = with urea addition; M1 = 80 % WHC, M2 = 100 % WHC, M3 = 150 % WHC and M4 = fluctuation between 150 % WHC and 100 % WHC (each for 12 days)
Soil NO$_3^-$ Contents

Nitrate contents throughout the incubation period are presented in Fig. 3 and Fig. 4. In the treatments without urea addition, NO$_3^-$ fluctuated less than 2 µg/g soil in all moisture condition (Fig. 3). There were no significant differences in comparison between NO$_3^-$ at the beginning (day 0) and at the end of incubation period (day 70). In contrast, all the treatments with urea followed a quadratic response curve (Fig. 4). Addition of urea at the start of incubation increased the NO$_3^-$ with time, followed by the declined of NO$_3^-$ after reaching maximum point. M1 achieved maximum NO$_3^-$ content at day 32, M2 at day 34, M3 at day 37 and finally M4 at day 35. Based on trend analysis, increase in soil moisture level delayed the maximum NO$_3^-$ release. However, this only happened in the presence of soluble N source (urea). Applying moisture fluctuation (M4) stimulate the nitrification process and thus NO$_3^-$ content in comparison to waterlogged condition (M3).
Net Mineralization and Nitrification

Although the soils were exposed to different moisture levels and condition, net mineralization was very low (0.02-0.09 µg N/g soil/day) in without urea addition (Fig. 5). A similar pattern was observed in net nitrification which was almost non-existent (ranging from 0.01-0.02 µg N/g soil/day) in without urea addition (Fig. 6). Net mineralization and nitrification increased significantly with urea addition, suggesting the role of soluble N to promote these processes in peat soil (Fig. 6 and Fig. 7). Net mineralization decreased with increasing soil moisture level from M1 to M3 (from 4.12 to 2.83 µg N/g soil/day) and slightly increased (3.01 µg N/g soil/day) with fluctuating soil moisture (Fig. 5). The net nitrification rates were significantly higher in M1 and M2 but no significant differences were observed in the M3 and M4 treatments (Fig. 6).

Potential Nitrification Rate (PNR)

There were no significant differences in PNR between different moisture levels and condition in without urea treatment (Fig. 7). In comparison between with urea and without urea treatments, addition of urea increased in PNR in all treatments with 55.10 % increase in M1, 47.83 % in M2, 27.91 % in M3 and 55.8 % in M4 (Fig. 7). Similar to net mineralization and nitrification, soil moisture determined the magnitude of PNR. Drier soil (M1 = 80 % WHC) showed the highest PNR rate (0.76 µg N/soil/day) compared with water-logged condition (M3 = 150 % WHC) with 0.55 µg N/soil/day. Water-logged condition reduced the PNR by 27.63 %. On the other hand, fluctuating moisture condition (M4 = 150 % WHC and 100 % WHC) increased PNR by 21.82 % compared with M3.

Fig. 5. Net mineralization rates in peat soil treated with different moisture condition

Fig. 6. Net nitrification rates in peat soil treated with different moisture condition
As shown by this study, nitrification in peat soil needed additional N supply regardless of soil moisture conditions. Soil moisture effect was only present after urea addition where it regulated the rate of nitrification (Fig. 4 and Fig. 5). Therefore, nitrogen addition through urea is the most significant factor inducing mineralization and nitrification in cultivated tropical peat soils. Under control treatments, the mineralization and nitrification remained very low and fluctuated in a tight range (0-0.09 µg N/g soil/day).

Soil pH is one of the major constraints of nitrification in peat soils. Sahrawat (2008) indicated that acidic soil did not nitrify unless stimulated by urea addition in ten different tropical soils. One of the peat soils used in his study recorded 5 mg/g soil NO$_3^-$, whereas in this study the maximum NO$_3^-$ concentration was only 1.69 µg/g soil in without urea treatment. Killham (1990), also observed similar results of this present study, where very low net nitrification (0.4-2.9 0-0.09 µg N/g soil/day) but provide PNR considerably. With the presence of excess substrate (NH$_4^+$) in PNR, nitrifiers community may no longer be under the same degree of constraint by the competition for mineral N. There is a possibility that oil palm grown under peat soil condition have an allelopathy inhibition on the nitrifiers for ecological implication to maintain N as NH$_4^+$ and therefore conserve energy.

Although peat soils have high N concentration (in the form of organic N), N$_2$ availability is limited due to the slow mineralization and nitrification as a result of low pH which impede microbial activity (Yao et al., 2011). In addition, high moisture content and fluctuating moisture condition minimize the OM decomposition via limited O$_2$ availability (Bohrerova, Stralkova, Podesvova, Bohrer, & Pokorny, 2004; Breuer, Kiese, & Butterbach-Bahl, 2002).

Increasing soil moisture resulted in lower NO$_3^-$ and PNR. This finding was consistent with previous findings (Agehara & Warncke 2005; Breuer, Kiese, & Butterbach-Bahl, 2002; Zhou et al., 2012) which indicated nitrification decreased with increasing soil moisture. Therefore, it was believed that the similar situation also recurs in peat soil condition. Application of urea tremendously induced mineralization and nitrification in peat and portrayed the effect of soil moisture on mineralization and nitrification. Under normal condition without any amendments, both of these processes remained considerably low with little fluctuation. This study results showed that soil moisture controlled the magnitude of PNR when urea was added. Increase in soil pH for urea-added systems ascribed to the consumption of H$^+$ during urea hydrolysis process in the soil (Tong & Xu, 2012).

Hydrolysis of urea increased the soil pH at the early stage which may have stimulated the nitrifies activity and the availability of soluble substrate enhanced the nitrification status. Therefore, there was high nitrification potential in urea-added soils. This process occurs over the first few days (0-7 days) following application. However, once nitrification processes start to become significant then the pH of the soil is decreased (Lu et al., 2012).

![Fig. 7. Potential nitrification rate (PNR) of peat soil treated with different moisture condition](image)
CONCLUSION AND SUGGESTION

In conclusion, nitrification needed additional N supply regardless of the soil moisture status. However, higher soil moisture resulted in 50 % and 28 % decrease of NO$_3^-$ availability and PNR in the presence of urea. Soil moisture conditions controlled the magnitude of urea being mineralized and nitrified. Fluctuation of soil moisture also enhanced nitrification. This study has an implication of timing on the urea application in regards to moisture to minimize N losses. Therefore, it is suggested that the application of N based fertilizer can be effective when using in low moisture content in the field.

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