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Influence of Water Table Depths, Nutrients Leaching Losses, Subsidence of Tropical Peat Soil and Oil Palm (*Elaeis guineensis* Jacq.) Seedling Growth

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ABSTRACT

Inadequate availability of nutrients and leaching losses due to water table fluctuations is a serious concern in oil palm cultivation on tropical peat land. The objectives of the study were to determine peat subsidence and leaching losses of N, P, K, Mg, Ca, Cu, and Zn from tropical peat soil under cultivation of oil palm seedlings at different water table depths. The study was conducted using cylindrical lysimeters with five water table depths namely, 25, 40, 55, 70, and 85 cm from the soil surface. The experimental layout was a Randomised Completely Block design. Leachate from each lysimeter was collected after a rainfall event to determine the leaching loss of nutrients. The highest water table depth (25 cm) from the soil surface showed the highest nutrient leaching losses, and the lowest water table depth (85 cm), showed the highest subsidence and lowest nutrients leaching losses. Plant growth was highest under the 55 cm water table depth, and the lowest under the highest and lowest water table depths of 25 and 85 cm. The 55 cm water table depth was the best for oil palm growth because the active root zone of oil palm is within the 60 cm soil depth.

Keywords: Peat soils, oil palm growth, nutrients leaching, subsidence, water table depth

INTRODUCTION

Tropical peat soils cover an area of 2.7 million hectares (Mha) in Malaysia, accounting for about 8% of the country's total land area (Abat *et al.*, 2012; Mutalib *et al.*, 1991). In Sarawak alone, the peat area occupies 1.7 Mha equivalent to 13% of the state's land area (Abat *et al.*, 2012; Tie and Kueh, 1979). Increasing demand for global oil palm products has led to an expansion in the area under oil palm cultivation. Reclamation of peat soil for agricultural purposes requires drainage

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that involves lowering of the water table and soil compaction for good aeration of the crop root zone (Luta *et al.*, 2017). Large areas of tropical peat soil have been cleared (especially in South-east Asia particularly Malaysia and Indonesia) for oil palm cultivation because of the expected economic returns from the product. Tropical peat soils have been considered as a problematic soil in their natural state because of unsuitability to crop cultivation as they are characterised by low pH (3-5) (Funakawa *et al.*, 1996), deficient in plant-available nutrient contents, especially Cu and Zn (Miyamoto *et al.*, 2009). They also have high water tables that pose problems in crop production. Moreover, water tables in peat soils within a certain range depend on weather conditions, and this has specific effects on the decomposition process (Laiho, 2006).

Peat soils have a serious problem of subsidence as they subside at a constant rate. Subsidence is termed as the permanent lowering of soil surface elevation. The height of water table, oxidation of soil organic matter, and soil shrinkage are among the factors responsible for peat subsidence. The rate of subsidence depends on the extent of control over the water table, organic matter content and cultivation practices. Tropical peat subsidence also occurs as a result of the removal of excess water that normally appears as flood waters due to the high water table, and compaction of soil from agricultural activities. Therefore, the level of water should be maintained to reduce subsidence as well as increase oil palm yield. Lowering the water table, allows peat lands to function more effectively (Macrae *et al.,* 2013), because a lower water table causes the peat surface to dry (Waddington *et al.*, 2010) resulting in reduced moisture storage (Holden *et al.*, 2004). Many studies have been conducted on peat subsidence based on different water tables and the general conclusion is that the lower the water table, the higher the peat subsidence (Shih *et al.*, 1979). Subsidence has been recorded in many countries over long periods of time such as 3.4 cm yr^{-1} s in New Zealand (Schipper and McLeod, 2002) and 6 cm year^{-1} in Sarawak at 75 – 100 cm water table depth (Tie and Kueh, 1979).

