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WATER DYNAMICS AND GROUND WATER QUALITY ASSESSMENT IN AN OIL PALM ECOSYSTEM

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

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Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfilment of the Requirements for Doctor of Philosophy

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May 2016

Chairman : Prof. Zaharah A. Rahman, PhD
Faculty : Agriculture

Oil palm crops have been estimated to use a lot of water for their growth and production. Hence, oil palm can cause a decline in the soil water table. In addition, oil palm also requires the use of fertilizers to maximize its growth and crop production, and this has led to detrimental effects on the ground water quality. Leaching causes a loss of nutrients as they are washed further downward into the soil apart from causing ground water pollution, eventually. Ground water contamination can cause serious problems to ground water as it is the main water source used by most people to meet their drinking water needs. Furthermore, there is still very little information about the sources of water uptake by oil palm although the information is important for water management system at oil palm plantations.

Hence, there is a need to evaluate water use and water quality at oil palm plantations. This study was undertaken with the following objectives:

i. To evaluate the impact of climatic factors on water table of an oil palm plantation and its surrounding region;
ii. To investigate the impact of oil palm fertilization on ground water quality;
iii. To identify water sources of oil palm; and
iv. To evaluate a water table model for an oil palm plantation.

The study on the dynamics of water table level at an oil palm plantation and its surrounding region was carried out by conducting a daily monitoring on water table level at Kabun – Aliantan (N: $00^0$2.925'E: $100^0$49.977') watershed area in Tandun, Riau, Indonesia, from 2009 until 2011.

Data analyses that were carried out included the correlation analysis on the water table level at each well point location with several climate elements in the same time period, and the correlation analysis on the changes on water table levels between the oil palm area and other locations during the same period. Besides, the study was also carried out to analyze the water system at a mature oil palm area, where an observation plot was built to measure the water balance in the area. The variables used to measure changes at the observation plot were precipitation, soil surface, evaporation, and runoff. Based on these variables, water infiltration was then determined.

The results showed that the height of water table level in the oil palm plantation area is related to elements of water balance which include rainfall, interception, evapotranspiration, and surface runoff water. Data show that water table level that declined in the dry season period increased again during the rainy season, indicating that the decline in water table level was not permanent. Water table levels in the area surrounding the oil palm plantation also fluctuated based on the conditions of rainfall. The decline in water table level in the area surrounding the oil palm plantation did not correlate with the oil palm crop itself. However, the condition of the water table at any location in the oil palm plantation areas shows that there is a relationship between one location to another.

Evaluations made based on the water table dynamics model fitted rather well the results of direct measurements, with coefficient of determination (R^2) of 0.8138 or 81.38 %. The value of Root Mean Square Error (RMSE) between the model and direct measurement was 27.33 mm while the correlation coefficient between the model and direct measurement was 0.90.

There is a relationship between water table level and oil palm productivity. Water table level at lag time of 8-9 months and 33-35 months before harvest affects oil palm productivity.

Oil palm plantations need fertilizers for optimum growth and production. However, excessive use of fertilizers can lead to ground water contamination. Due to this, a study on the quality of ground water in an oil palm ecosystem had been conducted. It involved monitoring of 9-point monitor wells and measurements of runoff. The parameters analyzed in the water samples were pH, nitrate-N (NO_3-N), nitrite-N (NO_2-N), ammonium-N (NH_4-N), phosphate (P), potassium (K), calcium (Ca), and magnesium (Mg). The findings of the study showed that the concentrations of pH, Nitrate-N (NO_3^-), Nitrite-N (NO_2^-), Ammonium-N (NH_4^+), Phosphate (P), Potassium (K^+), Calcium (Ca), and Magnesium (Mg) at the oil palm plantation did not exceed the contamination level for safe drinking water set by WHO. In general, the increased concentrations of pH, Nitrate-N (NO_3^-), Nitrite-N (NO_2^-), Ammonium-N (NH_4^+), Phosphate (P), Potassium (K), Calcium (Ca), Magnesium (Mg) that occured after fertilizer application eventually decreased with time.

This study clarified that fertilizer treatments in the oil palm plantation did not reduce the quality of ground water although data showed that the value of Ammonium-N (NH_4^+) was high in the housing complex and exceeded the safe drinking water limit set by WHO.

