**UNIVERSITI PUTRA MALAYSIA**

# *DIFFERENTIAL POTASSIUM UPTAKE AND UTILIZATION EFFICIENCY OF OIL PALM (Elaeis guineensis Jacq.) COMMERCIAL CULTIVARS*

**SIM CHOON CHEAK**

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# DIFFERENTIAL POTASSIUM UPTAKE AND UTILIZATION EFFICIENCY OF OIL PALM (*Elaeis guineensis* Jacq.) COMMERCIAL CULTIVARS

**By**

**SIM CHOON CHEAK**

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

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**October 2017**

**Chairman : Professor Zaharah Abdul Rahman, PhD**
**Faculty : Agriculture**

Conventional approaches of using higher fertilizer inputs to sustain profitable yields in oil palm plantations can be uneconomical and produce inconsistent results. In addition, the biological potential of attaining much higher oil yield is often limited by marginal environments. Nutrient efficient genotypes could potentially lead to higher productivity when grown on marginal land and eventually improve the sustainable use of resources and production of palm oil. Studies on interaction effects between planting material and nutrient inputs show differential uptake and utilization efficiency between the commercially available oil palm planting materials. The differences in leaf nutrient contents between genotypes and yield response to K fertilizer inputs demonstrated the presence of more efficient uptake characteristics. If such potassium efficient cultivars could be widely adopted, the industry would not only be capable of saving resources but also to increase productivity as well. Potassium use in palm oil production ranges from approximately 13 to 21 kg of palm oil per kg of potassium with varying degree of efficiency depending on planting varieties. The potassium use efficiency could potentially increase by 50 % in the most potassium efficient cultivar. The objectives of this study were (1.) to evaluate the growth response of selected oil palm crosses under K deficient environment and (2.) to estimate potassium use efficiency of different oil palm genotypes as part of the effort to elucidate the physiological mechanism potassium-efficient oil palms. Phenotypic responses of 5 oil palm genotypes with genetic origin from Deli and Nigerian Dura interbred with AVROS, Nigerian and Yangambi Pisiferas grown under deficient and adequate potassium supplies were evaluated. Potassium-efficient genotypes were differentiated in this experiment, where the potassium-efficient genotypes produced higher biomass (by 37.3 %) and had higher potassium uptake activity (by 41.7 %). The efficient genotypes were capable of extracting higher amount of soil potassium (by 95 %) under deficient potassium supplies. The K-efficient genotype was capable of sustain growth and to adapt to potassium-deficient environments. Alterations in rooting behaviour (increasing fine root proliferation) and maintenance of shoot growth (frond production rate) are the primary physical traits of adaptation to

potassium-deficient environment. The ability to remobilize the limiting nutrients from sink tissues to source tissues i.e. from the bole and rachis to the pinnae (the photosynthetically active tissues) and roots (to search for more nutrients allows the plant to further acquire more resources to ensure continuous growth) is also a key trait. Comparative analysis of transcriptomic differences between the efficient and in-efficient genotypes showed significant upregulation of potassium transporters (KUP3, KUP8 and KUP11) in the roots of the K-efficient genotype and genes which confer tolerance to stress, minimizes cellular damage, stress regulation and potassium homeostasis. Traits for potassium efficiency are conferred by the interaction of multiple complex mechanisms, governed by pool of genes controlling the physiological processes of stress regulation, cellular development and metabolite homeostasis. Stress detection and regulating cellular processes to mitigate the effect of stress could be the key in first tolerating and reducing damages to cellular and consequently enhancing the genotype's ability to adapt, absorb and utilize nutrients more effectively.

