UNIVERSITI PUTRA MALAYSIA

# *TROPICAL PEAT SUBSIDENCE, NUTRIENT LOSSES AND OIL PALM SEEDLING GROWTH DUE TO DIFFERENT WATER TABLE DEPTHS*

**SAFIYANU HASHIM ABUBAKAR**

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By

**SAFIYANU HASHIM ABUBAKAR**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science**

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**Chairman : Christopher Teh Boon Sung, PhD**
**Faculty : Agriculture**

Agricultural development on tropical peat land, which is characterized by highly acidic in nature, low nutrients status and high water table depths has been strongly criticized by the international community. Peat soils are unsuitable for cultivation in their natural states, but upon proper soil management and amendments, they can be converted for plantation crops such as oil palm, sago and pineapple with yield performances, at times, matching those on mineral soils. High water table and low nutrients availability are identified as the common problem in peat soils. Rapid changes of water table results in leaching losses of applied nutrients, making them unavailable for crops growth and development. As such, frequent monitoring of water table has become necessary. The objectives of this study were to determine the effects of several water table depths on the (1) Nutrient losses (N, P, K, Mg, Ca, Cu, and Zn), ammonia volatilization following application of urea, and tropical peat subsidence. (2) Oil palm seedlings vegetative growth using a high-density polyethylene containers.

Fifteen cylindrical lysimeters were constructed from a high-density polyethylene (HDPE) material, measuring 0.50 m in diameter and 1 m in height. They were set up to mimic the natural conditions of drained peats. The experiment was carried out in a randomized completely block design. The experiment consisted of five different water table depths (25, 40, 55, 70, and 85 cm) from the soil surface with three replication each. The water tables in the experiment were controlled based on the oil palm root zone depths according to the water table management that was used in tropical peat soil grown with oil palm. The water table depth were adjusted after rainfall events based on the actual water table depths. Leachate samples were collected after every rainfall event and analysed for N, P, K, Mg, Ca, Cu, and Zn contents. A total of 46 days rainfall events were recorded during the study period. A closed dynamic air flow system method was used to measure the daily ammonia loss from urea applied. The amount of urea applied to the peat soil were scale down according to the volume of the lysimeter in the field and volume of the plastic container used where 2 g of urea was surface applied to each of the plastic container containing 1533.02 g peat soil. The system was made of exchange chamber of air pump with the flow rate ranges between 1 and 3.5 L min-1, exchange chamber of (2670 mL plastic container) and a trap (250 mL Erlenmeyer flask). Ammonia loss from the soil was collected using a boric acid by air flow circulation that was passed through the exchange chamber into a trapping flask containing 75 mL boric acid mixed with bromocresol green and methyl red indicator. Based on rainfall events high water table depths (25 cm) showed higher nutrient leaching losses where they accounted for 22.3 N, 27.3 P, 22.3 K, 26.6 Mg, 24.4 Ca, 28.3 Cu, and 27.2 % Zn. The presence of high amount of water may had a major role in leaching losses which made the peat soil always moist and rendered the nutrients more soluble such that their loss from the soil were rapid. Tropical peat subsidence was higher for lower water table depths, where the water table depths 25, 40, 55, 70 and 85 cm (from the soil surface) subsided by 1.9, 2.2, 4.2, 4.6 and 5.6%, respectively. The total plant biomass weight for different water table depths, 25, 40, 55, 70, and 85 cm were 118, 211, 792, 250 and 189 g, respectively. There was a significant difference among the treatment. Fifty-five cm gave the highest biomass growth. High ammonia loss was recorded from high water table (3 cm) accounting for 35.5 % of total ammonia loss with regards to low water table (15 cm) that account only 7.7 %. Water table depth significantly affects nutrients leaching loss, subsidence, oil palm growth and ammonia loss on tropical peat soil cultivated with oil palm.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

# PEMENDAPAN GAMBUT TROPIKA, KEHILANGAN NUTRIEN DAN PERTUMBUHAN ANAK POKOK KELAPA SAWIT DISEBABKAN OLEH PERBEZAAN PARAS KEDALAMAN AIR