Soil fertility is altered by many processes, one of which is leaching. Nutrient leaching from agricultural land is a major environmental problem because of its effects on surface and groundwater pollution (for example, eutrophication due to N and P leaching). Plant cultivation is among the fundamentally most important sources of nutrient leaching (Nachmansohn, 2016). The rate at which the nutrients are removed from the soil solution, taken up by the plant roots or immobilised by microorganisms is influenced by water movement and leaching(Oliveira *et al.* 2002). Leaching of water soluble plant nutrients from the soil occurs mostly as a result of rainfall and irrigation water which wash the nutrients down beyond the root-zone, thus depriving them of the nutrients. Saffigna and Philips (2006) considered leaching as the downward movement (with the drainage water) of mineral nutrients or soil waste materials. As nutrients leach downward beyond the roots, they become unavailable for uptake by plant and are thereby lost from the soil-plant system (Ah *et al.*, 2009). Leaching losses especially, N and K, in their soluble forms is a problem in an area with a high amount of rainfall for crop production (Henson, 1999). Nutrient leaching losses have become a very serious issue in the plantation due to the rapid increase in the cost of fertilisers. Nutrients are important for plants growth and development, but if applied in excess, Cu and Zn especially can cause surface and groundwater pollution (Pedrosa *et al.*, 2017). The movement of Cu and Zn in the soil profile depends largely on the physical and chemical properties of the soil and the physic-chemical properties of the metal ions (Campos, 2010). The mobility of Cu and Zn in soil profile is low and leads to their accumulation on the soil surface, decreasing its leaching power (Pedrosa *et al.*, 2017). Campos (2010) also stressed that variation in pH, biological processes, and chemical toxicity of the Cu and Zn and environment also play an important role in their availability and mobility within the soil.

In view of the above facts, this study was carried out to determine the effects of different water table depths on nutrients (N, P, K, Mg, Ca, Cu, and Zn) leaching losses, subsidence and oil palm seedling growth cultivated on a tropical peat soil.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted using lysimeters at Universiti Putra Malaysia Campus Bintulu Sarawak (3° 12′ 13.58″N, 113° 4′ 16.96″E). The study area has a humid tropic weather with yearly average of low and high temperatures of 23°C and 34°C, respectively. The annual precipitation of this area is 2200 mm (Sarawak Meteorological Department2014). Tropical peat soil was sampled from Taan oil palm plantation located at 3°04′ 00.143″N, 112° 54′ 21.515″E. Based on the von post scale of H7 to H9, the peat soil was classified as well decomposed dark brown to dark coloured sapric peat soil with a thickness of 0.5 to 3.0 m.

Description of Lysimeters and Set Up

Fifteen cylindrical field lysimeters constructed from high-density polyethylene (HDPE) measuring 0.50 m in diameter and 1 m in height were set up to mimic the natural condition of drained tropical peats. The size and shape of the lysimeter was designed in such a way that it ensured satisfactory growth and development of the oil palm plants. The lysimeters were equipped with a water spillage opening that was attached to clear tubes mounted on the outside of the vessel to collect the leachate, and to regulate and monitor the water table. Each of the lysimeters was then filled with fresh peat soil to 1 m depth using a hydraulic excavator machine. The lysimeters with the peat soil were left in the field for one week to make sure the peat had settled before initiating the study.

Experimental Design

The experiment was conducted in a randomised completely block design (RCBD) consisting of five different water table depths as treatments, that is, 25, 40, 55, 70, and 85 cm from the peat surface with three replication each. The water table depth level in the experiment was controlled based on the oil palm root zone depths in accordance with the water table management system in place for oil palm grown in tropical peat soils. Water table depths were adjusted after rainfall events based on the actual water table depths measured by using a measuring tape.

Four-month old oil palm seedlings (*Elaeis guineensis* Jacq.) were planted in each lysimeter following estate procedures. N, P, K, and Mg were applied as urea (46%), rock phosphate (28%), muriate of potash (60%), and magnesium oxide (60.3%). Micronutrients were applied as Zincobor containing 3%, 6%, and 6% for Zn and Cu respectively. Fertilisation schedules and rates were in accordance with estate practices.

Soil Sample Preparation and Analysis

The soil samples collected during sampling were air-dried, ground and sieved using a 2-mm sieve before use for analysis of selected physical and chemical properties. Soil bulk density was determined using a core sampling method (Tan 2005). Soil pH was determined using the potentiometric method at a ratio of 1:10 soil to distilled water (Peech 1965). Cation exchange capacity of the soil and exchangeable cations (K, Mg, Ca, Cu and Zn) were determined using ammonium acetate (leaching method). Total N from the soil was determined using the Kjeldahl method (Bremner, 1965). The dry combustion method (loss-on-ignition method) was used to determine organic matter and total carbon from the soil sample. Inorganic N (exchangeable NH_4^+ and NO_3^-) was determined using the method of 2M KCl solution (Keeney and Nelson 1982). Single dry ashing method (Cottenie 1980) was used to determine total P, K, Mg, Ca, Cu and Zn of soil. Soil available P was determined using a double acid method (Mehlich, 1953).

