UNIVERSITI PUTRA MALAYSIA

GROWTH, CARBON ASSIMILATION AND BIOCHEMICAL CHANGES OF OIL PALM SEEDLINGS (Elaeis guineensis Jacq.) IN CLIMATE CHANGE FACTORS WITH POTASSIUM FERTILISATION

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By

TUAN SYARIPAH NAJIHAH BINTI TUAN MOHD RAZALI

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

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DEDICATION

This thesis work is dedicated to my husband, Mohd Shahrul Nizwanshah, who has been a constant source of support and encouragement during the challenges of graduate school and life. I am truly thankful for having you in my life. This work is also dedicated to my parents, Tuan Mohd Razali and Tuan Khatijah, who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve.

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

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The demand for palm oil is expected to increase due to the increase in world population. However, climate change poses significant challenges to the production of oil palm as its output can be directly affected by abiotic stress, especially water and temperature stress. Potassium (K) is a crucial element in oil palm plantation as it is directly involved in the crop physiological processes. Thus, this research was designed to determine how the use of the evapotranspiration replacement (ER) method and potassium fertiliser could be used to alleviate water and heat stress in oil palm seedlings. In the first experiment, four irrigation regimes [100% ER (well-watered), 75% ER (moderate water stress), 50% ER (high water stress), and 25% ER (severe water stress)] were used to investigate the effect of different water stress regimes on the physiology of 4-months old oil palm seedlings. Results showed that severe water stress decreased vegetative plant growth, plant water status, leaf gas exchange, water use efficiency (WUE), and f_v/f_m (maximum efficiency of photosystem II), but the malondialdehyde (MDA) and proline levels of oil palm seedlings were increased. In the second experiment, three levels of potassium rates (K1, K2, and K3) with five times applications (170, 340, and 510 kg KCl ha^{-1}), (480, 960, and 1440 kg KCl ha^{-1}), (170, 340, and 510 kg KCl ha^{-1}), (960, 1920, and 2880 KCl kg ha^{-1}), and (960, 1920, and 2880 kg KCl ha^{-1}) under three different levels of water stress (100% ER, 75% and 25% ER) were exposed on oil palm seedlings to identify the best rate of potassium fertiliser under water stress application and to understand the interaction between drought impacts and potassium application on oil palm seedlings. The result revealed that water stress hampered the growth of oil palm seedlings. As potassium fertiliser rates increased, no significant differences in the physiology of the seedlings were observed except for height, net photosynthesis, and intercellular CO_2 (C_i). However, the biochemical properties (proline, soluble sugars, and phenolics) of oil palm seedling increased by 50%, 60%, and 55% while MDA decreased by 40% compared to control when the application of K was doubled. Yet, there were no significant differences by applying double rate and triple rate of K. There was also an interaction between different water treatment levels and the rate of potassium fertiliser on the height, C_i and flavonoid level of oil palm seedlings. In the third experiment, three types of potassium

fertiliser (KCl; Potassium chloride, K_2SO_4; Potassium sulphate and KNO_3: Potassium nitrate) with a double rate of K under three levels of water stress (100% ER, 75% ER, and 25% ER) were exposed to oil palm seedlings to investigate the influence of potassium source in minimizing water stress effects in this crop. It was found that as the level of water reduced, the RGR (relative growth rate), LAR (leaf area ratio), LWR (leaf weight ratio), and SLA (specific leaf area) of oil palm seedlings reduced, but the value of R:S (root: shoot ratio) improved. The result also revealed that K_2SO_4 increased the leaf gas exchange and f_v/f_m as well as reducing the leaf temperature compared to KCl and KNO_3. There was an interaction between water stress and the source of K on respiration rate and electrolyte leakage. K_2SO_4 also reduced the biochemical properties of oil palm seedlings. In the last experiment, the study was designed to investigate the effect of elevated temperature on the physiology of oil palm seedlings, to examine the combination of heat and water stress as well as to explore the potential of potassium fertiliser in alleviating these stresses. Oil palm seedlings were treated with six regimes: A (well-watered + control amount of KCl + 30°C), B (well-watered + control amount of KCl + 32°C), C (moderate water stress + double rate of K_2SO_4 + 30°C), D (moderate water stress + double rate of K_2SO_4 + 32°C), E (severe water stress + double rate of KNO_3 + 30°C) and F (severe water stress + double rate of KNO_3 + 32°C). The results showed heat stress decreased vegetative plant growth, plant water status, and increased leaf temperature. The effects were exacerbated by the combination of water stress. However, there was no significant effect of high temperature on the leaf gas exchange, WUE, f_v/f_m, SPAD chlorophyll value, and biochemical properties of the palms. The level of MDA, proline, soluble sugar, and lipid peroxidation only greatly increased under severe water stress. The present study suggests that only the growth of oil palms seedlings is sensitive to the 2°C rise, but not leaf gas exchange and biochemical attributes. Potassium fertiliser can play a protective role during moderate water stress under ambient temperature, thus supplying 75% water from soil field capacity, and doubling K_2SO_4 on oil palm seedlings under water scarcity is recommended. From this project, it can be concluded that the application of the evapotranspiration replacement method and potassium fertiliser were able to alleviate the abiotic stress in oil palm seedlings.