The study also aimed to determine the current water source absorbed by the roots of oil palm by using the deuterium (δD) and oxygen isotope (δ^{18} O) method. The signatures of deuterium and oxygen isotope in total rainfall, throughfall, runoff, measurement at 5 soil depths (20 cm, 50 cm, 100 cm, 150 cm, and 200 cm), and in the stems of oil palm. The results showed that the values of deuterium and oxygen isotope varied significantly. Based on the Least Significant Difference (LSD) test, no significant difference was found in the deuterium and oxygen isotope in the stem water samples and other samples. This experiment showed that oil palm absorbs a mixture of soil water of ground water, soil water, and precipitation from several soil layers. Similar isotope signatures were also obtained from water samples taken at the depth of 0-50 cm and in the stem water. This result is in accordance with the oil palm root system, i.e. the quarternary roots (0-50 cm) is the most active root of oil palm that absorbs nutrients, water, and oxygen. This indicates that oil palm possibly absorbs water more dominantly from the depth of 0-50 cm.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENTAKSIRAN DINAMIK AIR DAN KUALITI AIR DI DALAM TANAH DALAM EKOSISTEM KELAPA SAWIT

Oleh

MUHAMMAD EDWIN SYAHPUTRA LUBIS

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Tanaman kelapa sawit memang dijangka memerlukan jumlah air yang banyak untuk pertumbuhan dan pengeluaran hasil. Jadi, tanaman kelapa sawit dapat menyebabkan penurunan air bawah permukaan tanah.

Selain itu, kelapa sawit juga memerlukan baja bagi memaksimumkan pertumbuhan dan pengeluaran hasil. Ini memberi kesan buruk terhadap kualiti air di dalam tanah. Kehilangan nutrien melalui proses larut lesap bergerak semakin dalam yang akhirnya menyebabkan pencemaran air di dalam tanah. Pencemaran air bawah tanah akan menyebabkan masalah yang serius kerana sumber air ini digunakan oleh ramai penduduk untuk keperluan air minuman mereka.

Selain itu, maklumat tentang pengambilan sumber air oleh kelapa sawit masih terhad, sedangkan, maklumat ini sangat penting dalam pengurusan sistem air di ladang kelapa sawit.

Oleh itu penilaian tentang penggunaan air dan kualiti air di ladang kelapa sawit perlu dijalankan. Objektif kajian ini adalah seperti berikut:

i. Untuk menilai kesan faktor cuaca terhadap air bawah permukaan tanah di ladang kelapa sawit dan di kawasan sekitarnya,
ii. Untuk mengkaji kesan pembajaan kelapa sawit terhadap kualiti air bawah tanah
iii. Untuk mengenal pasti sumber air untuk tanaman kelapa sawit, dan
iv. Untuk menilai satu model air bawah permukaan tanah di ladang kelapa sawit.

Kajian tentang dinamik kedalaman air bawah permukaan tanah di ladang kelapa sawit dan kawasan sekitarnya dilakukan dengan memantau kedalaman air bawah permukaan tanah di kawasan tadahan Kabun - Aliantan (N: $00^0$2.925’E: $100^0$49.977’) di Tandun, Riau, Indonesia setiap hari pada tahun 2009 - 2011.

Analisis data merangkumi: Analisis korelasi kedalaman aras air bawah permukaan tanah pada paras setiap perigi di lokasi dengan beberapa elemen cuaca pada masa yang sama, analisis korelasi terhadap perubahan kedalaman aras air bawah permukaan tanah

antara kawasan kelapa sawit dan lokasi yang lain pada masa yang sama. Selain itu, kajian juga dilakukan bagi menganalisis sistem air di kawasan ladang kelapa sawit yang matang, menggunakan plot pemerhatian yang dibina bagi mengukur keseimbangan air di kawasan tersebut. Pembolehubah yang digunakan untuk mengukur perubahan pada plot pemerhatian adalah pemendakan, permukaan tanah penyejatan dan larian air. Berdasarkan pembolehubah ini, kadar peresapan air ke dalam tanah dapat ditentukan.

Hasil kajian menunjukkan bahawa paras kedalaman air bawah permukaan tanah di ladang kelapa sawit berkait dengan unsur-unsur keseimbangan air termasuk hujan, tampanan, penyejatpeluhan, dan larian air di permukaan tanah. Aras air yang menurun pada tempoh musim kemarau akan meningkat sekali lagi semasa musim hujan. Oleh itu, penurunan kedalaman aras air tidak kekal. Aras air di kawasan ladang kelapa sawit juga berubah-ubah mengikut keadaan hujan. Penurunan paras air di kawasan kelapa sawit tidak berkait dengan tanaman kelapa sawit. Keadaan aras air di sebarang lokasi di kawasan ladang kelapa sawit mempunyai hubungan dengan lokasi ke lokasi lain.