Determination of Nutrients Losses

Leachate samples from the lysimeter were collected after rainfall in polyethylene bottles, which were washed once with leachate prior to final collection after every rainfall event, provided there was leaching subsequent to rainfall events. The pH of the leachate was immediately determined using the potentiometric method (Peech 1965), after which the samples were stored in the refrigerator prior to the analysis. Micro–Kjeldahl distillation method (Bremner, 1965) was used to determine total N concentration from the leachate collected. Phosphorous from the leachate was filtered using Whatman No. 2 filter paper and determined using the blue colour method of Murphy and Riley (1962). Cations (K, Mg, Ca, Cu, and Zn) were determined using atomic absorption spectrophotometer (AAnalyst 800, Perkin Elmer Instrument, Norwalk, CT). Growth of oil palm seedlings was determined by taking the dry weight of the seedling after the study. Tropical peat subsidence was determined using the Principal and Criteria for the Production of Sustainable Palm Oil (2013) method of inserting a long meter rule in each of the lysimeters and taking the reading at the end of the study period.

2.5 Statistical Analysis

Statistical analysis was employed following standard procedures for a randomised complete block design. Treatments effects were tested using analysis of variance (ANOVA) and the means of the treatments were compared using Tukey's test at $p \leq 0.05$ using a Statistical Analysis System version 9.4 SAS (2008).

RESULTS AND DISCUSSION

Physio-chemical Characteristics of the Tropical Peat Soil in the Sampling Site

The chemical characteristics of the peat soil are presented in Table 1. Soil pH was less than 4, denoting the acidic conditions of the peat. Bulk density was within the range of 0.05 to less than 0.5 g cm^{-3} in fabric and sapric peat as reported by Tie and Kueh (1979). The CEC of the peat soil could be high because of the formation of lignin-derivates during decomposition of organic materials as reported by Andriesse (1988). The peat soil had a very high organic matter content of nearly

TABLE 1

Selected chemical properties of sapric peat soil used in this study compared with those from other studies

Property	This study	Other studies
Bulk density (g cm^{-3})	0.35	0.05-0.5[d]
pH_{water}	3.3	3-4.5[a]
Organic matter (%)	93.8	99.1[c]
Total carbon (%)	54.6	12-60[a]
Total N (%)	0.8	0.3-4[b]
C/N ratio	68.25	23.4[c]
CEC ($cmol_c$ kg^{-1})	161.1	200[a]
($mgkg^{-1}$)		
Total P	232.2	100-5000 [b]
Total K	206.9	10-8000 [b]
Total Mg	205.6	100-15000[b]
Total Ca	596.8	100-60000[b]
Total Cu	8.7	3-100[b]
Total Zn	28.0	10-4000[b]
Avail. P	15.7	*n.a*
Exch. NH_4^+	202.5	58.2[c]
Avail. NO_3^-	80	198.4[c]
Exch. K	135.0	*n.a*
Exch. Mg	166.5	*n.a*
Exch. Ca	421.7	*n.a*
Exch. Cu	1.6	*n.a*
Exch. Zn	9.1	*n.a*

Notes: [a]Andriesse (1988); [b]Lucas (1982); [c]Melling *et al*., (2007); [d]Tie and Kueh (1979); *n.a* : not available.

94 %. Total carbon content of the peat was 54.6 % while the low N content of 0.8 % resulted in a high C: N ratio of 68.25. Total C and N were all within the range as reported by Andriesse (1988). Total P, K, Mg, Ca, Cu and Zn was low and within the range as reported by Lucas (1982). The very low total concentration of exchangeable cations (Ca, Mg, K, Cu, and Zn) indicate that the exchangeable sites in peat are dominated by acidic cations (H^+, Al^{3+}, and Fe^{2+}) and liming is necessary to reduce their acidic effect. A reported range for NH_4^+ and NO_3^- is not available. Soil available P, exchangeable K^+, Mg^{2+}, Ca^{2+}, Cu^{2+} and Zn^{2+} were all low which could be due to rapid uptake by plant at the site.

