UNIVERSITI PUTRA MALAYSIA

MULTISPECTRAL REMOTE SENSING FOR NITROGEN FERTILIZER MANAGEMENT IN OIL PALM

MOHAMMAD YADEGARI KHOUZANI

MULTISPECTRAL REMOTE SENSING FOR NITROGEN FERTILIZER MANAGEMENT IN OIL PALM

By

MOHAMMAD YADEGARI KHOUZANI

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

December 2017

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
Faculty: Engineering

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 PEMBAJAAN BAGI POKOK KELAPA SAWIT

Oleh

MOHAMMAD YADEGARI KHOUZANI

Disember 2017

Pengerusi: Professor Sr Gs Abdul Rashid Bin Mohamed Shariff, CEng, PhD
Fakulti: Kejuruteraan

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.

ACKNOWLEDGEMENTS

I would like to thank my supervisor Professor Dr. Abdul Rashid Bin Mohamed Shariff for his unwavering support and encouragement over the years. His patience and immense knowledge have always helped me through difficult times. He is an exemplary supervisor and a great human being to be followed. I indeed consider myself very fortunate to have had the chance to be his student. For his constant support in every possible circumstance, I owe him my deepest gratitude.

I am also deeply and forever indebted to my parents for their love, support and encouragement throughout my entire life.

Words cannot describe my gratitude and appreciation towards my wife, Samira, for her love and support, for all the late nights and early mornings, and her kindness are not comparable to any other motivation. Thank you for being my muse, editor, proofreader, and sounding board. But most of all, thank you for being my best friend.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Abdul Rashid Bin Mohamed Shariff, CEng, PhD
Professor Sr. Gs.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Khairunniza bt. Bejo, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research)

Signature: ________________________ Date: __________________

Name and Matric No.: ____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________________

Name of Chairman of Supervisory Committee: ______________________________

Signature: ______________________________

Name of Member of Supervisory Committee: ______________________________

Signature: ______________________________

Name of Member of Supervisory Committee: ______________________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
VIs	Vegetation Indices

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; Olfs 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 (Khorramnia 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

<table>
<tr><th>Method</th><th colspan="2">Results</th><th>Disadvantages</th><th>Reference</th></tr>
<tr><td>Spectroradiometer</td><td colspan="2">The nutrient content of the foliage can be obtained through foliar analysis of oil palm leaf from frond No 17.</td><td>The instrument need calibration, expensive, complex system and sunlight dependence. The battery life is low</td><td>(Mazlan Hashim et al. 2001)</td></tr>
<tr><td>Spectroradiometer at micro level</td><td colspan="2">The best correlation for nitrogen prediction was 0.616</td><td>Time Consuming,
Useless for a large area,
Need calibration</td><td>(Ibrahim et al. 2003)</td></tr>
<tr><td rowspan="2">GreenSeeker 505, SPAD 502 Plus, Multiplex 3, and FieldSpec 3</td><td>R</td><td>RMSE</td><td rowspan="2">Is useless in a large area
Time consuming</td><td rowspan="2">(K. Khorramnia et al. 2014)</td></tr>
<tr><td>0.3</td><td>0.96</td></tr>
</table>

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 if 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.

REFERENCES

Agrium, ed. 2016. *Cultivating Excellence Fact Book 2015 – 2016*. Toronto. http://www.agrium.com/.

Almodares, A., Taheri, R., Chung, I. M., & Fathi, M. 2008. "The Effect of Nitrogen and Potassium Fertilizers on Growth Parameters and Carbohydrate Contents of Sweet Sorghum Cultivars." *Journal of Environmental Biology* 29(4): 849–52.

Anatoly, A.Gitelson, N.Merzlyak Mark, and Gritz Yuri. 2003. "Relationships between Leaf Chlorophyll Content and Spectral Reflectance and Algorithms for Non-Destructive Chlorophyll Assessment in Higher Plant Leaves." *Journal of Plant Physiology* 160(3) :271-82 http://www.sciencedirect.com/science/article/pii/S0176161704704034 (September 26, 2017).

