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Effect of Liming and Fertilizer Application on Mineralization of Nitrogen in Hemic and Sapric of Tropical Peat Material

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ABSTRACT

This study was conducted to investigate the effect of liming and fertilizer application on mineralization of nitrogen in hemic and sapric peat material of Tropical Histosols. The peat materials were left to decompose aerobically for 8 weeks under laboratory incubation and samples were taken for extractable ammonium at every 1 week interval. The trends in nitrogen mineralization were found to be similar between hemic and sapric peat materials for all treatments; however the rate and amount of ammonium release differed. The application of lime increased the pH of the peat material from around 3.7 to a pH of about 6.0 but no significant differences were found in the amount of NH_4^+ at 8 weeks of incubation between treatments with and without liming material in hemic and sapric peat material respectively. Fertilizer application significantly increased NH_4^+ in both peat materials, where NH_4^+ in hemic material was significantly higher (23.85 g/kg) compared to sapric (16.48 g/kg) peat material. This study showed that the practice of liming to increase soil pH did not necessarily improve the mineralization of nitrogen in Hemic and Sapric peat therefore was not prerequisite unless the crops to be planted are intolerant to acidity.

Keywords: Ammonium, hemic, incubation, nitrogen mineralization, peat, sapric

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INTRODUCTION

Tropical peat comprises soils that are formed from incompletely decomposed organic materials developed in low-lying depressional areas which are waterlogged for most parts of the year. These organic materials contain large amounts of nutrients that are essential for plants, since they are

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of vegetative origin (Andriesse, 1988; Bot & Benites, 2005; Lickacz & Penny, 2001).

Upon decomposition, these nutrients will eventually be released in plant available form (Lickacz & Penny, 2001).One of the most important nutrients generally found in Histosols chiefly peat soils is nitrogen whereby its total content varies from 0.3-4.0% (Lucas, 1982). Values between 1.3-1.5% are common in tropical Histosols (Gurmit et al., 1987). Although such values are considered high in soils, however, most of the nitrogen are unavailable for plants due to its high C:N ratio. The waterlogging condition associated with peat swamps as well as having high acidity due to organic acids further impedes decomposition and thus the release of nutrient (Brady & Weil, 2002).

It has been a standard practice in agricultural activities to lime soils that are high in acidity. This is especially true for mineral soils, however the effectiveness of liming in organic soils to facilitate in mineralization of nitrogen is still unclear. While reports have shown that the application of lime increase the mineralized N in acid mineral soil (Nyborg & Hoyt, 1978) such result may be otherwise in organic soils. Studies by Chapin et al. (2003) discovered that the addition of lime in Northern Minnesota decreased potentially mineralizable N as well as cumulative N mineralization in the fen. Whereas according to Rangeley and Knowles (1988), liming may result to an increase in the activity of aerobic organisms in peat, but this has little effect in anaerobic condition. Such findings demonstrated that the effect of liming cause variation in mineralizable N due to the difference in the type and nature of peats. Moreover, according to reports by Andriesse (1988), microelement contents such as copper, iron, cobalt, manganese, zinc and molybdenum varies at different depths of the peat deposit. It was found that the contents of most if not all of these microelements decrease as depth of the deposit increases. The same pattern also applies for the contents of macro and secondary elements such as nitrogen, phosphorus and magnesium where the surface layer of the sapric material commonly showed higher values compared to the subsurface layers of hemic and fibric peat materials. This is partly due to the difference in the degree of decomposition where the availability of the nutrients differs between peat materials. The parent material for sapric, hemic and fibric might originate from the same material, but the ash content in these three materials resulting from different degrees of decomposition might portray contrasting values.