Nutrients Leaching Losses

The highest loss of all nutrients was from the treatment with the highest water table (25 cm) (Figure 1). The percentage decrease in leaching losses from the highest (25 cm) to lowest (85 cm) water table depth were 22 % N, 67% P, 31% K, 41% Mg, 27% Ca, 45% Cu, and 65% Zn respectively. For each water table, nutrients leaching losses decreased under low water table depth Peat soil was found to have high N content, low C/N ratio value, which increased the rate of mineralisation, but had a low content of other nutrients such as P, K, Mg, Cu, and Zn (Tayeb, 2005). As such, the fertility of tropical peat soil has to be improved through good water table depth management to reduce the loss of nutrients through leaching. For N to be available for plant uptake, organic N has to mineralised, which occurs under good aerated conditions enabling NH_4^+ to quickly oxidise into NO_3^- (Kurnain, 2005). The amount of N in the soil that is not adsorbed to the soil particles is expected to move to high depths mostly as NH_4^+ and NO_3^- which can be leached out easily. Also, the seasonal changes in rainfall patterns and distribution could also influence N leaching losses into the high water table depths (Rekha *et al.*, 2011).

Nitrogen leaching losses are mostly in the forms of NH_4^+ and NO_3^- and the latter is a negative charge ion that cannot be bound to the functional groups in peat soil, thus rendering it susceptible to leaching as reported by Ruckauf *et al.*, (2004). Owens *et al.* (2000) and Zhao *et al.*, (2001) reported that N can also leach out as surface or subsurface flow. The decrease in concentration under low water table depths could be a result of subsurface flow and sometimes due to the reduction of N through denitrification as previously reported by Spalding and Parrot (1994) and Mohammed *et al.* (2003). Most of the N in peat soil surface is quickly leached, thus affecting the quality of surface water (Droogers *et al.,* 2007).

P and K easily leach out from the peat soil due to their low adsorption capacity (Maas, 1997). The ability of peat soil to retain P is very low making it necessary for cations to bond with the functional group of peat with P. This results in P remaining on the exchange complex and preventing it from leaching. The decrease in P losses under a low water table depth could be due to the function of base cations which serve as a bridge between ions and organic groups, thus preventing P from being leached (Maftuah *et al.*, 2014). Moilanen *et al.* (2005)

also reported that the application of base cations such as Ca and Mg on peat soils can reduce the loss of P from fertilisers, because P is adsorbed by Ca and Mg in the soil. High water table depths increase the immobilisation of P which in turn increases the amount of P leached due to the increase in sorbed P. This is due to reduction and dissolution of Fe^{3+} oxides and hydrolysis of Al^{3+} phosphates within the soil profile (Obour *et al*., 2011). Higher P leaching from the high water table coincided with high amounts and intensity of rainfall encountered in this study. This result is consistent with the finding of Obour *et al*. (2011) who also found that P losses were higher in the higher soil depths (<30 cm). Terry *et al.* (1980) reported losses of P at 30 cm water table depth which was 20 times higher than P losses when the water table was at 90 cm depth. This finding is similar to that of Miyamoto *et al*. (2013) who reported high P leaching losses from peat soil under flooded compared to no flood conditions. Martin *et al*. (1997) also found P leaching from Histosols to increase with increasing high water table depths

As potassium is mobile in soils, it suffers from high amounts of leaching losses. Application of fertiliser and the extent of drainage water contribute significantly to K leaching losses (Alfaro *et al*., 2004). Potassium can easily dissolve and leach out from within the root zone because it exists in the ionic form of K^+ (Rosenani *et al*., 2016). High K solubility means K is mobile and moves freely with the draining water. Peat soil holds most strongly to positively charged nutrients except for K because of the weak attraction that exists between the peat soil and K^+. Consequently, K leaches easily from peat soil and becomes relatively low in available form for plant uptake. As reported by Miyamoto *et al.* (2009), the application of micro-nutrient fertiliser increased the leaching losses of K, Mg and Ca from a tropical peat soil which could be attributed to the replacement of exchangeable bases with the micronutrients. The finding of this study is similar to that of Damman (1978) who also found that K losses decrease under low water table depths.