Anchang, Julius Y, Erick O. Ananga, and Ruiliang Pu. 2016. "An Efficient Unsupervised Index Based Approach for Mapping Urban Vegetation from IKONOS Imagery." *International Journal of Applied Earth Observation and Geoinformation* 50(5): 211–20. http://www.sciencedirect.com/science/article/pii/S0303243416300502.

Arefaine, A. (2013). "Effects of rates and time of nitrogen fertilizer application on yield and yield components of tef." : In habro district, Eastern Ethiopia (Doctoral dissertation, M. Sc. Thesis, Haramaya University).

Aziz, N. A., W. Omar, R. Kassim, and N. Kamarudin. 2012. *Remote Sensing Measurement for Detection of Bagworm Infestation in Oil Palm Plantation*. Kuala Lumpur. http://palmoilis.mpob.gov.my/publications/TOT/TT-502.pdf (September 14, 2017).

Bagheri, Nikrooz. 2015. "Nitrogen Fertilizer Application Map by Multi- Spectral Satellite Imagery (Abstract in English)." In *Agricultural Engineering*, Iran, 7.

Bakri, Azwan, Norman Hj Kamarudin, and Norasikin A. Ludin. 2016. "Analysis of Energy Utilisation in Malaysian Oil Palm Mechanisation Operation." *Journal of Oil Palm Research* 28(4): 485–95. http://jopr.mpob.gov.my/analysis-of-energy-utilisation-in-malaysian-oil-palm-mechanisation-operation/?v=true.

Balasundram, Siva K, Hadi Memarian, and Rajiv Khosla. 2013. "Estimating Oil Palm Yields Using Vegetation Indices Derived from Quickbird." *Life Science Journal* 10(4). http://www.lifesciencesite.com (September 14, 2017).

Bannari, A., D. Morin, F. Bonn, and A. R. Huete. 1995. "A Review of Vegetation Indices." *Remote Sensing Reviews* 13(1-2): 95–120. http://www.tandfonline.com/doi/abs/10.1080/02757259509532298 (September 27, 2017).

Bill, Ralf, Edward Nash, and Görres Grenzdörffer. 2011. "GIS in Agriculture." In *Springer Handbook of Geographic Information*, Berlin, Heidelberg: Springer Berlin Heidelberg, 461–76. http://link.springer.com/10.1007/978-3-540-72680-7_24 (September 12, 2017).

Blackburn, G. A. 1998. "Spectral Indices for Estimating Photosynthetic Pigment Concentrations: A Test Using Senescent Tree Leaves." *International Journal of Remote Sensing* 19(4): 657–75. http://www.tandfonline.com/doi/abs/10.1080/014311698215919 (September 26, 2017).

BUSCHMANN, C., and E. NAGEL. 1993. "In Vivo Spectroscopy and Internal Optics of Leaves as Basis for Remote Sensing of Vegetation." *International Journal of Remote Sensing* 14(4): 711–22. http://www.tandfonline.com/doi/abs/10.1080/01431169308904370 (September 27, 2017).

V. C. Baligar, N. K. Fageria, and Z. L. He. 2001. "Nutrient Use Efficiency in Plant." *Soil Science and Plant Analysis* 32(8): 921–50.

C.S.T, Daughtry et al. 2000. "Estimating Corn Leaf Chlorophyll Concentration from Leaf and Canopy Reflectance." *Remote Sensing of Environment* 74(2): 229–39. http://www.sciencedirect.com/science/article/pii/S0034425700001139?via%3Dihub (September 26, 2017).

Cabangon, R. J., E. G. Castillo, and T. P. Tuong. 2011. "Chlorophyll Meter-Based Nitrogen Management of Rice Grown under Alternate Wetting and Drying Irrigation." *Field Crops Research* 121(1): 136–46.

http://www.sciencedirect.com/science/article/pii/S0378429010003163 (September 15, 2017).