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

PERTUMBUHAN, ASIMILASI KARBON DAN PERUBAHAN BIOKIMIA ANAK KELAPA SAWIT (*Elaeis guineensis* Jacq.) DALAM FAKTOR PERUBAHAN IKLIM DENGAN PEMBAJAAN KALIUM

Oleh

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Permintaan kepada minyak sawit dijangka meningkat kerana pertambahan penduduk dunia. Namun, perubahan iklim menimbulkan cabaran yang signifikan terhadap produksi kelapa sawit kerana hasilnya dipengaruhi secara langsung oleh tekanan abiotik, terutama tegasan air dan suhu. Kalium (K) adalah elemen penting dalam ladang kelapa sawit kerana ia terlibat secara langsung dalam proses fisiologi tanaman. Oleh itu, kajian ini dijalankan untuk menentukan bagaimana penggunaan kaedah penggantian evapotranspirasi (ER) dan baja kalium dapat digunakan untuk mengurangkan kesan ketegasan air dan suhu pada anak benih kelapa sawit. Dalam eksperimen pertama, empat tahap air [100% ER (air yang cukup), 75% ER (tegasan air sederhana), 50% ER (tegasan air tinggi) dan 25% ER (tegasan air teruk)] digunakan untuk menyiasat kesan tahap ketegasan air yang berbeza terhadap fisiologi anak benih kelapa sawit berumur 4 bulan. Hasil kajian menunjukkan bahawa tegasan air yang teruk menurunkan pertumbuhan tanaman vegetatif, status air tanaman, pertukaran gas daun, kecekapan penggunaan air (WUE) dan f_v/f_m (kecekapan maksimum fotosistem II), tetapi kadar malondialdehid (MDA) dan prolin anak sawit meningkat. Dalam eksperimen kedua, tiga tahap kadar kalium (K1, K2, dan K3) dengan lima kali aplikasi (170, 340, dan 510 kg KCl ha^{-1}), (480, 960, dan 1440 kg KCl ha^{-1}), (170, 340, dan 510 kg KCl ha^{-1}), (960, 1920, dan 2880 KCl kg ha^{-1}), dan (960, 1920, dan 2880 kg KCl ha^{-1}) di bawah tiga tahap air yang berbeza (100% ER, 75% dan 25% ER) diaplikasikan kepada anak benih kelapa sawit untuk mengenal pasti kadar baja kalium terbaik di bawah tegasan air dan untuk memahami interaksi antara kesan kemarau dan penggunaan kalium pada bibit kelapa sawit. Hasil kajian menunjukkan bahawa tegasan air merosotkan pertumbuhan bibit kelapa sawit. Apabila kadar baja kalium meningkat, tidak ada perbezaan yang signifikan dalam fisiologi anak benih yang diperhatikan kecuali tinggi, fotosintesis bersih, dan CO_2 antara sel (C_i). Walau bagaimanapun, sifat biokimia (prolin, gula larut, dan fenolik) bibit kelapa sawit meningkat sebanyak 50%, 60%, dan 55% sementara MDA menurun sebanyak 40% berbanding dengan kawalan dengan kadar dua kali ganda K. Namun, tidak ada perbezaan yang signifikan pembajaan kadar dua kali ganda dan kadar tiga kali ganda K. Terdapat juga interaksi antara tahap air yang berbeza dan kadar baja kalium kepada ketinggian