The lysimeter results from this study suggest that the amount of Ca and Mg leaching losses from the soil does not depend on the initial Ca and Mg content in the soil, but on the amount of water moving through the soil. Therefore, high amounts of these elements would be leached from soils with high water table depths. Application of fertiliser increased the movement of Mg as well, but the concentration of Mg during the leaching study in the lysimeter was lower as the water table depth was low, and this could be the result of strong retention of Mg by soil particles (Vigovskis *et al*., 2015). The high volume of water and moisture content associated with a high water table led to increased dissolution of nutrients, peat and the applied fertiliser which resulted in high Mg leaching losses compared to soils with a low water table depth because the former soils would have lesser moisture content.

Application of fertiliser considerably increased the Ca content in the leachate and this could result in high Ca-release during the process of higher soil organic matter mineralisation (Vigovskis *et al*., 2015). A high water table depth resulted in a large volume of water which accelerated the dissolution of nutrients that subsequently leached out easily from the soil. Low Ca leaching losses from peat with low water table depths could also be attributed to high CEC and organic matter in the tropical peat soil (Table 1) which leads to Ca being adsorbed to the surface forming solid complexes and preventing it from moving freely in soil solution; it is therefore not leached out easily through the draining water.

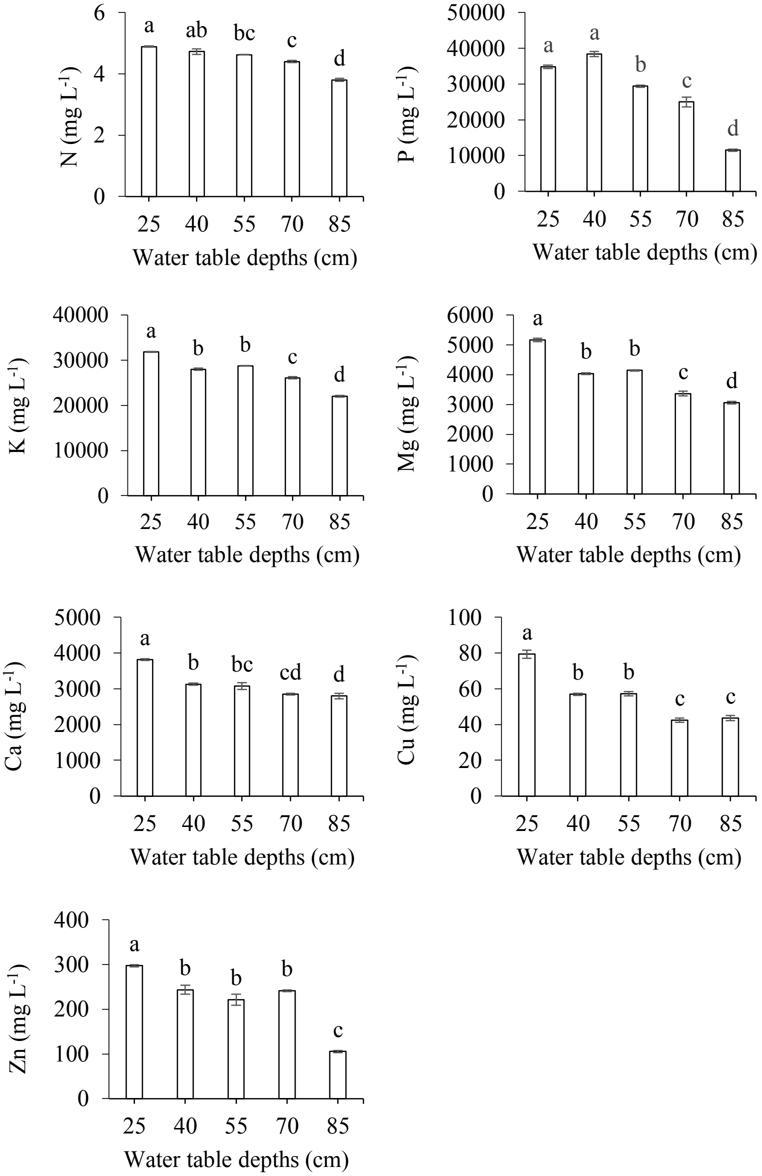

Fig. 1: Mean cumulative losses of nutrients for different water table depths at 46 days of rainfall events. Means with different letters are significantly different by Tukey's test at p ≤ 0.05).