CARTER, GREGORY A. 1994. "Ratios of Leaf Reflectances in Narrow Wavebands as Indicators of Plant Stress." *International Journal of Remote Sensing* 15(3): 697–703.http://www.tandfonline.com/doi/abs/10.1080/01431169408954109 (September 27, 2017).

CHAPMAN, G. W., and H. M. GRAY. 1949. "Leaf Analysis and the Nutrition of the Oil Palm (Elaeis Guineensis Jacq.)." *Annals of Botany* 13(4): 415–33. https://academic.oup.com/aob/article-lookup/doi/10.1093/oxfordjournals.aob.a083226 (September 11, 2017).

Chemura, Abel, Iris van Duren, and Louise M. van Leeuwen. 2015. "Determination of the Age of Oil Palm from Crown Projection Area Detected from WorldView-2 Multispectral Remote Sensing Data: The Case of Ejisu-Juaben District, Ghana." *ISPRS Journal of Photogrammetry and Remote Sensing* 100: 118–27. http://linkinghub.elsevier.com/retrieve/pii/S0924271614001968 (September 14, 2017).

Chen, Jing M. 1996. "Evaluation of Vegetation Indices and a Modified Simple Ratio for Boreal Applications." *Canadian Journal of Remote Sensing* 22(3): 229–42. http://www.tandfonline.com/doi/abs/10.1080/07038992.1996.10855178 (September 26, 2017).

Chen, Qiaoling, Yuanzhi Zhang, and Martti Hallikainen. 2007. "Water Quality Monitoring Using Remote Sensing in Support of the EU Water Framework Directive (WFD): A Case Study in the Gulf of Finland." *Environmental Monitoring and Assessment* 124(1-3): 157–66. http://link.springer.com/10.1007/s10661-006-9215-8 (September 26, 2017).

Cheng xu, Sun et al. 2011. "Growth and Physiological Responses to Water and Nutrient Stress in Oil Palm." *African Journal of Biotechnology* 10(51): 10465–71. http://academicjournals.org/journal/AJB/article-abstract/516C82732428.

Cheng, Yuqi, Le Yu, Arthur P. Cracknell, and Peng Gong. 2016. "Oil Palm Mapping Using Landsat and PALSAR: A Case Study in Malaysia." *International Journal* *of Remote Sensing* 37(22): 5431–42. https://www.tandfonline.com/doi/full/10.1080/01431161.2016.1241448 (September 13, 2017).

Chong, Khai Loong, Kasturi Devi Kanniah, Christine Pohl, and Kian Pang Tan. 2017. "A Review of Remote Sensing Applications for Oil Palm Studies." *Geo-spatial Information Science* 20(2): 184–200. https://www.tandfonline.com/doi/full/10.1080/10095020.2017.1337317.

Claudia, Domini., Vidal. Lorena, Cravotto. Giancarlo, and Canals. Antonio. 2009. "A Simultaneous, Direct Microwave/Ultrasound-Assisted Digestion Procedure for the Determination of Total Kjeldahl Nitrogen." *Ultrasonics Sonochemistry* 16(4): 564–69. http://www.sciencedirect.com/science/article/pii/S1350417708002113 (September 24, 2017).

Compton J.Tucker. 1979. "Red and Photographic Infrared Linear Combinations for Monitoring Vegetation." *Remote Sensing of Environment* 8(2): 127–50. http://www.sciencedirect.com/science/article/pii/0034425779900130?via%3Dihub (September 26, 2017).

Daniel, Asims, and Agamon John. 2002. "Relationships between Leaf Pigment Content and Spectral Reflectance across a Wide Range of Species, Leaf Structures and Developmental Stages." *Remote Sensing of Environment* 81(2-3): 337–54. http://www.sciencedirect.com/science/article/pii/S003442570200010X (September 26, 2017).

Daniela Stroppiana., Mirco Boschetti., Pietro Alessandro Brivio., and Stefano Bocchib. 2009. "Plant Nitrogen Concentration in Paddy Rice from Field Canopy Hyperspectral Radiometry." *Field Crops Research* 111(1-2): 119–29. http://www.sciencedirect.com/science/article/pii/S0378429008002268 (September 16, 2017).

