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EVALUATION OF NITROGEN NUTRITION STATUS IN OIL PALM BASED ON SPECTRAL RESPONSE AND MULTI-SENSOR IMAGES

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By

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Nitrogen (N) plays crucial roles in sustainability of oil palm (*Elaeis guineensis*) production, environmentally and economically. However, assessing N status of tall perennial crops such as oil palm was complex and not straightforward in comparison to annual crops due to complex N partitioning, age, and larger amount of respiratory loads. The focus of this study was to develop N prediction model to estimate N nutrition status of oil palm. N fertilization rates varied from 0 to 2 kg N palm^{-1} according to the age classes (immature, young mature and prime mature) nutrient requirements. Growth and spectral parameters measured for this study included height, diameter, leaf area index (LAI), leaf N content, chlorophyll meter reading and spectral reflectance in visible (VIS) and near infra-red (NIR) regions measured from a ground spectroradiometer and satellite images. The growth and spectral parameters responses to N fertilization were age-dependent, where only immature palm showed significant responses to the N fertilization. In comparing the growth and spectral parameters, correlation analysis indicated that the latter was more sensitive to foliar N, especially ones that were acquired from satellite images, and therefore have potential in predicting N nutrition status of oil palm. Foliar N content was found to be less influenced by the palm maturity classes, while chlorophyll meter readings were confounded by age, and would precluded the use of that measurement for N management. Based on these results, spectral reflectance then were employed for indices such as VIS spectra, NIR spectra and combination of VIS and NIR spectra (VIS+NIR) indices to predict N status in both immature and mature palms.Each age group was sensitive to different N indices. The VIS+NIR indices acquired from the ground level sensor such G+R+NIR (R^2 = 0.91) and SPAD (R^2 = 0.64) indices were found to be significantly useful to assess N status of immature and young mature palms respectively, while NIR (R^2 = 0.26) index was the best index for predicting N for prime mature palm. At the canopy level, foliar N were best assessed using different VIS indices such as B+R and GRI for young and prime mature palms, respectively. Additionally, the discriminant analysis (DA) illustrated that the chosen bands for discriminating N sufficiency levels were age-dependent as the accuracies of classification decreased as the data pooled across all maturity classes. The best discriminant function for all maturity classes was credited to the combination of original with narrow band spectra by using the spectroradiometer with accuracies ranging from 76.20 to 98.65%. The most pronounced spectral bands for all three maturity classes were the combination of original and narrow bandwidth; located at 405, 575, 625, 795, 925 and 955 nm. Based on the preliminary study, remote sensing has the opportunity to assist in plantation agronomic management involving nutrient management. The best method in assessing foliar N in oil palm was portrayed by DA. Hence, further studies should be done to develop a` suitable index or equation for predicting foliar N based on the DA findings.