Apart from liming, it is a prerequisite in agricultural practices to apply fertilizers where nutrients are suspected to be low. Peat soils are unique as they exhibit diverse physical and chemical properties which not every peat is of the same productivity as the other (Lim et al., 2012). The use of fertilizers tends to facilitate in accelerating the rate of decomposition, thus promoting more N to be released from the organic materials of the peat (Andriesse, 1988). However, McGreevy and Farrell (1984) found that although fertilizers provide more available nutrients into the soil, however the liberation is often short-lived in ombrotrophic peats after initial stimulation.

There is limited information on studies of nitrogen in tropical peat emphasizing on the different types of peat material as a response to liming and fertilizer application. Given such situation it is of great magnitude to assess according to the types of peat since different kinds of peat response differently upon mineralization due to their varied nutrient contents and other abiotic condition. Such information may provide significant importance in understanding the nutrient dynamics of the peat material brought upon by anthropogenic activities. Therefore, this study aimed to investigate the effect of liming and fertilizer application on mineralization of nitrogen through the amount of NH_4^+ extracted in hemic and sapric material of tropical peat.

MATERIALS AND METHODS

Experimental Materials

The peat utilized in this study was of ombrogeneous (rain-fed) oligotrophic (nutrient-poor) tropical peat (Histosols) comprising two different depths of organic materials based on the degree of decomposition; hemic (less decomposed) and sapric (well decomposed) respectively. These samples were taken from a peat secondary forest in Kampung Kundang, Kuala Langat, Selangor, Malaysia (02°42’839”N 101°33’269”E). Surface (0-30 cm) and subsurface samples (40-60 cm) were collected by stratified random sampling method using a MaCaulay peat sampler (peat auger). Sapric material was located on the surface layer containing well decomposed peat as it was exposed to air for decomposition to occur while that of hemic material was found in the subsurface layer comprising the semi-decomposed peat material which was often below groundwater table and therefore waterlogged for most period of time.

Analysis of Physical and Chemical Properties

The types of peat were classified based on their degree of decomposition by using the von Post pressing method as quoted by Andriesse (1988). This test was done directly on the field where the fresh peat samples were first pressed on the palm. The colour of the extruded liquor and the proportions of the extruded matter were observed in detail to classify the peat materials as to match on the Von Post scale while the percentage of unrubbed fibre content was determined following the method by Andriesse (1988). Bulk density was measured using a core sampler which dried at 105 ºC to a constant weight. Moisture content was also determined using gravimetric method (American Society for Testing and Materials [ASTM], 1988). The pH of the samples was determined potentiometrically in soil suspensions of 1:10 volumetric ratio of air dried samples to water. The soil organic carbon (SOC) was quantified using LECO Total Organic Carbon analyser whereas total nitrogen from the soil samples was determined following semi micro-Kjeldhal method.

Treatments

The treatments applied to each type of peat soil, hemic and sapric material respectively were no application of lime and fertilizer (T1), application of 20 g of liming material ($CaCO_3$) (T2) and application of 20 g of liming material ($CaCO_3$) with 5g of compound fertilizer 12:12:17:2 (T3). The lime and fertilizer treatments were based on a recommendation for oil palm seedling stage of up to 12 months (Gillbanks, 2003). The mineralization of nitrogen in hemic and sapric peat material following application of treatments were assessed using plastic containers of 15 cm (diameter) x 10.5 cm (depth) with laboratory temperature of 30°C. The initial weight of the peat with the container was recorded prior to application of treatments. Moisture was controlled by maintaining at 70% field capacity. As much as 800 g of fresh peat soil were placed into the container. The peat materials were left to decompose aerobically for 8 weeks and samples were taken for the determination of extractable ammonium (NH_4^+) at every 1 week interval.

Analysis on Nitrogen Mineralization

As much as 4.0 g of the peat samples were collected from the container in 4 replicates in accordance to the type of peat material and treatment applied. The determination of extractable N was based on mineral N (NH_4-N) where organic forms of nitrogen such as that of proteins were converted into simpler compounds of amino acids and the nitrogen was released as ammonium ion (NH_4^+) as it decomposed. Therefore by analysing the extractable NH_4^+ in the peat soil, nitrogen mineralization can be assessed. This was done by extracting the soil samples with 2 M KCl solution at 1: 5 ratio of soil to extractant (Maynard et al., 2008).