Datt, B. 1998. "Remote Sensing of Chlorophyll A, Chlorophyll B, Chlorophyll A+b, and Total Carotenoid Content in Eucalyptus Leaves." *Remote Sensing of Environment* 66(2):111–21.http://www.sciencedirect.com/science/article/pii/S0034425798000467 (September 27, 2017).

———. 1999. "Visible/near Infrared Reflectance and Chlorophyll Content in Eucalyptus Leaves." *International Journal of Remote Sensing* 20(14): 2741–59. http://www.tandfonline.com/doi/abs/10.1080/014311699211778 (September 26, 2017).

———. 2003. "Preprocessing Eo-1 Hyperion Hyperspectral Data to Support the Application of Agricultural Indexes." *IEEE Transactions on Geoscience and Remote Sensing* 41(6): 1246–59. http://ieeexplore.ieee.org/document/1220232/ (September 26, 2017).

Driss, Haboudane et al. 2004. "Hyperspectral Vegetation Indices and Novel Algorithms for Predicting Green LAI of Crop Canopies: Modeling and Validation in the Context of Precision Agriculture." *Remote Sensing of Environment* 90(3): 337–52. http://www.sciencedirect.com/science/article/pii/S0034425704000264?via%3Dihub (September 26, 2017).

Eitel, J U H, D S Long, P E Gessler, and A M S Smith. 2007. "Using in-Situ Measurements to Evaluate the New RapidEye™ Satellite Series for Prediction of Wheat Nitrogen Status." *International Journal of Remote Sensing* 28(18): 4183–90. http://www.informaworld.com/openurl?genre=article&doi=10.1080/01431160701422213&magic=crossref.

Elfatih M.Abdel-Rahman, Fethi B.Ahmed, and Maurits van den Berg. 2010. "Estimation of Sugarcane Leaf Nitrogen Concentration Using in Situ Spectroscopy." *International Journal of Applied Earth Observation and Geoinformation* 12: S52–57. http://www.sciencedirect.com/science/article/pii/S0303243409001147?via%3Dihub (September 21, 2017).

Bennett, W. F. (1959). Fertilizers and Their Use. *Bulletin/Texas Agricultural Extension Service; no. 167.*

Fairhurst, T., and R. Härdter. 2003. Oil palm: management for large and sustainable yields. *Oil Palm: Management for Large and Sustainable Yields.* Potash & Phosphate Institute. https://www.cabdirect.org/cabdirect/abstract/20043148306 (July 6, 2017).

FAO. 2013. "Food and Agricultural Organization." http://www.fao.org/faostat/Rome (July 24, 2017).

Fausti, S., Erickson, B. J., Clay, D. E., & Carlson, C. G. (2017). Deriving and Using an Equation to Calculate Economic Optimum Fertilizer and Seeding Rates. *Practical Mathematics for Precision Farming*, (practicalmath).

"Fertilizer Consumption." 2014. *The World Bank*. http://data.worldbank.org/indicator/AG.CON.FERT.ZS?locations=MY-ID-TH (July 30, 2017).

Filella, I., L. Serrano, J. Serra, and J. Peñuelas. 1995. "Evaluating Wheat Nitrogen Status with Canopy Reflectance Indices and Discriminant Analysis." *Crop Science* 35(5): 1400.https://www.crops.org/publications/cs/abstracts/35/5/CS0350051400 (September 16, 2017).

Foster, H.L. 1999. "Assessment of Oil Palm Fertilizer Requirementse." In *The Oil Palm. Management for Large and Sustainable Yields*, Singapore: PPI/PPIC.

Fridgen, Jennifer L., and Jac J. Varco. 2004. "Dependency of Cotton Leaf Nitrogen, Chlorophyll, and Reflectance on Nitrogen and Potassium Availability." *Agronomy Journal* 96(1): 63–69. https://dl.sciencesocieties.org/publications/aj/abstracts/96/1/63 (September 21, 2017).