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

PENILAIAN STATUS NITROGEN DALAM POKOK KELAPA SAWIT BERDASARKAN RESPON SPEKTRUM DAN IMEJ MULTI-SENSOR

Oleh

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Nitrogen (N) memainkan peranan penting dalam kemampanan (*Elaeis guineensis*) pengeluaran kelapa sawit, alam sekitar dan ekonomi. Walau bagaimanapun, menilai status N bagi tanaman saka yang tinggi seperti kelapa sawit adalah kompleks dan tidak mudah berbanding dengan tanaman tahunan kerana pembahagian N yang kompleks, umur, dan jumlah beban pernafasan yang lebih besar. Fokus kajian ini adalah untuk membangunkan model ramalan N untuk menganggarkan status N kelapa sawit. Kadar pembajaan N berbeza dari 0 ke 2 kg N per sawit mengikut keperluan nutrien setiap kelas umur (tidak matang, matang muda dan matang perdana). Pertumbuhan dan parameter spektrum yang diukur dalam kajian ini termasuk ketinggian, diameter, indeks area daun (LAI), kandungan N daun, bacaan klorofil meter dan pantulan spektrum kawasan yang boleh dilihat (VIS) dan infra-merah (NIR) yang diukur menggunakan spektroradiometer dan imej satelit. Tindak balas pertumbuhan dan parameter spektrum terhadap pembajaan N adalah bergantung kepada umur, dimana hanya pokok sawit tidak matang menunjukkan respon yang signifikan terhadap pembajaan N. Dalam perbandingan antara pertumbuhan dan parameter spektrum, analisis korelasi menunjukkan bahawa yang kemudian adalah lebih sensitif kepada N daun, terutamanya yang diperolehi daripada imej satelit, dan mempunyai potensi dalam meramalkan status N kelapa sawit. Kandungan daun N kurang dipengaruhi oleh kelas kematangan sawit, manakala bacaan meter klorofil dikelirukan oleh umur, dan akan menyukarkan langkah untuk pengurusan N. Berdasarkan keputusan ini, spektrum digunakan dalam indeks seperti spektrum VIS, rantau spektrum NIR dan kombinasi spektrum VIS dan NIR (VIS + NIR) bagi meramal hubungan daun N dengan kumpulan umur sawit. Setiap kumpulan umur sensitif pada indeks ramalan N yang berbeza. Indeks VIS+NIR yang diperolehi daripada sensor paras tanah seperti G+R+NIR indeks (R^2 = 0.91) dan SPAD indeks (R^2 = 0.64) adalah yang terbaik dalam meramal N bagi pokok sawit tidak matang dan pokok matang muda mengikut aturan, manakala indeks NIR (R^2 = 0.26) berguna untuk mengakses status N dalam pokok sawit matang perdana. Pada peringkat kanopi, daun N boleh dinilai menggunakan indeks VIS seperti B+R bagi pokok sawit matang muda dan GRI untuk pokok sawit matang perdana. Persembahan analisis diskriminan (AD) menggambarkan bahawa band yang dipilih bergantung kepada kelas umur dimana ketepatan klasifikasi menurun apabila data dikumpulkan dari semua kelas kematangan. Fungsi diskriminan terbaik untuk semua

kelas kematangan dikreditkan kepada gabungan original dengan band spektrum sempit dengan menggunakan sensor di paras tanah dengan ketepatan dari 76.20 sehingga 98.65%. Band spektrum yang kerap muncul bagi kombinasi original dan spektrum band sempit bagi ketiga-tiga kelas kematangan adalah band spektrum di kedudukan 405, 575, 625, 795, 925 dan 955 nm. Berdasarkan kajian awal, penderiaan jarak jauh memberikan peluang untuk membantu pengurusan agronomi perladangan yang melibatkan pengurusan nutrient. Kaedah yang terbaik dalam mengakses daun N kelapa sawit ditunjukakan oleh AD. Oleh itu, kajian lain harus dilakukan bagi membangunkan indeks atau persamaan yang sesuai menganggarkan daun N berdasarkan penemuan AD.

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APPROVAL

I certify that a Thesis Examination Committee has met on 21 June 2016 to conduct the final examination of Amiratul Diyana Binti Amirruddin on her thesis entitled "Evaluation of Nitrogen Nutrition Status in Oil Palm Based on Spectral Response and Multi-Sensor Images" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

LAI	Leaf Area Index
FFB	Fresh Fruit Bunch
VIS	Visible
NIR	Near Infrared
R^2	Coefficient of Determination
VI	Vegetation Index
DA	Discriminant Analysis
CVA	Cross Validation Accuracy
TA	Training Analysis
CV	Cross Validation
D	Deficient
O	Optimum

CHAPTER 1

INTRODUCTION

1.1 Background

Palm oil contributed about 52.1 million tons of world oil consumption in 2013. Growing number of population worldwide has increased the demand for edible oil which resulted in greater oil palm cultivation. Malaysia ranks as the second largest palm oil producer after Indonesia, with close to 5.23 million hectares of land in Malaysia cultivated to oil palm. In oil palm plantation industry, good agronomic practices especially nutrient management is important in order to maximize production. The crop's nutrients are constantly removed through the harvested fresh fruit bunch (FFB) or sequestered in the standing biomass; thus, the consumed nutrients must be profusely replaced (Wahid *et al.*, 2005a).