pokok, C_i dan tahap flavonoid bibit kelapa sawit. Dalam eksperimen ketiga, tiga jenis baja kalium (KCl; Kalium klorida, K_2SO_4; Kalium sulfat dan KNO_3: Kalium nitrat) dengan kadar dua kali ganda K di bawah tiga tahap tegasan air (100% ER, 75% ER, dan 25% ER) didedahkan kepada anak pokok kelapa sawit untuk menyiasat pengaruh sumber kalium dalam meminimumkan kesan tegasan air pada tanaman ini. Didapati bahawa apabila kadar air berkurang, RGR, LAR, LWR, dan SLA berkurang, tetapi nilai R: S bertambah baik. Hasilnya juga menunjukkan bahawa K_2SO_4 meningkatkan pertukaran gas daun dan f_v/f_m serta mengurangkan suhu daun berbanding KCl dan KNO_3. Terdapat interaksi antara tegasan air dan sumber K pada kadar pernafasan dan kebocoran elektrolit. K_2SO_4 juga mengurangkan sifat biokimia benih kelapa sawit. Dalam eksperimen terakhir, kajian ini dirancang untuk menyelidik pengaruh peningkatan suhu pada fisiologi anak benih kelapa sawit, untuk mengkaji kombinasi tegasan suhu dan air, serta untuk mengetahui potensi baja kalium dalam mengurangkan tegasan ini. Anak benih kelapa sawit dirawat dengan enam rejim: A (air cukup + kadar KCl yang disyorkan + 30°C), B (air cukup + kadar KCl yang disyorkan + 32°C), C (tegasan air sederhana + dua kali ganda kadar K_2SO_4 + 30°C), D (tegasan air sederhana + dua kali ganda kadar K_2SO_4 + 32°C), E (tegasan air teruk + dua kali ganda kadar KNO_3 + 30°C) dan F (tegasan air teruk + dua kali ganda kadar KNO_3 + 32°C). Hasil kajian menunjukkan tegasan suhu menurunkan pertumbuhan tanaman vegetatif, status air tanaman, dan meningkatkan suhu daun. Kesannya lebih buruk dengan gabungan tegasan air. Walau bagaimanapun, tidak ada pengaruh signifikan suhu tinggi pada pertukaran gas daun, WUE, f_v/f_m, nilai klorofil SPAD, dan sifat biokimia. Tahap MDA, prolin, gula larut, dan peroksidasi lipid hanya meningkat di bawah tegasan air yang teruk. Kajian ini menunjukkan bahawa hanya pertumbuhan anak pokok kelapa sawit yang sensitif terhadap kenaikan 2°C, tetapi pertukaran gas daun dan sifat biokimia tidak terkesan. Baja kalium dapat memainkan peranan pelindung dibawah tegasan air sederhana pada suhu biasa, jadi bekalan air sebanyak 75% dari kapasiti tanah dan pemberian dua kali ganda K_2SO_4 pada anak benih kelapa sawit ketika kekurangan air adalah disyorkan. Dari projek ini, dapat disimpulkan bahawa penggunaan kaedah penggantian evapotranspirasi dan baja kalium dapat mengurangkan tekanan abiotik pada anak benih kelapa sawit.

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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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I hereby confirm that:

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%	percent
*	significant at 0.05 probability level
**	significant at 0.01 probability level
µmol m^{-2} s^{-1}	micromole per square meter per second
µmol m^{-1}	micromole carbon dioxide per mole air
°C	degree Celsius
A	net photosynthesis
ATP	adenosine triphosphate
ANOVA	analysis of variance
cm^2	centimetre square
C_3	carbon 3 species
C_i	intercellular carbon dioxide concentration
CO_2	carbon dioxide
DW	dry weight
E	transpiration rate
ER	evapotranspiration replacement
f_m	maximal fluorescence
f_o	minimal fluorescence
f_v	variable fluorescence
f_v/f_m	maximum efficiency of photosystem II
FW	fresh weight
g	gram
g_s	stomata conductance
GDP	gross domestic product

ha	hectares
IPCC	Intergovernmental Panel on Climate Change
K	potassium
kg	kilogram
KCl	potassium chloride
K_2SO_4	potassium sulphate
KNO_3	potassium nitrate
LAR	leaf area ratio
LMC	leaf moisture content
LWR	leaf weight ratio
LWP	leaf water potential
MDA	malondialdehyde
Mg	magnesium
mL	millilitre
MOP	Muriate of Potash
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
NASA	National Aeronautics and Space Administration
N	nitrogen
P	phosphorus
PSII	photosystem II
RCBD	randomized complete block design
RGR	relative growth rate
R:S	root to shoot ratio
Rubisco	Ribulose bisphosphate carboxylase/oxygenase
RWC	relative water content

SOP	Sulphate of Potash
SLA	specific leaf area
TW	turgid weight
WUE	water use efficiency