Gao, Yongnian et al. 2015. "Remote Sensing Estimation of the Total Phosphorus Concentration in a Large Lake Using Band Combinations and Regional Multivariate Statistical Modeling Techniques." *Journal of Environmental Management* 151(5): 33–43. http://dx.doi.org/10.1016/j.jenvman.2014.11.036.

Gevaert, Caroline. 2014. "Combining Hyperspectral Uav And Multispectral Formosat-2 Imagery For Precision Agriculture Applications." Lund University.

Gevaert, Caroline M., Juha Suomalainen, Jing Tang, and Lammert Kooistra. 2015. "Generation of Spectral-Temporal Response Surfaces by Combining Multispectral Satellite and Hyperspectral UAV Imagery for Precision Agriculture Applications."

IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 8(6): 3140–46.

Ghazali, Kamarul Hawari, Saifudin Razali, Mohd. Marzuki Mustafa, and Aini Hussain. 2008. “Machine Vision System for Automatic Weeding Strategy in Oil Palm Plantation Using Image Filtering Technique.” In *2008 3rd International Conference on Information and Communication Technologies: From Theory to Applications*, IEEE, 1–5. http://ieeexplore.ieee.org/document/4530075/ (September 13, 2017).

Gitelson, A. A., Y. J. Kaufman, and M. N. Merzlyak. 1996. “Use of a Green Channel in Remote Sensing of Global Vegetation from EOS-MODIS.” *Remote Sensing of Environment* 58(3): 289–98. http://www.sciencedirect.com/science/article/pii/S0034425796000727 (September 27, 2017).

Gobron, N., B. Pinty, M. M. Verstraete, and J. L. Widlowski. 2000. “Advanced Vegetation Indices Optimized for up-Coming Sensors: Design, Performance, and Applications.” *IEEE Transactions on Geoscience and Remote Sensing* 38(6): 2489–2505.

Goffart, J. P., M. Olivier, and M. Frankinet. 2008. “Potato Crop Nitrogen Status Assessment to Improve N Fertilization Management and Efficiency: Past-Present-Future.” *Potato Research* 51(3-4): 355–83.

Goh, K. J. 1977. “Fertilizer Recommendation Systems for Oil Palm : Estimating the Fertilizer Rates.” *Proceedings of MOSTA best practices workshops: agronomy and crop management, Malaysia, March to August 2004. Sdn* 12(2): 235–68. http://www.aarsb.com.my/AgroMgmt/OilPalm/FertMgmt/Computation/Fertilizer recommendation systems for oil palm - estimating the fertilizer rates.pdf.

Goh, K. J., and Buloh P.O. 2005. “Fertilizer Recommendation Systems for Oil Palm : Estimating the Fertilizer Rates.” *Proceedings of MOSTA best practices workshops: agronomy and crop management, Malaysia, March to August 2004. Sdn* 57(3): 235–68. http://www.aarsb.com.my/AgroMgmt/OilPalm/FertMgmt/Computation/Fertilizer recommendation systems for oil palm - estimating the fertilizer rates.pdf.

Goh, K.J., P.H.C. Ng, and C.T. Lee. 2009. “Fertilizer Management and Productivity of Oil Palm in Malaysia.” *AAR Newsletter* 17(4): 2–24.

Gomez-Casero, M T et al. 2007. “Assessing Nitrogen and Potassium Deficiencies in Olive Orchards through Discriminant Analysis of Hyperspectral Data.” *Journal of the American Society for Horticultural Science* 132(5): 611–18.

Gottfried Konecny. 2014. *Geoinformation: Remote Sensing, Photogrammetry and Geographic Information ... - Gottfried Konecny - Google Books*. 2nd ed. Taylor and Francis. https://books.google.com.my/books?hl=en&lr=&id=8TcyAwAAQBAJ&oi=fnd&pg=PP1&dq=remote+sensing+and+The+Electromagnetic+Spectrum&ots=Z1rjMhxbam&sig=o0NfNBZqHZeEQ7t9ePkcGUCWFM8&redir_esc=y#v=onepage&q=Electromagnetic Spectrum&f=false (September 13, 2017).

