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CHANGES IN PHYSICAL AND CHEMICAL PROPERTIES OF HEMIC AND SAPRIC PEAT INFLUENCED BY LIMING AND FERTILIZER APPLICATION

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CHANGES IN PHYSICAL AND CHEMICAL PROPERTIES OF HEMIC AND SAPRIC PEAT AS INFLUENCED BY LIME AND FERTILIZER APPLICATION

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

May 2015

DEDICATION

To my wonderful parents, Abdul Reeza Abdul Rahman and Sharifah Sham Mustafa Aljofri,

My supportive husband, Mohd Zuhairi Mohammad Sabri,

and

My precious son, Muhammad Aqief Imran Mohd Zuhairi

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

CHANGES IN PHYSICAL AND CHEMICAL PROPERTIES OF HEMIC AND SAPRIC PEAT MATERIAL AS INFLUENCED BY LIME AND FERTILIZER APPLICATION

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Studies on peat of tropical regions on their physical and chemical changes as a consequence of liming and fertilizers are mostly inconclusive due to the variations in the type of peat, climate, hydrology as well as the botanical origin of the peat lands. Hence, this study was conducted to determine the changes in physical and chemical properties specifically in Hemic and Sapric peat material upon liming and fertilizer application; to compare the rate of carbon dioxide release between Hemic and Sapric peat material upon lime and fertilizer application under a small-scale laboratory incubation study; to evaluate the effect of liming and fertilizer on availability of Nitrogen (N), Phosphorus (P), Potassium (K) in Hemic and Sapric material; to examine the changes in the level of Carbon (C) and N content in the two types of peat materials as a result of lime and fertilizer application during the course of planting maize and the availability of N for the plant.

Experiments were conducted both in laboratory and netted-house where the first and final objectives were conducted using the same experiment where maize were grown until tasselling stage (8 weeks) in the netted-house of Ladang 16, UPM. Four treatments in triplicates were applied (C) control; (T1) compound fertilizer NPK (12:12:17:2); (T2) dolomite adjusted to pH5.5; (T3) combination of compound fertilizer NPK and dolomite adjusted to pH5.5. The second objective was conducted using an open chamber incubation approach to capture CO_2 release while the third objective was assessed by using basins of 32 x 15 cm dimension with temperature setting of 30°C. Three treatments applied in the latter two studies in triplicates were (T1) no additives; (T2) addition of lime at 2.5 g per 100 g of peat; (T3) addition of lime and fertilizer NPK (12:12:17:2) at 3 g per 100 g of peat. The peat materials were left to decompose aerobically for 8 weeks and samples were taken for the determination of CO_2 –C, available N, P and K at every 7 days interval.

The addition of lime (T2) and fertilizers (T3) caused significant increases in pH from pH 3.7-3.8 to pH 5.6-5.79 and CEC from an average of 121.1 meq $100g^{-1}$ to 233.9 meq $100g^{-1}$ while significantly reducing the organic carbon (average of 53.6% to 50.0%), MWD (average of 4.4 mm to 3.1 mm) and water availability (average of 78.7% to 34.1%) of the two types of peat material. The use of FTIR further justify the enhanced decomposition in the T2 and T3 by the disappearance of aliphatic and aromatic C=C stretch at 1700 and 1600 cm^{-1}. Sapric material often showed higher carbon dioxide release than Hemic regardless of treatment application. The response patterns on nutrient availability were similar between the two peat materials, only that they differ between treatments. Although NH_4^+ was significantly lower in T2 (202.13 mg kg^{-1}) compared to T1 (264.07 mg kg^{-1}) in Hemic, however the release may persist longer in T2 as the response was linear compared to T1 where response was quadratic. The introduction of lime (T2) did not improve the release of P (58.7-73.2 mg kg^{-1}) compared to under controlled condition (79-96.5 mg kg^{-1}). Liming peat material also resulted in lower amounts of exchangeable K^+ (19.27- 27.72 mg kg^{-1}) compared to under controlled condition (21.73-33.89 mg kg^{-1}).