Copper and Zn are mostly retained in the soil and their mobility increases as the soil pH decreases (Linn and Elliot, 1988). A little of these nutrients can be leached out from the soil as a result of rainfall or irrigation. Movements of organic and inorganic constituents often follow Cu and Zn movement within the soil. The movement of dissolved micro-nutrients like Cu and Zn through the soil profile as a result of water application is solely related to either the structure or texture of the soil as reported by Alvarez *et al.* (2001). Therefore, to explain the mobility and leaching of Cu and Zn, it is necessary to look at the relative stability of Cu and Zn complexes in the soil (Gonzalez *et al*., 2015).

Copper and Zn leaching losses in the soil have been reported to mainly depend on the quantity of Cu and Zn applied, the type of clay mineral, and the amount of organic matter content in the soil (Alvarez *et al*., 2001). The leaching of Cu and Zn in a cultivated soil under different water tables was observed to increase after Cu and Zn fertilisers were added to the soil. Under high water table depths, Cu and Zn can be easily reduced to soluble Cu and Zn sulphide which makes them mobile, facilitating leaching from the soil (Damman, 1978). Additionally, a large amount of organic matter in the soil increases the amount of dissolved organic C and results in higher Cu and Zn losses within the soil solution as reported by Stephan *et al.* (2008). The high organic matter content in peat soil may provide greater opportunities for Cu and Zn leaching losses. The presence of organic matter provides negative charges to the ground, and this in turn serves to maintain the adsorbment of positively charged Cu and Zn, which consequently decreases their mobility in the soil profile (Pedrosa *et al*., 2017).

Nutrients Content in the Peat Soil

Except for total N, there was a significant difference between the different water table depths for total peat nutrients content. Low water table depths showed high nutrient content compared with high water table depths (Figure 2). A higher concentration of nutrients retained in the soil was observed under the low water table depth, indicating low mobility of these elements in tropical peat soil.

Low water table depth results in a rapid expansion of microbial activity but raising of water table depth near to the peat surface, on the other hand, results in limited N utilisation by micro-organisms (Williams 1974). Decomposition of organic matter generally depends on factors such as environmental conditions, substrate quality, presence of micro-organisms and availability of nutrients (Laiho, 2006). Regardless of the different water table depths, the concentration of total nutrients with the exception of N increased under low water table depths and this could be possible because a low water table depth in the peat surface will decrease the water content, and consequently increase the oxygen content by air-filled porosity (Boggie, 1977). Conditions for the aerobic decomposition of organic matter, which is faster than anaerobic decomposition, improved due to the changes in low water table depth (Laiho, 2006). Leaching studies on the effects of water table depth on nutrients have revealed significant changes in the concentration of nutrient content of tropical peat soil. The concentration of nutrients is known to decrease after leaching but the extent of leaching depends on water table depths. The initial increase in nutrients from low water table depths is consistent with the increase in leaching of nutrients observed under high water table depth.