Statistical Analysis

Simple linear and non-linear regression was used to analyse the trend in extractable NH_4^+ for each of the treatments tested in both peat materials using SigmaPlot version 12.0. Analysis of variance (ANOVA) was conducted to test the effects of treatments applied onto the peat materials while meant comparison was done using Tukey's Test at 5% level using Statistical Analysis System (SAS) version 9.2.

RESULTS AND DISCUSSION

Physico-chemical Properties

Two types of peat material were used in this study where both types were determined based on their degree in decomposition measured by fibres these peat materials contained. The percentage of unrubbed fibre content was higher in hemic compared to sapric material as described in Table 1. This result corroborates with the findings in Soil Survey Staff (1975) where moderately decomposed materials such as hemic had more fibre content as compared to the well

Table 1
Selected physical and chemical properties of hemic and sapric peat material prior to incubation

Properties	Type of peat material		
	Hemic	Sapric	Range
von Post scale	H6	H8	
% unrubbed fibre	40± 2.719	26.67±2.723	
Munsell notation	10YR 7/4	10YR 3/4	
pH	3.74	3.67	3-4.5[a]
Total carbon (%)	63.95±1.26	62.2±1.14	12-60[a]
Total Nitrogen (%)	0.82±2.11	1.35±2.57	1-4[b]
Bulk density (g/cm)	0.15±2.83	0.18±2.851	0.1-0.2[c]
Moisture content (%)	72.11±0.62	68.57±0.85	

Source: [a]Andriesse (1988); [b]Lucas (1982); [c] Soil Survey Staff (1975)

decomposed sapric material due to the advanced mineralization leaving the more resistant materials remaining in the soil forming humic material. Thus, it is for this reason that the colour in sapric material as indicated by the Munsell notation has a higher value of 3/4 and is therefore much darker than that of hemic material which indicated a value of 7/4. This result also supports with the characteristics determined by Von Post Scale of humification where sapric material had a higher scale of humification of H8. It indicates a very highly decomposed peat where most of the materials are amorphous and exhibit very indistinct plant structure after squeezing between fingers. Hemic having a degree of humification of H6 implies moderately high decomposed peat where plant structures are more distinct after the material has been squeezed.

Bulk density value for hemic and sapric material was consistent with the range of values documented in Soil Survey Staff (1975). Bulk density has a direct relationship with fibre content. The more fibre of a soil material contains per unit volume, the lower its weight over its volume therefore the lesser of its bulk density. Hence material such as hemic which contains more fibre has a lower bulk density as compared to sapric material. Hemic material was saturated with water at the time of sampling, therefore it contains more moisture than the surface layer of sapric material. Thus, this explains the lower value of moisture content in sapric material (68.57%) as shown in Table 1 compared to the hemic material (72.11%). The pH for hemic was slightly acidic than that of sapric. Such difference is attributed to the distinct degree of decomposition. Nonetheless, the pH for both types of peat material was typical for an ombrogenous oligotrophic tropical peat soil with a pH range in water of 3.0 to 4.5 (Andriesse, 1988). The higher degree of decomposition in sapric resulted in lower carbon content due to conversion to CO_2. Hence, lower carbon content may also imply progressive decomposition process. Consequently, element such as nitrogen (N) is higher in sapric material than the sub-surface hemic material.

Nitrogen Mineralization

The rate of nitrogen mineralization by determining the amount of extractable NH_4^+ for T1 increased throughout 8 weeks of incubation period regardless of the types of peat material (Figure 1). The trend in NH_4^+ release can be described by the quadratic equation where both types of peat material exhibit significant quadratic response at 1% level. Based on the response shown in Figure 1, it can be postulated that mineralization of nitrogen through the release of NH_4^+ will continue to increase after 8 weeks of incubation.