Model dinamik aras air bawah permukaan tanah agak sesuai dengan hasil pengukuran langsung dengan pekali penentuan (R^2) iaitu 0.8138 atau 81.38%. Nilai Ralat Min Punca Kuasa Dua (RMSE) antara model dengan pengukuran langsung adalah 27.33 mm dan korelasi antara model dan pengukuran langsung adalah 0.90.

Terdapat hubungan antara tahap aras air bawah permukaan tanah dengan produktiviti kelapa sawit. Jika air bawah permukaan tanah menurun dalam tempoh 8-9 bulan dan 33-35 bulan sebelum tuaian memberi kesan terhadap produktiviti kelapa sawit.

Ladang kelapa sawit memerlukan pembajaan untuk pertumbuhan dan pengeluaran yang optimum. Tetapi, penggunaan baja yang berlebihan boleh menyebabkan pencemaran air bawah permukaan tanah. Oleh itu, kajian tentang air bawah tanah dalam ekosistem kelapa sawit dengan 9 lokasi telaga pemantauan, dan ukuran larian, telah dijalankan. Parameter yang dianalisis pada sampel air adalah pH, nitrat-N (NO_3^-N), nitrit-N (NO_2^-N), ammonium-N (NH_4^-N), fosfat (P), kalium (K), kalsium (Ca) dan magnesium (Mg). Umumnya, pH, NO_3^-N, NO_2^-N, NH_4^-N, P, K, Ca dan Mg meningkat selepas pembajaan dan menurun selepas suatu tempoh.

Kajian ini telah menunjukkan bahawa pembajaan di ladang kelapa sawit tidak mengurangkan kualiti air bawah permukaan tanah. Walau bagaimanapun, nilai Ammonium-N (NH_4^+) di dapati tinggi di di kawasan perumahan melebihi had air minuman yang ditetapkan Pertubuhan Kesihatan Sedunia (WHO).

Kajian ini dijalankan untuk menentukan sumber air semasa yang diserap oleh akar kelapa sawit menggunakan deuterium dan isotop oksigen. Kewujudan deuterium dan isotop oksigen terdapat pada jumlah hujan, curahan terus, aliran air, pengukuran pada lima kedalaman tanah yang berbeza (20 cm, 50 cm, 100 cm, 150 cm, 200 cm), dan dalam batang kelapa sawit. Keputusan menunjukkan terdapat variasi nilai deuterium dan isotop oksigen yang signifikan. Berdasarkan ujian Beza Keertian Terkecil (BKT/LSD), tiada nilai yang signifikan antara deuterium dan isotop oksigen dalam batang kelapa sawit dan sampel-sampel yang lain. Eksperimen ini menunjukkan bahawa kelapa sawit menyerap campuran air tanah air bawah tanah, air tanah dan air hujan daripada beberapa lapisan tanah. Ini telah diperolehi pada kedalaman 0-50 cm pada air batang. Keputusan ini selaras dengan sistem pengakaran kelapa sawit, iaitu pada akar kuarteneri (0-50 cm) adalah akar kelapa sawit yang paling aktif yang menyerap nutrien, air dan oksigen. Ini menunjukkan bahawa kelapa sawit mungkin menyerap air secara lebih dominan pada kedalaman 0-50 cm.

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment 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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A	upper part of the well
ANOVA	analysis of variance
AWS	automatic weather station
B	soil surface
C	point reference
$CaMg\ (CO_3)_2$	calcium magnesium carbonate
$CR_{n(t)}$	the increase in capillary water in the layer n, at time t
CR	rate of rise of capillary water
CRD	completely randomized design
D	surface water table surface
E	Evaporation
ET	evaporation and transpiration surface plant (cm)
Eta	actual evapotranspiration (mm)
H	water surface difference (mm)
Ha	Hectare
$H_2PO_4^-$	ortho phosphate
HUM	humidity (%)
h_t	water table depth at time t (cm)
I	quantity of rain water (mm)
$I_{(t)}$	calculated as a function of precipitation (P,cm), and surface flow (run-off, RO, cm)
INTSP	Interception
INTSP	interception (mm)
INTER	interception (mm)
LAI	leaf area index
LSD	least significant difference
M	effective porosity
(NH_4^+)	level of ammonium
(NO_3^-)	level of nitrate
P	rainfall measurement (mm)
Pg	rainfall gross (mm)
$Pc_{n-1(t)}$	percolation from layer n-1, at time t