Maize plants were unable to grow in the control and T1 due to the extreme acidity of the peat materials as they grew only when the peat materials were amended with lime in T2 and T3. Although no significant differences found on N concentrations in maize plants when planted on the two types of peat material, yet the maize plants showed better growth when planted on Sapric. However, the N content in the plant was significantly reduced in the second planting for T2 (15.25-26.34 mg kg^{-1}) compared to the same treatment during the first planting (65.63-90.88 mg kg^{-1}) due to the decline of ammonium supply in these peat materials. Treatment with both application of lime and fertilizer (T3) showed highest dry matter weight in the two plantings. Although the practice of lime and fertilizer application in Hemic and Sapric material resulted in higher nutrient availability (N, P and K), however, this practice also resulted in higher amounts of carbon dioxide release with time, breakdown of larger-sized aggregates of organic material as well as reduction in water retention capability which in turn may induce the susceptibility of wind and water erosion of this fragile peat materials.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PERUBAHAN FIZIK DAN KIMIA PADA HEMIK DAN SAPRIK KESAN DARI PENGAPLIKASIAN KAPUR DAN BAJA

Oleh

AMEERA BINTI ABDUL REEZA

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Kajian mengenai gambut di kawasan tropika membabitkan perubahan fizik dan kimia oleh tanah tersebut kesan dari pengkapuran serta pembajaan masih lagi tidak muktamad disebabkan kepelbagaian jenis gambut, cuaca, topografi, hidrologi serta asal tumbuhan tanah gambut itu. Dengan itu, kajian ini telah dijalankan bagi menentukan perubahan fizik dan kimia khususnya pada jenis gambut yang dinamakan Hemik dan Saprik kesan dari pengkapuran dan pembajaan; membandingkan kadar pelepasan karbon dioksida di antara Hemik dan Saprik setelah pengkapuran dan pembajaan melalui cara inkubasi skala kecil di makmal; menilai mineralisasi nutrien seperti Nitrogen (N), Fosforus (P) dan Kalium (K) di dalam Hemik dan Saprik kesan dari pengkapuran dan pembajaan; menyelidiki perubahan pada kandungan Karbon (C) dan N di dalam kedua-dua jenis gambut ini akibat pengaplikasian kapur dan baja sepanjang penanaman jagung serta ketersediaan nutrien N bagi penyerapan oleh pokok jagung tersebut.

Kajian telah dijalankan di dalam makmal dan juga rumah jaring di mana objektif pertama dan terakhir telah dijalankan menggunakan eksperimen yang sama dengan menanam jagung sehingga fasa pengeluaran bunga jantan (8 minggu) di ladang 16, UPM. Terdapat 4 jenis rawatan dalam 3 replikasi telah digunakan iaitu (C) kawalan; (T1) baja kompoun NPK (12:12:17:2); (T2) kapur ditambah sehingga mencapai pH 5.5; (T3) penggabungan kapur dan baja kompoun NPK (12:12:17:2). Objektif kedua telah diuji dengan pendekatan inkubasi bekas terbuka dengan pemerangkapan CO_2 yang berterusan manakala objektif ketiga telah dijalankan menggunakan besen yang bersaiz 32 x 25 cm dimensi pada ketetapan suhu 30 °C. Tiga jenis rawatan dalam 3 replikasi telah dijalankan iaitu (T1) kawalan; (T2) penambahan kapur pada 2.5 g bagi setiap 100 g gambut; (T3) penambahan kapur serta baja kompoun NPK (12:12:17:2) pada 3 g bagi setiap 100 g gambut. Gambut tersebut dibiarkan mereput dengan kehadiran oksigen selama 8 minggu di mana sampel tanah diambil setiap 7 hari sekali bagi penentuan karbon dioksida serta perubahan N, P dan K tersedia.

Penambahan kapur (T2) dan baja (T3) telah mengakibatkan kenaikan pH sebanyak 2.0 dari pH 3.75 serta CEC sebanyak 112.8 meq $100g^{-1}$ dari 121.1 meq $100g^{-1}$, manakala penurunan pada karbon organic (dari purata sebanyak 53.6% kepada 50%), MWD (purata dari 4.4 mm kepada 3.1 mm) serta ketersediaan air (purata dari 78.7% kepada 34.1%) pada kedua-dua jenis gambut ini. Penggunaan FTIR membuktikan peningkatan dalam pereputan pada T2 dan T3 disebabkan hilangnya rangkaian alifatik dan aromatic C=C pada 1700 dan 1600 cm^{-1}. Rawatan T3 kerap mencatatkan jumlah penghasilan CO_2 yang tertinggi berbanding rawatan lain tidak kira jenis gambut. Respon yang serupa dalam ketersediaan nutrien dapat dilihat antara kedua-dua jenis gambut, ianya hanya berbeza mengikut rawatan. Walaupun NH_4^+ yang dihasilkan dalam rawatan T2 lebih rendah (202.13 mg kg^{-1}) dari T1 (264.07 mg kg^{-1}), tetapi pelepasan NH_4^+ di T2 mampu bertahan lebih lama disebabkan respon yang linear berbanding kuadratik di T1. Rawatan kapur (T2) tidak menunjukkan kenaikan dalam pelepasan P inorganik (58.7-73.2 mg kg^{-1}) berbanding rawatan T1 (79-96.5 mg kg^{-1}). Rawatan T2 juga menyebabkan jumlah ketersediaan K^+ boleh ganti yang lebih rendah (19.27- 27.72 mg kg^{-1}) berbanding T1(21.73-33.89 mg kg^{-1}).