Oleh

**SAFIYANU HASHIM ABUBAKAR**

**Mac 2018**

**Pengerusi : Christopher Teh Boon Sung, PhD**
**Fakulti : Pertanian**

Pembangunan pertanian di tanah gambut tropika, yang dicirikan dengan keasidan tinggi di alam semulajadi, status nutrien rendah dan paras kedalaman air yang tinggi telah dikritik dengan hebat oleh komuniti antarabangsa. Tanah gambut tidak sesuai untuk penanaman berdasarkan keadaan semulajadinya, namun pengurusan dan pemulihan tanah yang betul, mereka boleh ditukarkan untuk penanaman tumbuhan seperti kelapa sawit, sagu dan nanas dengan prestasi hasil, yang sesekali, berpadanan dengan di tanah mineral. Paras air yang tinggi dan ketersediaan nutrien yang rendah dikenal pasti sebagai masalah umum dalam tanah gambut. Perubahan cepat paras air menyebabkan kehilangan larut lesap pada nutrien yang diberi, menjadikan mereka tidak tersedia untuk pertumbuhan dan perkembangan tanaman. Oleh itu, pemantauan paras air yang kerap telah menjadi keperluan. Objektif kajian ini adalah untuk menentukan kesan paras kedalaman air pada: (1) Kehilangan nutrien (N, P, K, Mg, Ca, Cu dan Zn), penyejatan ammonia berikutan aplikasi urea, dan pemendapan gambut tropika. (2) Pertumbuhan vegetatif anak pokok kelapa sawit menggunakan bekas polietilena berketumpatan tinggi.

Lima belas silinder lisimeter telah dibina daripada bahan polietilena berketumpatan tinggi (HDPE), berukuran 0.50 m diameter dan 1 m tinggi. Alat ini disusun untuk menyerupai keadaan semulajadi gambut bersaliran. Eksperimen telah dijalankan dalam rekabentuk blok rawak penuh. Eksperimen terdiri daripada lima paras kedalaman air yang berbeza (25, 40, 55, 70 dan 85 cm) daripada permukaan tanah dengan tiga replikasi setiap satu. Paras air di dalam eksperimen dikawal berdasarkan kedalaman zon akar pokok kelapa sawit mengikut pengurusan paras air yang digunakan pada tanah gambut tropika yang ditanam dengan kelapa sawit. Paras kedalaman air diubah selepas kejadian hujan berdasarkan paras kedalaman air yang sebenar. Sampel larut lesap diambil setiap kali selepas hujan dan dianalisa untuk kandungan N, P, K, Mg, Ca, Cu dan Zn. Sejumlah 46 hari kejadian hujan telah direkodkan semasa tempoh kajian. Kaedah sistem aliran udara tertutup yang dinamik telah digunakan untuk mengukur kehilangan ammonia setiap hari dari urea yang diaplikasikan. Jumlah urea yang diaplikasikan kepada tanah gambut telah dikurangkan mengikut isipadu lisimeter di ladang dan isipadu bekas plastik yang digunakan di mana 2 g urea diaplikasikan di permukaan setiap bekas plastik yang mengandungi 1533.02 g tanah gambut. Sistem ini dibuat daripada pertukaran ruang pam udara dengan kadar aliran 1 higga 3.5 L min$^{-1}$, antata ruang pertukaran (2670 mL bekas plastik) dan perangkap (250 mL kelalang Erlenmeyer). Kehilangan ammonia dari tanah diambil dengan menggunakan asid borik dari kitaran aliran udara yang melalui ruang pertukaran ke dalam kelalang perangkap yang mengandungi 75 ml asid borik dicampur dengan bromokresol hijau dan penunjuk metil merah. Berdasarkan kejadian hujan kedalaman parasa air tinggi (25 cm) menunjukkan kehilangan larut lesap nutrien yang tinggi sebanyak 22.3 N, 27.3 P, 22.3 K, 26.6 Mg, 24.4 Ca, 28.3 Cu dan 27.3% Zn. Kehadiran jumlah air yang tinggi mungkin berperanan besar dalam kehilangan larut lesap yang menjadikan tanah gambut sentiasa lembap dan menjadikan nutrien lebih larut justeru itu kehilangannya dari tanah adalah cepat. Pemendapan gambut tropika lebih tinggi pada paras kedalaman air yang rendah, di mana pada paras kedalaman air 25, 40, 55, 70 dan 85 cm (dari permukaan tanah) masing-masing menyusut sebanyak 1.9, 2.2, 4.2, 4.6 dan 5.6%. Jumlah berat biojisim pokok untuk kedalaman paras air berbeza, 25, 40, 55, 70 dan 85 cm masing-masing adalah 118, 211, 792, 250 dan 189 g. Terdapat perbezaan signifikan di kalangan rawatan. Lima puluh lima cm memberikan pertumbuhan biojisim paling tinggi. Kehilangan ammonia yang tinggi telah direkodkan daripada paras air tinggi (3 cm) sebanyak 35.5% daripada jumlah kehilangan ammonia berbanding paras air rendah (15 cm) dengan hanya 7.7%. Paras kedalaman air memberi kesan secara signifikan pada kehilangan larut lesap nutrien, pemendapan, pertumbuhan kelapa sawit dan kehilangan ammonia pada tanah gambut tropika yang ditanam dengan kelapa sawit.

