



UNIVERSITI PUTRA MALAYSIA

***MULTISPECTRAL REMOTE SENSING FOR NITROGEN FERTILIZER
MANAGEMENT IN OIL PALM***

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MANAGEMENT IN OIL PALM**

By

MOHAMMAD YADEGARI KHOUSANI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfilment of the Requirement for the Degree of Master of Science**

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

MULTISPECTRAL REMOTE SENSING FOR NITROGEN FERTILIZER MANAGEMENT IN OIL PALM

By

MOHAMMAD YADEGARI KHOUZANI

December 2017

Chair: Professor Sr Gs Abdul Rashid Bin Mohamed Shariff, CEng, PhD
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Environmental concerns are growing about excessive applying nitrogen (N) fertilizers specially in oil palm. Some conventional methods which are used to assess the amount of nutrient in oil palm are time consuming, expensive, and involve frond destruction. Remote sensing as a non-destructive, affordable and efficient method are widely used to detect the concentration of chlorophyll (Chl) from canopy plants using several Vegetation Indices (VIs) because there is a strong relative between the concentration of N in the leaves and canopy Chl content. The objectives of this research were (i) to evaluate and compare the performance of various Vegetation Indices (VIs) for measuring N status in oil palm canopy using SPOT7 imagery (ii) to develop a regression formula that can predict the N content using satellite data (iii) to assess the regression formula performance on testing datasets by testing the correlation between the predicted and measured N contents. Spot 7 was acquired in a 6 ha oil palm planted area in Pahang, Malaysia. To predict N content 28 VIs based on spectral range of SPOT 7 satellite image were evaluated. Several regression models were applied to determine the highest correlation between VIs and actual N content from leaf sampling. MSAVI generated the highest correlation ($R^2= 0.93$). MTVI1 and Triangular VI had the highest second and third correlations with N content ($R^2= 0.926$ and 0.923 respectively).

The accuracy assessment of developed model was evaluated using several statistical parameters such as Independent T-test, and p-value. The accuracy assessment of developed model was more than 77%.

Keywords: Multispectral Remote Sensing, Nitrogen, SPOT 7, Vegetation Indices, MSAVI.

Abstrak tesis yang dikemukakan kepada Senate Universiti Putra Malaysia sebagai keperluan untuk ijazah Master Sains

PENDERIAAN JAUH PELBAGAI SPEKTRAL UNTUK PENGURUSAN PEMBAJAJAN BAGI POKOK KELAPA SAWIT

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Isu alam sekitar yang kian meningkat adalah mengenai penggunaan baja nitrogen (N) secara berlebihan terutama di dalam kelapa sawit. Terdapat beberapa kaedah konvensional yang digunakan untuk menilai jumlah nutrien dalam kelapa sawit, namun kaedah tersebut mengambil masa yang lama, mahal, serta melibatkan kemusnahan pada daun. Penderiaan jauh merupakan kaedah yang tidak merosakkan, mampu milik serta kaedah yang berkesan digunakan secara meluas untuk mengesan kepekatan klorofil (Chl) dari tumbuh-tumbuhan kanopi menggunakan beberapa indeks tumbuhan (VIs) kerana mempunyai hubungan relatif yang kukuh diantara antara kepekatan N di dalam daun dan kandungan Chl kanopi. Objektif kajian ini adalah (i) untuk menilai dan membandingkan prestasi pelbagai Indeks tumbuh-tumbuhan (VIs) bagi mengukur status N kanopi kelapa sawit menggunakan imej SPOT7 (ii) untuk membangunkan formula regresi yang boleh meramal kandungan N menggunakan data satelit (iii) untuk menilai prestasi formula regresi pada ujian datasets dengan menguji hubung kait antara kandungan N ramalan dan diukur. Spot 7 diperolehi bagi 6 ha kawasan penanaman kelapa sawit di Pahang, Malaysia. Untuk meramalkan kandungan N, 28 VI berdasarkan spektrum imej SPOT 7 telah dinilai. Beberapa model regresi digunakan untuk menentukan korelasi tertinggi antara VI dan kandungan sebenar N dari pensampelan daun. MSAVI menghasilkan korelasi tertinggi ($R^2 = 0.93$). MTVI1 dan Triangular VI mempunyai korelasi kedua dan ketiga tertinggi dengan kandungan N ($R^2 = 0.926$ dan 0.923 masing-masing). Penilaian ketepatan model yang dibangunkan dinilai menggunakan beberapa parameter statistik seperti Independent T-test, dan p-value. Penilaian ketepatan model yang dibangunkan adalah lebih daripada 77%.