Pokok jagung ini didapati tidak dapat hidup dalam rawatan kawalan dan T1 disebabkan keasidan yang tinggi pada tanah gambut. Ianya hanya dapat hidup pada rawatan yang mengandungi kapur seperti di T2 dan T3. Meskipun tiada perbezaan yang nyata pada kepekatan N dalam jagung yang ditanam pada kedua-dua jenis gambut, namun pertumbuhan jagung kelihatan lebih baik apabila ditanam pada Saprik berbanding Hemik. Namun begitu, kandungan N pada jagung ini berkurangan dengan sangat ketara pada penanaman yang kedua bagi rawatan T2 (15.25-26.34 mg kg^{-1}) berbanding penanaman yang pertama (65.63-90.88 mg kg^{-1}) disebabkan kekurangan bekalan ammonium di dalam kedua-dua gambut ini. Rawatan T3 bagi kedua-dua jenis gambut ini menunjukkan berat kering jagung yang tertinggi dalam kedua-dua penanaman. Meskipun penggunaan baja dan kapur pada kedua-dua jenis gambut ini menunjukkan peningkatan pada ketersediaan nutrient N, P dan K, tetapi ianya juga menyebabkan kenaikan pada pelepasan gas karbon dioksida, perpecahan pada agregat bahan organik yang lebih besar serta pengurangan pada keupayaan kedua-dua gambut ini untuk menyerap lebih banyak air. Ini mungkin akan menyebabkan kebarangkalian yang lebih tinggi untuk terjadinya hakisan air dan angin pada Hemik dan Saprik tersebut.

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I certify that a Thesis Examination Committee has met on 11th May 2015 to conduct the final examination of Ameera Binti Abdul Reeza on her thesis entitled "Changes in Physical and Chemical Properties of Hemic and Sapric as Influenced by Lime and Fertilizers" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

I hereby confirm that:

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LIST OF ABBREVIATIONS

N	Nitrogen
P	Phosphorus
K	Potassium
NH_4^+	Ammonium
NO_3^-	Nitrate
OH	Hydroxyl
COOH	Carboxyl
ppm	parts per million
Ca^{2+}	Calcium ion
Mg^{2+}	Magnesium ion
H^+	Hydrogen ion
SO_4^-	Sulfate ion
$CaCO_3$	Calcium carbonate
$CaMg(CO_3)_2$	Dolomite
CEC	Cation exchange capacity
C	Carbon
FTIR	Fourier Transform Infra-Red
SEM	Scanning Electron Microscopy
ANOVA	Analysis of Variance
MWD	Mean Weight Diameter

CHAPTER 1

INTRODUCTION

Peat (malay term: *gambut*), being an organic soil is distinctively different from mineral soils where specific care and attention has to be given regarding its land use and management. Peats are soils that are usually dark in colour and while many presume that when a soil is dark in colour, these soils are very likely to be very fertile and productive. However, this is not always true. Although peat is developed from incomplete decomposition and transformation of plant remains that defines the term ‘organic’, however such soils are generally classified as poor soils for farming. This is due to both physical limitations where it is waterlogged with high water table during most parts of the year as well as chemical constraints since most nutrients such as potassium, zinc, boron and copper are highly deficient.