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**Christopher Teh Boon Sung, PhD**
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

**Ahmed Osumanu Haruna, PhD**
Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia Bintulu Campus
(Member)

**ROBIAH BINTI YUNUS, PhD**
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ANOVA | Analysis of variance |
| ASTM | American Society for Testing and Materials |
| CRD | Complete Randomized Design |
| DAP | Days after planting |
| ERP | Egypt rock phosphate |
| FFB | Fresh Fruit Bunches |
| HDPE | High Density Polyethylene |
| MOP | Murate of potash |
| NH4OAc | Ammonium acetate |
| RCBD | Randomized Complete Block Design |
| rpm | Rounds per minute |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background and problem statement

Agricultural development on tropical peatlands is getting more attention because of the problems associated with it such as high water table depth, low nutrients contents, acidic in nature, and subsidence that leads to low yield. Approximately half (24.8 million hectares) of the tropical peatland area of the world are found in South-East Asia which constitutes 56% of world peat soil particularly in Indonesia and Malaysia (Hoojier et al., 2010). In Malaysia, peat soil occupies an area of about 2.5 million hectares of which 1.6 million hectares, are found in Sarawak (Mutalib et al., 1991). Peat in Malaysia can be categorized as a tropical peat with unique characteristics. Thus, makes it significantly different from other peat.

In its natural state, this soil is normally dark reddish brown to black and consists of partly decomposed leaves, branches, twigs and tree trunks, and with a low mineral content (Zainorabidin and Wijeyesekera, 2007). Peat soils are considered as poor soils for agriculture due to their inherent physical and chemical problems. One of the physical problems is high water table that needs to be drained before the commencement of planting (Yew et al., 2010). In addition, the waterlogged conditions of the peat soils hinder the use of heavy-duty tillage implements (Lim and Wahyudi, 2010). Despite the constraints posed by peat soils, some farmers continue to use peat soils for agriculture (Yew et al., 2010), which has occurred over time in different parts of the world (Oleszczuk et al., 2008). It is estimated that 30, 15, and less than 5 million hectares of total peat soil in the world is used for agriculture, forestry and mining activities respectively (Strack, 2008). As a result of low nutrient content, agricultural production on peat soil is often criticized for causing more problems to agronomists and farmers for finding difficulty in cropping on it (Gurmit et al., 1987; Tayeb, 2005). Also, contrary to true that peat soils have low nutrients, but still there has been increasing number of areas of peatlands being reclaimed for agricultural activities (Strack, 2008). This leads to the increasing consideration in nutrients management as to achieve optimum crops yield grown on it (Ameera et al., 2014).

Nutrients are essential for crop production. All plants require nutrients to grow and a significant portion of these nutrients are removed out of the field when the crop is harvested. The amount of nutrients in the fertilizer that are not utilized during growth and development by crops are subjected to loss from the field through a number of pathways such as through volatilization, surface runoff or leaching to groundwater. These losses are classify as economic losses and also resulted in negative impacts on the environment and human health (Drury et al., 1996). Water table depth is one of the most important factors that determine the water movement in peatlands with response to rainfall (Holden et al., 2011). Under natural condition, the water table depth in undisturbed peatlands were found near to the peat surface for most of the year and the fluctuations were rather limited (Evans et al., 1999; Holden et al., 2011). Fluctuations of water table depths in peatlands were mostly found under shallow upper peat layer that is made up of poorly decomposed organic matter which resulted in relatively large pore structure and high hydraulic conductivity (Holden et al., 2011). During the period of rainfall, the peat soil might be flooded and thus, increase the losses of plant nutrients through drainage water, especially losses of C, N, and P (Martin et al., 1997). A strong relationship exists between the amounts of nutrient stored in the peat and the moisture content, where elements such N, S, and P have direct relation to moisture contents in peatlands (Adesiji et al., 2014). High water table depth and its associated condition in peat soil are the main issues in sustaining peatlands vegetation composition and productivity (Cao et al., 2017). However, the water table depth in a peat soil can be varies differently in the tropical region because of the changes in the rainfall pattern (Jauhiainen et al., 2005). The lowering of the water table depth increases the aeration in the surface of peat layers and increasing the aerobic decomposition of organic matter (Wright et al., 2013).