Oil palm consumes a large amount of nitrogen (N), phosphorus (P) and potassium (K) to support their growth and produce high yield. Nitrogen (N) is one of the crucial elements to sustain oil palm production. Nitrogen is ranked second after K in importance, and most of the uptake by the plant is in form of the soluble nitrate ion (NO3-). N plays an important role in plant growth where N application influence palm height (Uwumarongie-Ilori *et al.,* 2012), chloroplast development and functions, leaf area index (LAI), susceptibility to pest and disease attack and consequently affect oil and fresh fruit bunch (FFB) quality (Goh and Härdter, 2003).

Deficient N palm shows chlorosis symptom on older fronds and stunted palm stand (Goh and Härdter, 2003). On the other hand, excessive N applications can increase the susceptibility to disease and insect pest such as leaf-eating caterpillars and bagworms as well as induce B deficiency (Goh and Härdter, 2003). Over-application of N may also cause groundwater pollution due to leaching and surface runoff. Leached N will go to the waterway and result in eutrophication which eventually contributes to death of aquatic organism. Furthermore, by-products of N from denitrification such as nitric oxide (NO) or nitrous oxide (N_2O) were detrimental to the humans and environment. According to Wright (2003), N_2O is capable to absorb infrared radiation hundred times higher than carbon dioxide (CO_2) and involved in depletion of ozone layer. Meanwhile, a high concentration of inhaled NO is harmful to health which causes coma and death (Paul *et al.*, 2008).

1.2 Justification

In oil palm production, fertilizer consumes the largest portion the cost of production (Goh *et al.*, 2003). The prices of the fertilizers are unstable and would fluctuate from time to time. The urea price skyrocketed from USD 84.29 in 1993 to USD 316.21 per metric ton in 2014 (The World Bank, 2015). The excessive application of fertilizers is not only harmful to environment but also represents economic loss. Based on calculation made by Goh (2005), it is estimated that the oil palm industry will benefit

USD 56 million per year if excessive ammonium nitrate application as much as 0.25 kg $palm^{-1}$ $year^{-1}$ can be avoided. Thus, it is vital to estimate the optimum requirement of N for plant uptake in order to sustain the environment and the industry itself.

Conventionally, foliar analysis is practiced to observe nutrient levels in palms. However, this practice is time consuming, labor intensive and expensive. Studies of N using remote sensing approach can be more efficient and cost effective. This method can reduce the cost for analyzing N contents by minimizing the chemical and labor cost as well as the chemical wastage. Many studies on N estimation for other crops using remote sensing have been established since 1960 but there is still a research gap in studying the N nutrition status in oil palm using remote sensing. Therefore, this study focuses on using remote sensing application to evaluate and detect N nutrition status in oil palm. This study will provide better insight for better N management for efficient plantation management activities.

1.3 General Objective

The overall objective of this study is to develop N prediction model to estimate N nutrition status of oil palm.

1.3.1 Specific Objectives

The specific objectives of this study are:

i) To investigate oil palm growth and spectral parameters in response to the N fertilization. This involves examining the relationships between oil palm growth and spectral parameters with foliar N content.

ii) To examine and develop several N prediction models such vegetation index model (VI), red, blue, green (VIS) and near infrared (NIR) model and discriminant analysis model to estimate N concentration of oil palm using spectral reflectance techniques.

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Appendix A: Pearson correlation between plant n indicators (foliar N content and SPAD readings) with height, LAI and diameter according to oil palm age.

Age Group	Foliar N Content (%)			SPAD Readings (SPAD Unit)		
	Height (m)	**LAI**	**Diameter (m)**	**Height (m)**	**LAI**	**Diameter (m)**
Immature						
Young Mature						
Prime Mature			0.555*			

*, **, ***, **** Denote significant levels (P-value) at 0.05, 0.01, 0.001, and 0.0001, respectively.