Despite such restrictions, some agrarian societies have resorted to utilize peat soils for farming, driven by the need to make a living, in the absence of better alternative mineral soils (Foong et al., 2010). The tropical peat lands are currently under tremendous pressure from agriculture since most of the desirable ‘dry’ lands (mineral soil) are occupied by urbanization development. As such, peat lands have been deforested at a rapid rate of 1.5% per year on average. While the world demand for palm oil is forecast to increase especially in Europe for biofuel, consequently greater peat land areas have been reclaimed to make way for large scale oil palm plantations. Such activities on peat land pose environmental instability where once the peat is being deforested, it alters the flux of the dominant greenhouse gases (GHG) especially when peat is being drained for agriculture to commence (Hooijer et al., 2006). Apart from that, subsidence which is the lowering of the surface of reclaimed peat is also a major problem and a permanent constraint when attempting for sustainable agricultural activities.

With regard to many of the controversial issues surrounding peat reclamation, henceforth there is a crucial need to focus on several fundamental aspects of the characteristics and behaviour of peat in order to manage the land use properly and efficiently without compromising their benefits for the future. In spite of this, studies on peat of tropical regions regarding the behaviour of organic soils by emphasizing on its physical and chemical changes as a consequence of agricultural practices such as liming and fertilization are mostly inconclusive. This is due to the variations in the type of peat, climate, topography, hydrology as well as the botanical origin of the peat lands. Although it has been well documented that liming increases decomposition rate of organic matter in soils (Fuentes et al., 2006; Marschner and Wilczynski, 1991; Ivarson, 1977;) however several studies found that liming in peat soils cause a decrease in nutrient availability (Chew et al., 1976a and b; O’Toole, 1968; Hardon and Polak, 1941). Still, it should be remarked here that these studies were done on a temperate climate as well as having different parental vegetation. Thus, this present study might be able to clarify the conflicting reports which focus on tropical Histosols that are of dipterocarp vegetation.

While the debate on the global warming issue has been attracting many attention and special emphasis was given by the western counterpart on oil palm planted on peat land, the agricultural use of tropical peat has since commonly viewed with great scepticism. Thus there is a need to provide some solid scientific data to support, counteract and if possibly to shift their frame of mind that cropping in peat land is possible with a moderate compromise view that agriculture should be given concessions in areas which can be permanently drained on shallow and moderately-deep peat at reasonable cost without endangering the environment. In fact, while peat soils are progressively being converted into agricultural purposes that might lead to the release of carbon, other major nutrients are being released as well. Major nutrients such as nitrogen (N), phosphorus (P) and potassium (K) are also being released along with energy, water and resynthesized organic carbon compounds. Soil organisms especially microorganisms utilize soil organic matter that is abundant in peat (65-100% organic matter) as food. As they break down the organic matter, any excess nutrients (N, P and S) are released into the soil in forms that plants can use. Although many studies have been done on nutrient release (Chapin et al., 2003; Lopez-Hernandez and Nino, 1992; McGill and Cole, 1981; Leeper, 1952) however, none of such findings focus on the types of peat material especially in tropical Histosols. This is important as the chemical composition (pH, nutrient content, CEC) consequently, the inherent fertility of the organic soil is influenced by the type of peat material (Mohd Tayeb, 2005).

Apart from the agronomic aspects of peat materials, the physical characteristics of peat materials upon anthropogenic activities such as liming and fertilizer application should also be highlighted as such aspect also influence on the fertility of the peat materials. In spite of this, very limited studies, if any, were done on such attributes especially on the structural changes upon agricultural practices (Ciarkowska, 2010). Therefore, this current study may provide important information in anticipating changes not only in chemical, but also in physical attributes of the different types of peat material that have been brought upon by the application of lime and fertilizers.

In a nutshell, this study may contribute fairly on information regarding the effect of agricultural practices towards the physical aspect as well as on the nutritional supply of the peat materials chiefly Hemic and Sapric peat respectively so as to facilitate in better planning and application of lime and fertilizers. Therefore, despite of viewing on the negative issues, we should optimize on the benefits that peat land can provide and manage its potential sufficiently and efficiently.

Thus, the objectives of this study were:

1. To determine the changes in physical and chemical properties of Hemic and Sapric peat upon liming and fertilizer application.

2. To compare the rate of carbon dioxide release between Hemic and Sapric peat material upon lime and fertilizer application.

3. To investigate the effect of liming and fertilizer application on availability of nitrogen (N), phosphorus (P) and exchangeable potassium (K) in Hemic and Sapric material.

4. To examine the changes in the level of carbon (C) and N content in the two types of peat materials as a result of lime and fertilizer application and the availability of N for maize.

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