Nutrients leaching losses should be less serious under a crop than under a non-crop area but will increase when fertilizers are applied (Wong et al., 1992). Proper measurement of cations leaching from a tropical peat soil is however limited. This is because of the variability in concentrations in soil and water samples that affects the measurement (Wong et al., 1992). Therefore, better measurements are important since the leaching of nutrients ions may be useful understanding the chemical deterioration of the soil during cultivation. Research on nutrients leaching losses is gaining more attention due to the movement of these nutrients below the root-zone which causes large loss to the plant, and an economic loss to the farmer (Heng et al., 1991).

Losses of plant nutrients as a result of percolation have been studied on various soils. (Bolton et al., 1970). Good maintenance of peat soils can also serve as a source and a reservoir of nutrients, based on the types of peat and drainage patterns (Heathwaite 1991). Well-managed peat soils are considered as a source of nutrients because the indigenous peat which contains large amounts of nutrients that are capable of leaching (Heathwaite 1990). Saffigna and Philips (2006) assumed leaching as the downward motion of chemical nutrients or waste materials in soils as the result of draining water. As such, when substances are leached beyond the root zone, is therefore, difficult for uptake by plant and is being lost from the soil-plant system (Ah et al., 2009). As a result of high amount of water draining from the plant root zone, the leached substances may be deposited at a certain depth in the soil which will, in turn, contaminate the underground water (Ah et al., 2009). Leaching losses, particularly of readily soluble forms of N and K, have been extensively reported to be more in an area of crop plant in the humid tropics due to the high amount of rainfall intensity (Henson, 1999). A high water table is one of the characteristics of tropical peat soil which affects the utilization of fertilizer applied by the plant.

High water table, which affects drainage are known to decrease crop yields. However, high water table can lead to death of young palms as well as reduce the yield of older ones (Henson et al., 2008). Leaching losses of nutrients as the results of drainage are difficult to quantify under the high water table, because of the import/export of nutrients as the result of lateral flow in drainage may become problem. Maintaining an optimum water table depth is thus important for getting high yield, although studies relating oil palm yield to water table depth are sadly limited. Lim (2005) reported the highest bunch yield when the water table was around 50-75 cm below the surface and the yield decrease when the water table fluctuate between ± 25 cm from the surface.

Ammonia loss is one the largest global gas emissions into the atmosphere from the applied nitrogen (Hayashi et al., 2006). Nitrogen applied as a fertilizer can be lost in the soil-crop system due to ammonia volatilization (Ahmed et al., 2010; Omar et al., 2010). Nitrogen applied that is not taken by plants or immobilized in soils are susceptible to lose through volatilization, denitrification, leaching, and runoff eventually cause detrimental problems to the environment (Canfield et al., 2010). After the fertilizer application, ammonia volatilization is rapid and strongly affected by the following factors such as $NH_4^+$ concentration, pH, temperature and wind velocity (Hayashi et al., 2006). The method of N fertilizer application influences $NH_4^+$ concentration in floodwater (Fillery et al., 1984) and therefore plays an important role in $NH_3$ volatilization (Jayaweera and Mikkelsen, 1991).

Rapid fluctuation of water level occurs mostly during the rainy or dry season. As such, it is of paramount importance for frequent monitoring of water level in peat soil for proper growth and development of the plant. Because of the increasing use of fertilizers in oil palm plantations on peat soil especially in Malaysia, and with the problem of high water table depth associated with, there is a need to look at the effect of water table depth on nutrients leaching losses. Consequently the effect of nutrient losses due to leaching in peat soils under different water table depth found to be greater practical importance. Losses of nutrients in peat under different water table depth conditions have been shown to be great. This has been due to the physical and chemical properties of peat. It was worried that losses of nutrients may be high due to the necessity of maintaining the peat at a constant depth. The study on the effect of water table depth on nutrients leaching losses from tropical peat was limited.

## 1.2 Objectives

The main objectives of this study were to determine the effects of several water table depths on the:

1. Nutrient losses (N, P, K, Mg, Ca, Cu, and Zn), ammonia volatilization following application of urea, and tropical peat subsidence.
2. Oil palm seedlings vegetative growth using a high-density polyethylene containers.

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