Kata kunci: penginderaan jauh multispektrum, Nitrogen, SPOT 7, Indeks tumbuhan, MSAVI.

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I certify that a Thesis Examination Committee has met on 26 December 2017 to conduct the final examination of Mohamad Yadegari Khozani on his thesis entitled "Multispectral Remote Sensing for Nitrogen Fertilizer Management in Oil Palm" 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

4RNSF	4R Nutrient Stewardship framework
B	Boron
C	Carbon
Cl	Chlorine
Co	Cobalt
Cu	Copper
CPO	Crude Palm Oil
DV	Dependent Variable
EME	Electromagnetic Energy
FLAASH	Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube
FFB	Fresh Fruit Branches
GIS	Geographic Information System
GPS	Global Position Systems
GHG	Green-House Gasses
H	Hydrogen
IV	Independent Variable
Fe	Iron
LSU	Leaf Sampling Unit
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
NIR	Near Infrared
Ni	Nickel
N	Nitrogen
NUE	Nutrient Use Efficiency
O	Oxygen
P	Phosphorus
K	Potassium
PA	Precision Agriculture
RFID	Radio- Frequency Identification
RCBD	Randomized Complete Block Design
RS	Remote Sensing
SSM	Site Specific Management
SPAD	Soil Plant Analysis Development
SAM	Spectral Angle Mapper
SRS	Stratified Random Sampling
S	Sulfur
SAR	Synthetic Aperture Radar
VI _s	Vegetation Indices



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CHAPTER 1

INTRODUCTION

1.1 General Background

Oil palm (*Elaeis guineensis*) is a species of palm that provides one of the leading vegetable oils produced globally accounting for one quarter of global consumption and approximately 60% of international trade in vegetable oils (The World Bank Group Framework and IFC Strategy for Engagement in the Palm Oil Sector, 2011). Malaysia and Indonesia are the main key players in the palm oil sector, and these two countries together account about 90% of the palm oil world export. The oil palm industry is considered a very profitable one in Malaysia; hence, the plantation of oil palm has increased significantly over the years (Sheil et al. 2009). Over the last decade, specifically from 2005 to 2015, the oil palm planted area has increased by 42% in the country. Currently Malaysia has the second largest area under oil palm cultivation after Indonesia. The export trends of oil palm by-products also increased by 9% from 2008 to 2016 in Malaysia (MPOB 2016)

However, the sector is likely to have its profitability reduced due to the declination of world prices, high-cost conventional farming practices, and loss of production due to nutrition deficiencies, pests and disease. Malaysia oil palm industry specifically suffers from the high costs of labor and low yields due to poor fertilizer management to an extent that the country's place is being threatened by Indonesia in the profitable oil palm market (Oil 2009). Appropriate pest and fertilizer management can increase the production of oil palm by managing the pest and disease as well as solving the nutrition problems of plants. In addition, an efficient management solution can reduce the labor efforts and costs; hence, increasing the profitability of the plantations.

One of the most important deficiencies that influences the production of any crop, and in particular oil palm, is Nitrogen. In plant growth, physiology and carbohydrate content terms, Nitrogen (N) is the most important nutrient element (Almodares et al. 2008; Mohidin et al. 2015). It is the main raw material needed for nucleotide and protein construction, cell multiplication, rise in chlorophyll contents, enlargement in size and length of leaves and stems, and finally the growth of plants (Arefaine 2013; Xu, Fan, and Miller 2012). Nitrogen deficiency is observed for most crops all over the world due to the high mobility nature of Nitrogen under normal condition (Torres-Olivar et al. 2014). While a feasible fertilizer management system implemented in oil palm plantations must address Nitrogen deficiency adequately to ensure optimum production, it should also prevent surplus fertilizer and fertilizer losses to surface and ground waters (Sabri 2009).

The most usual practices that help farm managers to approximate fertilizer requirements in oil palms are foliar sampling and chemical analysis. These types of analysis determine the average of leaf nutrient status in the field. This conventional fertilizer management

system is extremely expensive due to the high cost of labour and the high costs associated with laboratory procedures. As a result, the leaf sampling and analysis are only performed for a small number of oil palms in a plantation. Therefore, the results of these analyses do not represent the exact nutrient content and possible deficiencies or surplus of each individual oil palm in a plantation, and are deemed inconclusive for a precise managerial fertilizer plan.