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Oil palm, *Elaeis guineensis* Jacq. is a tropical tree species of the family Arecaceae which produce the highest yield per ha among all oil crops (Corley & Tinker, 2015a; Khatun et al., 2017). This crop produces the most important vegetable oil in the world and Malaysia contributes about 28% of world palm oil production (Malaysian Palm Oil Council [MPOC], 2020a). The industry has grown to become one of the most important GDP contributors in Malaysia and it plays a significant role in the country's economic growth (Kushairi et al., 2017). Considered as a golden crop, oil palm has been used not only for cooking but also for cosmetics, personal care items and recently for biodiesel (Kurnia et al., 2016; Paterson et al., 2017). The growing global demand for palm oil triggered the industry to produce more to cope with the increasing world population.

However, the issue of climate change and global warming provides major challenges to this industry as its production can be affected by biotic and abiotic stresses (Paterson & Lima, 2018). Water stress and high temperature are among the abiotic stresses that have been facing by all agricultural industries including the oil palm industry. For the last two decades, the amount of rainfall in Malaysia experienced irregularities (Tang, 2019) and globally, drought is expected to be more intense and frequent in the future (Sheffield et al., 2012). This trend is worrying as oil palm needs at least 2000 mm of rainfall per year for optimum growth with no dry season (Oettli et al., 2018; Tiemann et al., 2018). On the other hand, Mahmood et al. (2019) stated that the world temperature is expected to keep rising at a rapid rate and has already increased by about 0.74 °C ± 0.18 °C in the past 100 years (1906–2005). In the worst case, it is expected that the world temperature will rise by around 2-3 °C in the next 30-50 years (Hatfield & Prueger, 2015) and in Malaysia, Paterson et al. (2015) stated that the mean surface temperature in this country will increase about 1.5 to 2.0 °C by 2050.

Extreme weather can affect the growth of the crop. The increase in temperature and drought raises concerns not only for oil palm production but also for all farmers who grow food crops. The event of El Niño usually causes lower rainfall with an increase in temperature which could lead to the development of water stress for palm trees (Oettli et al., 2018). Water deficit is reported to decrease the photosynthetic abilities and increase the proline level of oil palm trees (Cha-um et al., 2013). It is expected that the production of oil palm to be reduced by 30% if temperature rises 2 °C above optimum and rainfall decrease by 10% (Siwar et al., 2013; Paterson et al., 2015; Paterson & Lima, 2018). Water scarcity and high-temperature stress are believed to affect the physiological and developmental processes of the oil palm, yet it is still not known as to what extend oil palm seedlings will be impacted by these phenomena due to climate change (Ibrahim & Jaafar, 2012; Kancherla Suresh, 2013).

One of the alternative ways to enhance crop's tolerance to drought stress and improve the crop's instantaneous water use efficiency is by applying potassium fertiliser. Few studies have reported that potassium fertiliser plays an important role in plant mechanisms and numerous studies have shown that this fertiliser has the potential to alleviate adverse effects of water stress on plant growth (Kumar et al., 2016; Bahrami-Rad & Hajiboland, 2017; Tiemann et al., 2018). Potassium has a favourable influence on the water management of plants by its ability to control the stomatal opening, thus it involved with carbon dioxide uptake in photosynthesis activity (Sardans & Peñuelas, 2015; Hasanuzzaman et al., 2018).

However, the study of potassium application on oil palm seedlings under water scarcity and high temperature has never been reported. Thus, further study on oil palm physiology mechanisms is required to improve its tolerance to these abiotic stresses. Basic information on oil palm physiology is important if growers are to adapt to climate change by improving efficiency in water usage to produce more crop per drop. The information could be useful to oil palm planters for future planning management, the design of new cropping systems and a basis for agronomic practices.

Therefore, the current project consists of four experiments that were conducted with the following objectives:

I. To evaluate water stress impacts on oil palm carbon assimilation, growth, and biochemical changes.

II. To identify the activity of the oil palm seedlings exposed to a different rate of potassium fertiliser under water stress condition.

III. To compare the growth analysis, leaf gas exchange and biochemical response of *Elaeis guineensis* as affected by irrigation regimes and different sources of potassium fertilisers.

IV. To determine the effect of high temperatures under water stress condition with potassium supplementation on oil palm carbon assimilation, growth, and biochemical changes.

It was hypothesised that water application on oil palm seedlings could be reduced by using the evapotranspiration method. It was also hypothesised that the addition of potassium fertilisers could alleviate the negative impact of water stress and high temperature on the growth, physiology and biochemical of this crop.

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