By using the quadratic equation of $Y=59.19 + 47x - 2.47x^2$ for sapric material, it can be estimated that the maximum release of NH_4^+ in sapric can be achieved at 9.5 week with as much as 282.8 mg/kg of extractable NH_4^+ . As for hemic, by applying the equation of $Y= 80.5167 + 39.398x – 1.98x^2$, the proposed maximum amount of extractable NH_4^+ will occur at week 10 with an estimated amount of 276.5 mg/kg of NH_4^+. Thus it can be understood that the two types of peat produced similar response on the amount of NH_4^+, however, their differences was shown where hemic released lower amounts of NH_4^+ which might stretch for an extended period of time compared to sapric.

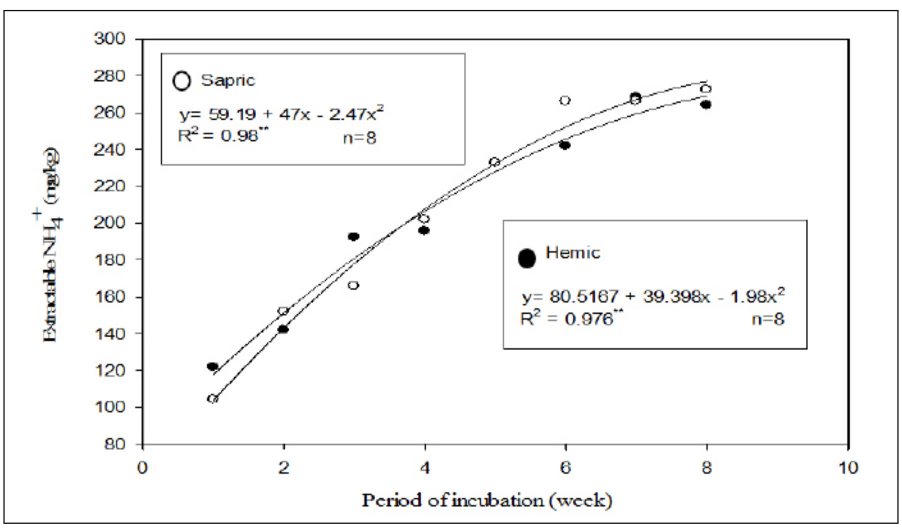

Figure 1. Extractable ammonium (NH_4^+) extracted throughout 8 weeks of incubation for hemic and sapric peat material under control condition (T1).

The response of NH_4^+ release for both hemic and sapric peat material under limed treatment (T2) was found to be linear at 1% significant level respectively (Figure 2). Although the trends of ammonium release throughout the incubation period were similar between the two types of peat where they increase exponentially, yet the amount of extractable NH_4^+ was lower in hemic material compared to sapric. Such observation was also found in T1 where hemic material responded in lower amounts of extractable NH_4^+. This can be explained based on the nature of the peat material itself where sapric material consists of well decomposed organic material containing higher amounts of nutrients such as nitrogen, capable of releasing higher amounts of NH_4^+ at a faster rate compared to hemic.

It should be emphasized that since the response was linear under limed treatment (T2), therefore the release of ammonium might continue to increase for a much longer period of time in contrast with T1 where the response was quadratic where the release of ammonium might follow a declining pattern afterwards soon after achieving their maximum amount at week 10. This demonstrates that liming peat materials resulted in more NH_4^+ being released from its organic pool due to the increase in pH of the soil that might have triggered a suitable condition for more microorganisms to perform decomposition resulting in rapid mineralization of nitrogen (Neale et al., 1997).