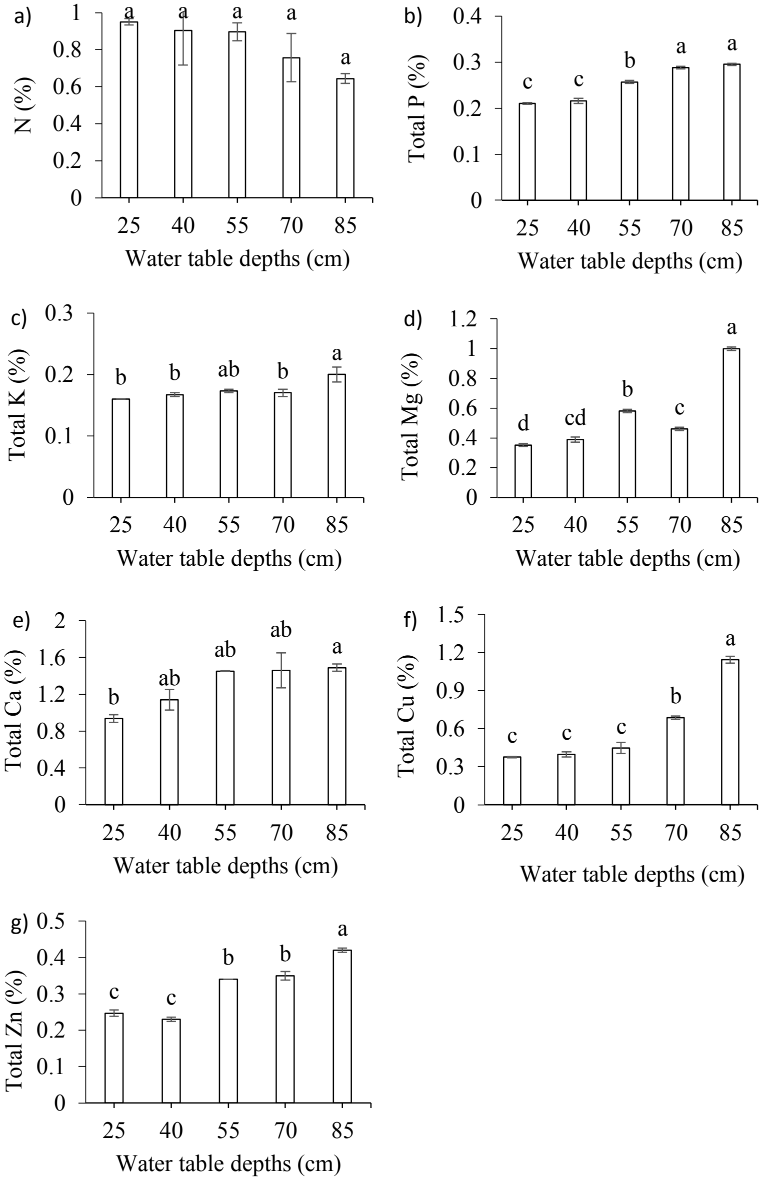

Fig. 2: Mean (± s.e) of different water table depths (25, 40, 55, 70 and 85 cm) on total (a) N, (b) P, (c) K, (d) Mg, (e) Ca, (f) Cu, and (g) Zn retained in the soil after the study period. Means with different letters are significantly different by Tukey's test at $p \leq 0.05$

Oil palm Seedling Growth

There was a significant difference between the treatments with the 55 cm water table depth showing highest plant growth compared with 25, 40, 70 and 85 cm (Figure 3). No significant difference was recorded between 40 and 85 cm water table depths. Lowest plant growth was recorded at 25 cm water table depth.

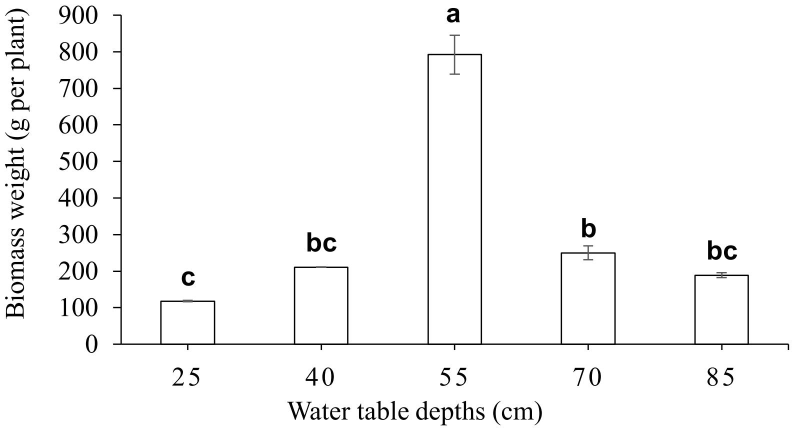

Fig. 3: Mean (± s.e) total dry plant biomass at harvesting time from the treatments of 25, 40, 55, 70 and 85 cm. Biomass means with different letters are significantly different by Tukey's at $p \leq 0.05$