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

**PERBEZAAN DALAM PENGAMBILAN DAN PENGGUNAAN KALIUM OLEH KULTIVAR KOMERSIAL KELAPA SAWIT (*Elaeis guineensis* Jacq.)**

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Pendekatan konvensional menggunakan kadar pembajaan yang tinggi untuk mengekalkan penghasilan yang menguntungkan oleh industri kelapa sawit sering mencapai keputusan yang tidak konsisten dan tidak ekonomik. Di samping itu, potensi untuk mendapatkan hasil minyak sawit yang tingi sering dijejaskan oleh keadaan persekitaran yang tidak memberangsangkan. Genotip yang cekap di dalam penggunaan nutrien mampu meningkatkan potensi produktiviti dan mengurangkan penggunaan sumber. Kajian terhadap interaksi di antara genotip dan nutrien menunjukkan perbezaan dalam pengambilan dan penggunaan nutrien antara kultivar komersial. Penanaman kultivar yang cekap dalam penggunaan kalium memerlukan baja kalium yang rendah dan secara tidak langsung mampu meningkatkan hasil sawit nasional serta menjimatkan penggunaan sumber baja. Ketika ini, industri kelapa sawit menghasilkan antara 13 hingga 21 kg minyak sawit untuk setiap kilogram baja kalium diggunakan. Pengunnaan kultivar yang cekap dalam kalium mampu meningkatkan hasil sebanyak 50 %. Objektif kajian ini adalah untuk menilai pengaruh kalium dalam tanah terhadap pertumbuhan genotip sawit terpilih dan kecekapan penggunaan kalium oleh baka tanaman sawit ini. Di samping itu, mekanisi fisiologi dalam penggunaan kalium akan dikaji. Tindak balas fenotip baka tanaman yang berlainan asal-usulnya iaitu AVROS, Nigeria dan Yangambi dibawah pengaruh kalium telah dikaji. Kadar pengambilan kalium dan pertumbuhan pokok diukur di dalam rumah kaca dengan menggunakan teknik radioisotop. Tindak balas molekular telah diprofilkan dan dikira. Genotip yang ber-kecekapan tinggi berupaya menghasilkan biojisim yang lebih tinggi (> 37.3 %), mempunyai kadar pengambilan kalium yang lebih tinggi (> 41.7 %) dan berupaya mengextrak kandungan kalium yang lebih tinggi (> 95 %) daripada tanah yang mempunyai kandungan kalium yang rendah. Genotip yang sedemikian menyesuaikan diri kepada persekitaran kalium rendah dengan mengubah tingkah laku perakaran, meningkatkan percambahan akar dan mengekalkan nisbah akar dan daun. Tiada variasi atau perubahan morfologi di antara genotip. Analisis perbandingan perbezaan transkrip antara genotip cekap dan cekap memperlihatkan peningkatan besar pengangkut potasium (KUP3, KUP8 dan KUP11) dalam akar genotip dan gen yang efisien yang memberikan toleransi terhadap stres, mengurangkan kerosakan selular, peraturan tekanan dan kalium homeostasis. Ciri-ciri kecekapan kalium diberikan oleh interaksi pelbagai mekanisme kompleks, yang

dikendalikan oleh gen gen yang mengawal proses fisiologi pengawalan tekanan, pembangunan selular dan homeostasis metabolit. Pengesanan tekanan dan mengawal selia proses selular untuk mengurangkan kesan tekanan boleh menjadi kunci dalam menoleransi pertama dan mengurangkan kerosakan kepada selular dan seterusnya meningkatkan keupayaan genotip untuk menyesuaikan, menyerap dan menggunakan nutrien dengan lebih berkesan.

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Forever indebted.