The response to lime and fertilizer treatment (T3) can be described by the quadratic equation and both peat materials showed significant quadratic relationship at 1% level (Figure 3). Hemic material attained higher amounts of extractable NH_4^+ compared to sapric; a condition

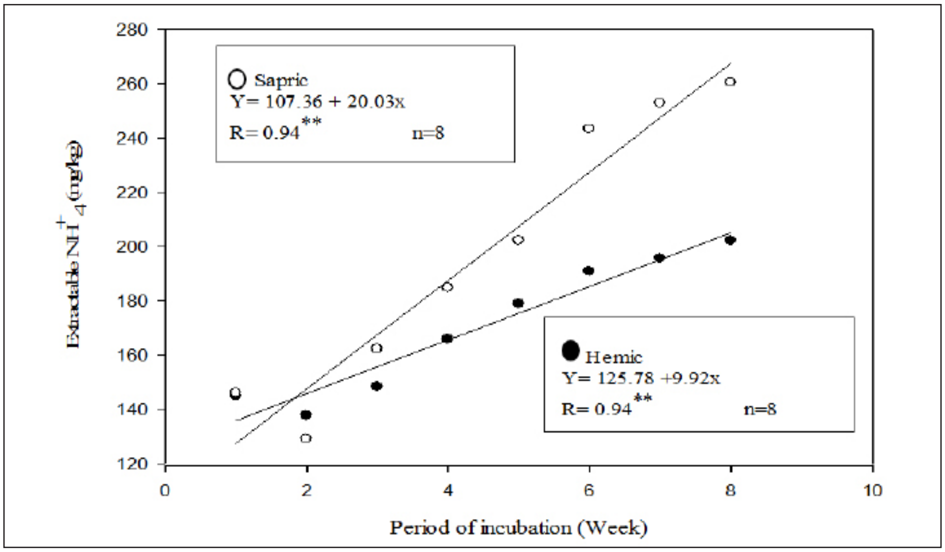

Figure 2. Extractable ammonium (NH_4^+) extracted throughout 8 weeks of incubation for hemic and sapric peat material under limed condition (T2)

which was otherwise comparing to the aforementioned treatments (T1 and T2) where the mineralization rate was higher in sapric than in hemic.

The maximum value of NH_4^+ extracted was found at week 5 for sapric with as much as 2.10% of extractable NH_4^+ while hemic material achieved 2.49% of extractable NH_4^+ also at 5th week. These values were achieved when the pH of the peat material was the highest. Sapric achieved its highest pH of 6.9 while hemic achieved its highest pH of 7.05. Such observation demonstrated that different types of peat material might exhibit similar response in nutrient release within similar soil condition (in this case, soil pH) however; the amount of the nutrient release may vary since different peat types have different chemical properties.

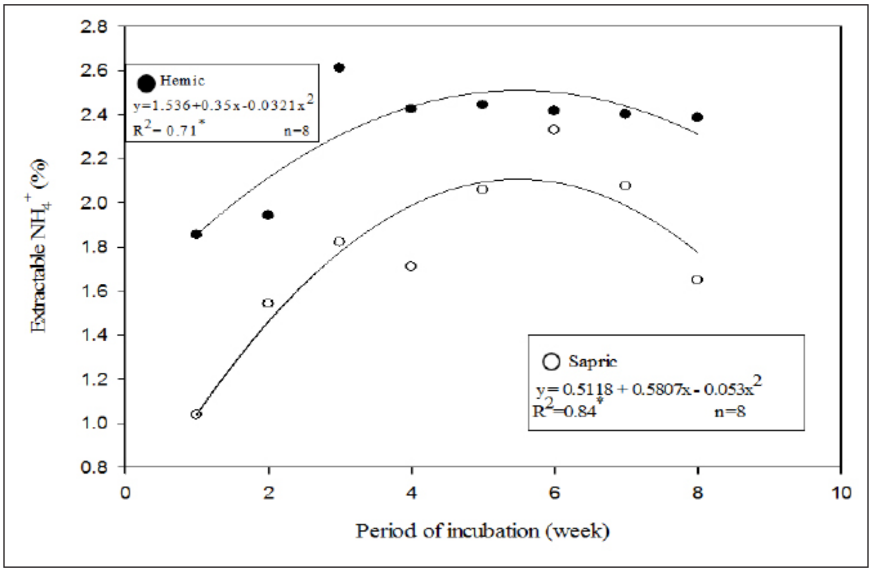

Figure 3. Extractable ammonium (NH_4^+) extracted throughout 8 weeks of incubation for hemic and sapric peat material under limed and fertilized condition (T3)