The right management practices at the right places and right times are the aims of Precision Agriculture (PA). PA provides adequate solutions to manage the farm inputs like fertilizers, herbicides, seeds etc., better. By using precision agriculture, the fields can be divided into the zones and receive the inputs based on varying soil types, landscape position and the history of the field management (Mulla 2013; Wang 2016). Remote Sensing (RS) has been recommended by researchers as a precision agriculture technique to detect plant nitrogen status since it provides a precise, affordable and efficient solution for fertilizer management compared to traditional methods (Saberioon et al. 2014). Khorramnia, (2013) examined four optical sensor systems in an effort to estimate tree-specific oil palm leaflet nutrient deficiency and to aid in determining the required fertilizer dosage rates. However, the suggested model couldn't predict accurately the percentage of nutrient in oil palm leaf.

Alternatively, remotely sensed images such as satellite imageries with high spatial resolution can be used as base maps in variable rate applications of fertilizers to identify nutrient deficiencies or surplus (Link and Reusch 2006; Olf et al. 2005; Wright et al. 2003a).

Information from these images helps to identify problems within a field remotely before they can be visually identified. This information allows an accurate prediction of Nitrogen fertilizer needs at each point in the field at lower cost. As a result, the crop yield can be increased. This approach would also reduce surplus fertilizer in the crop production system without reducing crop yield, which would in return reduce N losses to surface and ground waters. Further, a remotely sensed fertilizer management system based on satellite imageries can reduce the labor costs associated with leaf sampling, and laboratories related costs (Seelan et al. 2003).

Overall, Malaysia can benefit from the advantages that remote sensing techniques offer to narrow down the gap in the yield, sale and profit margins between its production amount and the top country in the oil palm sector, Indonesia.

1.2 Problem Statement

In an oil palm plantation, the common practice to achieve the best yield quantitatively is to add N via fertilizers. In Malaysia, 46% to 85% of field costs goes into the purchase of the fertilizers alone (Goh and Buloh 2005; Pardon et al. 2016a; Silalertruksa, Bonnet, and Gheewala 2012). Goh, Ng, & Lee (2009) emphasised that obtaining optimum

fertilizer rates is the first and the most important factor in the fertilizer management system.

Besides, the excessive fertilizer use can cause a number of environmental and ecological problems, such as air pollution, soil acidification and degradation, water eutrophication, crop yield reduction, and finally decreasing the sustainability of the agricultural practices (Savci 2012). Specifically, there is a serious concern about the excess use of N fertilizers in oil palm plantations because of N losses and N leaching. For instance, the amount of N fertilizers commonly applied to produce 1 ton of Fresh Fruit Branches (FFB) generates around 50% of the Green-House Gasses (GHG) (Pardon et al. 2016b; Tilman et al. 2002).

According to the several surveys, leaf sampling and analysis is the most common method to assess the nutrient status in oil palm leaf (Chapman and Gray 1949; Fairhurst and Härdter 2003). It is recommended to conduct leaf sampling twice a year for analysis and diagnosis of oil palm leaf. However, the leaf sampling and the consecutive laboratory analysis are costly, hence it is a common practice to perform only one sampling each year in a 1% of total plantation area (Fairhurst and Härdter 2003; Turner and Gillbanks 2003).

Stratified Random Sampling (SRS) is the current methodology for leaf sampling. In this method, the population size is divided into smaller groups called strata. The strata are homogeneous within and heterogeneous among themselves (Sahu 2013). According to Fairhurst & Härdter (2003), Malaysia has 18 stratum which is called Leaf Sampling Unit (LSU) (the estimation of maximum LSU areas in Malaysia are about 234,000 ha). Each LSU constitutes several similar fields in terms of soil type, terrain, the age of oil palm tree etc.

In 2013, the total costs for annual leaf sampling and analysis in Malaysia was estimated around RM10,800,000 with 5.2 million ha area under oil palm cultivation (Khorrarnia 2013). In other words, the leaf sampling and analysis costs around RM100 for a single oil palm tree. It is worthwhile to note that the area under oil palm cultivation has increased to 5.8 million ha in 2016; hence, the total cost of oil palm production accounting for labor costs, leaf sampling and analysis has also risen (MPOB 2016). In an effort to reduce the cost of leaf sampling, plantations often conduct their own experiment (Liri 2015); However, the procedure itself and the consecutive analysis costs still burden the plantations financially.

The expensive and time-consuming nature of conventional leaf sampling and analysis have forced many farm managers to decrease the LSU as much as possible. Consequently, they do not possess comprehensive information about the specific needs of the farm from point-to-point basis. The poor knowledge about the actual condition of the tress can effect on their management decisions about the precise amount of fertilizer, the application time, and the type of fertilizers required. The unbalance fertilizer can cause deficiency or surplus in the plant, and it can affect the yield and surrounding environment respectively.