Two patterns of plant growth were noticed. First, there was limited plant growth at 25 and 40 cm water table depths and this could be as the result of the roots being submerged in water, thus reducing soil aeration. The second pattern of plant growth was at 70 and 85 cm which was also limited and this could be due to drier soil that made lesser water available for nutrients uptake by the plants. The highest seedlings growth was found at 55 cm being found at adepth of 0-50 cm (Melling *et al*., 2007). Gurmit *et al*., (1987) and Tayeb (2005) recommend that the water table be controlled and maintained within a depth of 50 to 70 cm from the peat surface. A good water table management practice for oil palm cultivation on peat soil which is one that effectively maintains the water table depth of 40-60 cm (Lim *et al*. 2012). The physiology and growth of oil palm seedlings is enhanced with the application of fertilisers. Oil palm active roots should not be waterlogged, as very low or high water content within the palm rooting zone will seriously affect nutrient uptake and FFB production (Lim *et al.* 2012). Therefore, the water table should be constantly monitored to be able to control the access surface and subsurface water rapidly during the raining season and be able to preserve water for as long as possible during the dry season. The results of our study are similar to that of Sharma (2013) who also found that FFB yield was high when the water table depth was at 50-75 cm compared with 0-25, 25-50, 50-75, 75-100, and >100 cm water table depths. Other studies on *Myriga gale* L. plants reported similar highest growth response when the water table was at 29 cm compared with 3, 15, 29, 42, 52, 69, and 79 cm water table depths (Schwintzer and Lancelle 1983). Our study also confirmed the results presented by Rivard *et al.* (1990) on marsh reed grass (*Calamagrostis canadensis*) where total biomass growth was greatest at the 20 cm water table depth compared to water table depths from 10 and 40 cm. Another study with similar findings was that of Zhu *et al.* (2013) on the growth of soybeans who found highest growth at 2 m water table depth compared with 0.2, 0.4, 0.6, 0.8, 1, 3, 4, and 5 m water table depths.

Peat Subsidence

Peat subsidence increased with decreasing water table depth, as seen in Figure 4, where the highest peat subsidence is seen in the 55 to 85 cm depths while the lowest subsidence is seen in the 25 and 40 cm water table depths. The subsidence recorded in the low water table depths could be attributed to high organic matter decomposition due to the availability of oxygen which speeds up the activities of micro-organisms (Laiho and Pearson, 2016). High water table depths could also decrease the mineralisation rate of organic matter from peat soil and therefore reduce the subsidence (Tan and Ambak, 1989; Best and Jacobs, 1997; Wosten *et al.*, 1997; Potvin *et al.*, 2015). Our study results are also similar to the findings of Millette and Broughton (1984) who found high organic soil subsidence when the water table depth was low, from 0.6 to 0.9 m from the surface.

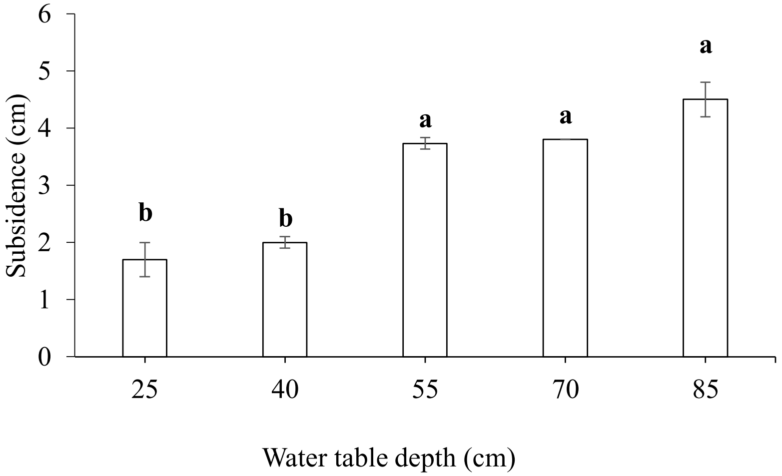

Fig. 4: Mean (± s.e) effects of treatments (25, 40, 55, 70 and 85 cm) after the study, and subsidence mean with different letters being significantly different by T ukey's test at $p \leq 0.05$

CONCLUSION

Different soil water table depths significantly affected the amount of nutrient losses in oil palm cultivation on tropical peat soil. Leaching losses of nutrients increased with higher water table depths, but the water table depth of 55 cm gave the highest oil palm growth because the active roots of oil palm were not submerged in water as in the case of high water table depths; also the roots did not have difficulty in taking up water from the water table depths. This study provides a significant understanding of the effects of water table depth on nutrient leaching losses for plants cultivated on peat environments as there are limited studies on the relationship between water table depths and nutrient losses for peat soils. Therefore, it is recommended that the water table depth in peat soil be kept within 55 cm depth for good oil palm growth and low nutrient leaching.

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