Comparison on Extractable NH_4^+ at 8 Weeks Incubation between Treatments

The extractable NH_4^+ in T1 and T2 for Hemic and Sapric peat material at 8 weeks of incubation as shown in Table 2 was significantly higher than in the initial condition (fresh peat material). However, no significant differences on the amount of extractable NH_4^+ in T1 and T2 regardless of the peat material.

The increase in pH due to the addition of liming material in T2 did not cause any significant increase in the amount of NH_4^+ during the period of incubation. Alternatively, the application of fertilizer as in T3 showed significant increase in the amount of NH_4^+ for both peat types compared to T1 and T2. This was attributed to the the introduction of fertilizers from the treatment that added in nitrogen which could be easily dissolved in the soil solution. However, it was observed that hemic material in T3 accumulated significantly higher amount of NH_4^+ compared to sapric of the same treatment. Such result reveals that hemic and sapric materials behave differently upon the application of fertilizers albeit the same amount of treatment was added into the soil. The higher microbial population in sapric material as reported by Ivarson (1977) may cause most of the NH_4^+ to be incorporated into the biomass of microorganisms rendering it unavailable for extraction using potassium salt (KCl) which may explain the significantly lower values of NH_4^+ in sapric.

Table 2

Comparison on the amount of extractable NH_4^+ (mg/kg) between at initial condition and at 8 weeks of incubation for hemic and sapric peat material

Treatment	Extractable NH_4^+ (mg/kg)	
	Hemic	Sapric
Initial condition	102.88cA	86.84cB
T1 (no additives)	264.07bB	272.45bA
T2 (lime only)	202.13bcB	260.35bA
T3 (lime and fertilizer)	23,849.6aA	16,476.5aB

Note. Small letters display mean separation in a column by Tukey at 5% level. Capital letters display mean separation in a row using Tukey at 5% level

Changes in Total Carbon Content

Hemic material contained significantly higher amounts of carbon compared to sapric material initially and in T1 respectively (Figure 4). However, such condition was otherwise in T2 and T3 where sapric material accumulated significantly higher amounts of carbon in contrast to hemic material. The application of lime and fertilizer in T3 resulted in the lowest amount of total carbon. This shows that carbon was lost from the peat material when treatments were applied whereby the addition of lime and fertilizer stimulates more decomposition of the organic material in the peat soil. This result is corroborated with other findings (Zhang et al., 2012) that the incorporation of inorganic fertilizer enhances the mineralization of organic matter such that when N fertilizers are applied to the soil, it triggers the mineralization of recalcitrant organic N pool from the organic material. This implies that the agricultural practices of liming and adding fertilizers into peat soil will cause more carbon to be lost despite more nutrients are being released from the soil system, thus depleting the carbon storage in peat soil that is well known for its capability to act as a carbon sink.

Many of the findings by other workers (Dong et al., 2012) observed the application of fertilizers resulted in build-up of carbon but these literatures were mainly referring to mineral soils. In order for mineralization to occur in organic soils, it requires the participation of microbes to breakdown the organic form of an element into inorganic. Hence, microbes will use the carbon source from the organic matter as energy to facilitate in the mineralization process leading to release of carbon dioxide, water and available nutrients as end products thus justifying the reduction of carbon in T3.