The new emerging technologies with high productivity and reliability have found their ways into replacing conventional techniques and technologies. Table 1.1 represents some methods like spectroradiometer, SPAD, GreenSeeker, etc. that had been used by some researchers. However, these methods had some disadvantages either in method, or their results.

Table 1.1. Previous Methods for Detecting Nitrogen Stress in Oil Palm

Method	Results	Disadvantages	Reference
Spectroradiometer	The nutrient content of the foliage can be obtained through foliar analysis of oil palm leaf from frond No 17.	The instrument need calibration, expensive, complex system and sunlight dependence. The battery life is low	(Mazlan Hashim et al. 2001)
Spectroradiometer at micro level	The best correlation for nitrogen prediction was 0.616	Time Consuming, Useless for a large area, Need calibration	(Ibrahim et al. 2003)
GreenSeeker 505, SPAD 502 Plus, Multiplex 3, and FieldSpec 3	R	Is useless in a large area Time consuming	(K. Khorramnia et al. 2014)
	RMSE		
	0.3	0.96	

Satellite imagery, as one of the remote sensing tools, can be used effectively to identify nutrient status in oil palm trees. While some researchers have utilized ground-based remote sensing techniques to predict the nutrients amount in oil palm (Rendana et al. 2015) the accuracy of the predictions are rather poor.

Thus, it is of great interest to investigate the application of satellite imageries in predicting the nitrogen content, and establishing a relationship between the data obtained from satellite imageries and the canopy nitrogen.

1.3 Objectives of the Research

This study aims to investigate the feasibility of satellite imageries in predicting the nitrogen content in oil palms. The specific objectives of this thesis are:

1. To evaluate and compare the performance of various Vegetation Indices (VIs) for measuring N status in oil palm canopy using SPOT7 imageries.
2. To develop a regression formula to predict the N content using satellite data.

3. To assess the regression formula performance on testing datasets by testing the correlation between the predicted and measured N contents.

1.4 Scope of Study

The primary focus of this research is to predict the amount of N from the SPOT7 satellite image using different VIs. The predicted N values are compared to the actual data from laboratory analysis to find the best VIs as predictor.

The data for this study was obtained from a 6 ha oil palm (*Elaeis guineensis Jacq*) farm located at Pahang, Malaysia which belongs to FELDA Agricultural Services SDN. BHD. The farm is divided to 18 plots with 3 treatments (A= Good Agronomic Practice, B= Standard Practice, and C= Sub-Standard), and 6 replications. However, the amount and the type of fertilizers used for all replications are similar. Each plot has around 48 palm with the same age of 7-years old, and 24 of them were selected randomly as experimental samples. The leaf sampling was carried out on March 22nd, 2016 and 24 leaves were taken from each plot from frond 17. The leaves, combined together, were sent to the laboratory for total nutrient content analysis of leaf tissues by the Kjeldahl method.

The coordinates for each sample plant were collected using GPSMAP 76csx with a 1m accuracy. The closest in date image available from SPOT7 with minimum cloud coverage over the study area was captured on March 29th, 2016. A few image pre-processing procedures such as geometric and radiometric correction was carried out using Envi 5.3. Further, the FLAASH atmospheric correction was applied to the image. Finally, 28 different VIs were compared with each other. Using ArcMap 10.3, the value for each point were extracted, and the IBM SPSS v24 statistical software was used to develop different regression formulas to determine the best correlation with the lowest Root Means Square Error (RMSE).

To calibrate and validate the results, we divided the datasets into two groups with each group including 9 plots. The data from the first group was used to establish the regression formula, and the formula was later tested for prediction of N amount in the second group. The predicted N values were then compared to the actual amount obtained from the laboratory.

1.5 Thesis Organization

This thesis consists of five chapters. The outlines are as follows:

Chapter 1 provides a general overview about the oil palm production challenges and possible solutions offered by precision agriculture. The problem statement, research objectives and the scope of the study are also included in this chapter.

Chapter 2 reviews the literature on the oil palm and different methodologies of determining nutrient requirements. It covers different studies conducted on different spectral VIs and different plants. It also examines the previous studies that uses precision agriculture techniques for oil palm fertilizer management.

Chapter 3 provides a detail description about the study area, leaf sampling method, and the characteristics of the satellite images. The different image-processing methods used are explained in this chapter. The statistical approaches used for this study are also elaborated in this chapter.

Chapter 4 is devoted to the research result and analysis. The best vegetation index with the highest correlation is used to develop a regression formula. The developed regression formula is represented for predicting the amount of nitrogen. Chapter 5 concludes this study, and provides suggestions for future researchers.

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