$Pc_{n(t)}$	percolation in a layer to n at time t
Rain	daily rainfall (mm day^{-1})
Rad	daily solar radiation (MJ m^{-2})
RH	daily air humidity (%)
RO	total run off
RO	total run off (mm)
STF	stemflow (mm)
T_AIR	temperature (˚C)
TF	throughfall (mm)
Temp	daily air temperature (^{0}C)
USDA	United States Departement of Agriculture
V-SMOW	Vienna standard mean ocean water
WSPD	wind speed (m s^{-1})
Θa	soil moisture content on the actual condition
$\theta a_{n-1(t)}$	actual water content in the layer to n-1 at time t
θfc_{n-1}	field capacity water content in the layer to n-1
Θs	soil water content at saturated conditions
θu	the content of the air
δ^2H	analysis of the deuterium content
Δd	analysis of the deuterium content
ΔS	ground water reservation
Δh	changes in the depth of the water table
$\Delta h_{(t)}$	changes in water table level at time t
$\Delta Va_{(t)}$	changes in volumetric soil water at time t
$\Delta Va_{n(t)}$	changes in volumetric soil water in the layer to-n, at time t
Δt	time change

CHAPTER 1

INTRODUCTION

Oil palm is commonly grown in tropical areas where rain is abundant throughout the entire year. In areas where rain does not meet water demands, production can be negatively affected. The annual water requirement of a mature plantation is in the range of 1300 mm, and during its peak in hot days, the daily requirement may go up to 300-350 liters tree^{-1} (Naandanjain, 2011). Oil palm plantations have been allegedly accused of causing the decrease in soil water content, which can also lower water table (Harahap et al., 2006). Soil water table refers to the upper boundary of saturated sub-surface water or aquifer zone at atmospheric pressure, whereby the pressure in this boundary equals to the atmosphere (He et al., 2002). Any addition or loss of water from the saturated zone will cause fluctuations in water table level. Infiltration and percolation from precipitation, evaporation, and transpiration are the two main factors that determine the status of the water table. When recharge occurs, the ground water usually follows the topography and flows to rivers, streams or depressions, and lowlands. When there is no recharge, water table level can still continue to decline before stabilizing at a certain level. However, when discharge is higher than recharge, there will a lowering of water table, and reserve flow will occur. In the oil palm plantation areas, evapotranspiration is one of the controlling factors of the ground water dynamics. Since water table depth influences the growth and productivity of oil palm, it is highly essential to understand its dynamics in the plantation areas.

To boost production, high yielding varieties are being planted. These varieties usually need higher doses of fertilizers, especially nitrogen fertilizer (Corley and Tinker, 2003). An increase in fertilizer use, however, could cause leaching of nitrates into ground water, which in turn, could cause health risks such as the blue baby syndrome, caused by the contamination of nitrate in drinking water (Petronella et al., 2009). At the same time, development of residential and industrial areas is causing a reduction in water infiltration, thereby, causing water deficit in ground water. This aggravates the effects of fertilizers as it can lower the quality of ground water on top of deteriorating and declining water tables, due to erratic and limited amounts of rainfall which also causes the supply of water for agricultural purposes to be uncertain. In such a situation, proper planning of water resources according to the plant's water requirements is important.
Thus, it is important to understand soil-water-plant-atmosphere relationship in order to maximize water use efficiency and optimize long term use of water resources. Stable isotopes are being used to study plant-water relationships such as water use pattern, water use efficiency, water transport and uptake mechanism, adaptation of arid environment by plants etc., in accordance with availability of different water resources (Yang et al., 2010).

In addition to the identification of water resources, the use of stable isotopes has added advantages such as only a small quantity of sample is needed from plants, making it almost non-destructive; involves no radioactivity, and makes continuous recording of information and quantification of water extraction from different soil depths, and investigation carried out in-situ. Given the fact that different water sources contain different isotopic compositions, xylem water analysis for δD and $\delta^{18}O$ may lead to the identification of water sources (Brunel et al., 1995).

However, the vertical profile in soil water is not always intuitively steady in isotopic value due to evaporation (Walker and Richardson, 1991). In addition, the isotopic signature of water in plant stems is assumed to represent the soil over replacement time (i.e., the amount of water in plant body can increase) and causes the amount of water in plant body to increase. As a result, it was expected that the oxygen isotope ratio of water in plant body could differ from the soil water isotope ratio in the rooting zone, especially under conditions of active evaporation (e.g. high temperature, or low humidity), in which soil water can become rich with heavier isotopes over time. The investigation may be useful in establishing the best water management practices for an oil palm plantation.

Therefore, the study was undertaken with the following objectives:

i. To evaluate the impact of climatic factors on water table of an oil palm plantation and its surrounding region.

ii. To investigate the impact of oil palm fertilization on ground water quality.

iii. To identify water sources taken up by the oil palm, and

iv. To evaluate a water table model for an oil palm plantation.

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