Sim Choon Cheak
August 2017

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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| | |
|---|---|
| $^{86}Rb$ | Radioactive isotope of Rubidium |
| Ca | Calcium |
| CEC | Cation exchange capacity |
| CPM | Count per minute |
| CRD | Complete Randomized Design |
| DPM | Disintegrations per minute |
| ICP-OES | Inductively Coupled Plasma - Optical Emission Spectrometry |
| K | Potassium |
| KdfF | Potassium derived from fertilizer |
| KUE | Potassium use efficiency |
| KUpE | Potassium uptake efficiency |
| KUtE | Potassium utilization efficiency |
| Mg | Magnesium |
| MgUpE | Magnesium uptake efficiency |
| MgUtE | Magnesium utilization efficiency |
| N | Nitrogen |
| NE | Nutrient efficient |
| NitUpE | Nitrogen uptake efficiency |
| NitUtE | Nitrogen utilization efficiency |
| P | Phosphorus |
| PUpE | Phosphorus uptake efficiency |
| PUtE | Phosphorus utilization efficiency |
| RCBD | Randomized Complete Block Design |
| RNA | Ribonucleic acid |

# CHAPTER 1

# INTRODUCTION

Occupying merely 4.8 % of the total oil crop area planted worldwide, the oil palm contributed approximately 34.7 % of the global vegetable oil production, ranking it the highest oil producing crop known to-date. At a global production average of 3.8 tonnes of crude palm oil (CPO) per hectare, the palm oil productivity has very much stagnated over the last two decades especially in Malaysia. The stagnation could be attributed to the expansion of oil palm plantation on marginal land where the soil and terrain is least favorable for oil palm cultivation (Jalani *et al*. 2002). The efficient dissemination of selected planting material to end users, particularly to small holders is also a key factor for productivity improvement in the oil palm.

The projected biological potential of oil palm via experimental data indicates that the best progenies could be capable of yielding 11.5 tonnes of CPO per hectare. The highest plantation yield reported to-date achieved an average of about 6.5 tonnes of CPO, which is equivalent to about half of its biological yield potential. The vast gap between this biological yield potential and actual yield attained indicates an immense opportunity for yield improvement. The productivity of CPO increased from 1.3 to 6.5 tonnes per hectare through breeding advances, introduction of pollinating weevils and improved management whilst fertilization alone accounted for 29 % of the increase (Davison, 1993; Corley and Tinker, 2003). Combination of both adequate fertilization regime and improved materials that could strive under poor and marginal growing conditions could provide viable alternatives in ensuring and improving sustainable production of oil palms grown on those marginal areas.

Amongst all oil crops, oil palm consumed the highest amount of potash fertilizer i.e. about 7 % of total global potash consumption, whilst soybean and other oil crops collectively consumed 12 % (Heffer, 2013). On the contrary, consumption of nitrogenous and phosphorus fertilizer is relatively low with potash constituting almost 60 % of total fertilizer usage for oil palm cultivation. The demand of potassium inputs for growth and oil production increases in parallel to the yield and it is further elevated by losses caused by the degraded land in the tropics. On per hectare basis, the oil palm requires up to 250 kg of potassium annually (Goh *et al*. 1994) and its planting on tropical soils that are inherently low in potassium fertility and prone to potassium leaching (Amberger, 2006) further contributes to high potassium requirement.

Yield responses to potassium fertilization are mostly soil-dependent and are affected by the soils inherent potassium fertility; higher yield response is recorded on soils with low soil potassium reserve and vice versa. Such yield response variations often translate into varying degree of optimal potash fertilization rate which is generally site specific. Generally, less than 1.3 kg K palm$^{-1}$ yr$^{-1}$ on fertile coastal soils to as high as 6.0 kg K palm$^{-1}$ yr$^{-1}$ are needed for maximum yield on sandy textured soils. On most inland sedentary soils, many of the long-term fertilization trial showed an optimum range of 1.8 to 2.3 kg of potassium palm$^{-1}$ yr$^{-1}$.

Realizing such limitations, gradual effort is now being concentrated into improving the oil palm productivity via adopting nutrient efficient genotypes which could potentially lead to higher productivity on marginal land and eventually to a more sustainable use of resources and to the sustainable production of palm oil. The main objectives of this study are (1) to assess the variability of oil palm genotypes in potassium use efficiency and (2) to identify the physiological mechanism underlying the adaptation to potassium-deficient soil and the increase of potassium use efficiency.

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