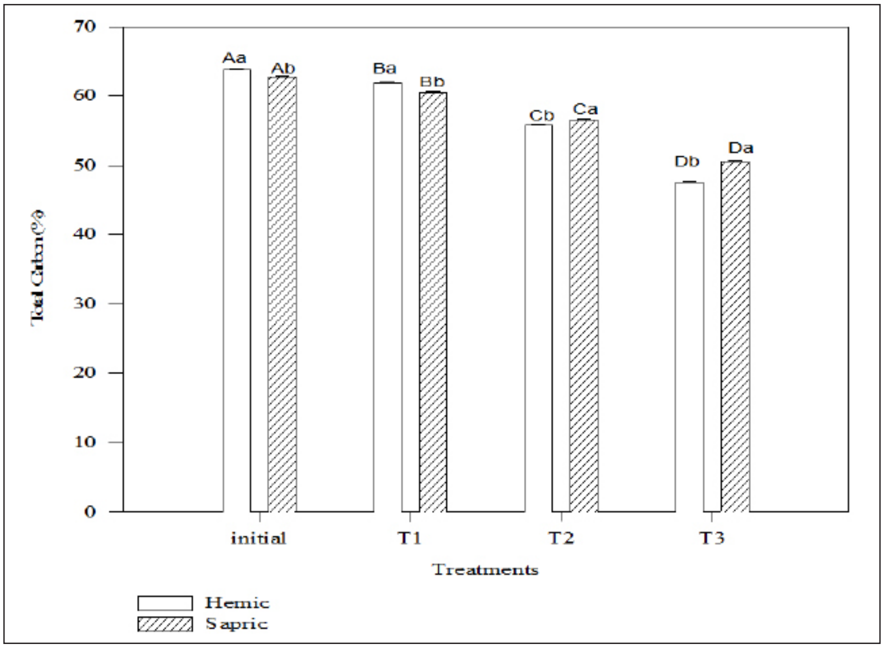

Figure 4. Differences in total carbon (%) in hemic and sapric peat prior to incubation (initial condition) and at 8 weeks incubation period (T1, T2 and T3).
Note. Capital letters display mean separation between treatments within a single type of peat material by Tukey at 5% level while small letters referring to mean separation between types peat material in a particular treatment using Tukey at 5% level

CONCLUSIONS

The crux was no significant differences in the amount of NH_4^+ accumulated at the end of 8 weeks incubation period in T1 and T2 for the two types of peat material, however, the pattern of nitrogen mineralization differed as it would likely to continue for T2 even after 8 weeks of incubation and thus releasing ammonium for a longer period of time compared to T1. Conversely, while the amount of NH_4^+ accumulated was highest in T3 for both peat materials comparing to T1 and T2, however, the mineralization of NH_4^+-N was found to be temporal as it declined after 6 weeks of incubation.

This study shows that the application of lime (only) may not necessarily improve the nutrient availability in these two types of peat material although results showed that these peat materials that were limed underwent progressive decomposition process. Instead, it resulted in higher carbon loss due to rapid decomposition process which might lead to subsidence and this might affect the sustainability of the peat materials in years to come. This study may provide better understanding on the behaviour of hemic and sapric peat material upon the addition of lime and fertilizers in chemical aspects. Such information is useful in predicting changes in the nutrient dynamics of peat soils that are brought upon by anthropogenic inputs as to facilitate in better planning and application of lime and fertilizers.

RECOMMENDATION

Cropping on peat land is very different from that in mineral soils as one should always bear in mind that peat soils will disappear with time as carbon dioxide when inputs are much lesser than the outputs. Based on the results from this study, although it is highly recommended not to cultivate on peatlands, however, if the need is crucial, then this can be done by choosing acid tolerant crops, so that farmers will be able to maintain the acidity of the organic soils so decomposition process can be controlled and also not to be burdened by the high amounts of lime to be added. Apart from that, it is also suggested by choosing perennial crop than annual crops so as to not disturb the soil too much upon harvesting and replanting which may also accelerate the decomposition. Also, it is recommended to plant crops that have shallow and fibrous roots so that the water table can be maintained as high as possible so as not to expose much of the peat soils to oxidation.

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