Goward, S.N. et al. 2003. “Acquisition of Earth Science Remote Sensing Observations from Commercial Sources: Lessons Learned from the Space Imaging IKONOS Example.” *Remote Sensing of Environment* 88(1-2): 209–19. http://www.sciencedirect.com/science/article/pii/S0034425703002426 (September 26, 2017).

Gu, Zhujun, G. Arturo Sanchez-Azofeifa, Jilu Feng, and Sen Cao. 2015. “Predictability of Leaf Area Index Using Vegetation Indices from Multiangular CHRIS/PROBA Data Over Eastern China.” *Journal of Applied Remote Sensing* 9(1): 096085. http://remotesensing.spiedigitallibrary.org/article.aspx?doi=10.1117/1.JRS.9.096085.

Guo, Y., and F. Zeng. 2012. “Atmospheric Correction Comparison of Spot-5 Image Based on Model Flaash and Model Quac.” *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 12(7): 7–11.

Hadjimitsis, D. G. et al. 2010. “Atmospheric Correction for Satellite Remotely Sensed Data Intended for Agricultural Applications: Impact on Vegetation Indices.” *Natural Hazards and Earth System Science* 10(1984): 89–95.

Hashim, M. et al. 2001. “Detecting Oil Palm Tree Growth Variability Using a Field Spectroradiometer.” *ASIAN-PACIFIC Remote Sensing and GIS Journal* 5(14): 25–

32. https://core.ac.uk/download/pdf/11778668.pdf (September 16, 2017).

Hashim, Mazlan et al. 2001. "Detecting Oil Palm Tree Growth Variability Using a Field Spectroradiometer." *ASIAN-PACIFIC Remote Sensing and GIS Journal* 14(5): 25–31.

Hawkesford, Malcolm J, Stanislav Kopriva, and Luit J De Kok. 2014. 10 Plant Ecophysiology *Nutrient Use Efficiency in Plants: Concepts and Approaches*. eds. Luit J. De Kok and Malcolm J. Hawkesford. Springer US.

Hoffland, Ellis et al. 2000. "Nitrogen Availability and Defense of Tomato Against Two-Spotted Spider Mite." *Journal of Chemical Ecology* 26(12): 2697–2711. http://link.springer.com/10.1023/A:1026477423988 (September 14, 2017).

Houborg, Rasmus et al. 2015. "Joint Leaf Chlorophyll Content and Leaf Area Index Retrieval from Landsat Data Using a Regularized Model Inversion System (REGFLEC)." *Remote Sensing of Environment* 159(2): 203–21. http://dx.doi.org/10.1016/j.rse.2014.12.008.

Huete, A, C Justice, and H Liu. 1994. "Development of Vegetation and Soil Indices for MODIS-EOS." *Remote Sensing of Environment* 49(3): 224–34. http://www.sciencedirect.com/science/article/pii/0034425794900183 (September 26, 2017).

Ibrahim, AbLatif et al. 2003. "Detecting and Mapping Nutrients Concentration in Oil Palm Plantation Using Remote Sensing and Geographic Information System." In *International Palm Oil Congress (Agriculture)*, Kuala Lumpur, 261–71.

Jacquemoud, Stéphane et al. 2009. "PROSPECT + SAIL Models: A Review of Use for Vegetation Characterization." *Remote Sensing of Environment* 113(4): S56–66. http://dx.doi.org/10.1016/j.rse.2008.01.026.

Jat, Mahesh Kumar, P. K. Garg, and Deepak Khare. 2008. "Monitoring and Modelling of Urban Sprawl Using Remote Sensing and GIS Techniques." *International Journal of Applied Earth Observation and Geoinformation* 10(1): 26–43.

Jebur, Mustafa Neamah, Helmi Zulhaidi Mohd Shafri, Biswajeet Pradhan, and Mahyat Shafapour Tehrany. 2014. "Per-Pixel and Object-Oriented Classification Methods for Mapping Urban Land Cover Extraction Using SPOT 5 Imagery." *Geocarto International* 29(7): 792–806. http://www.tandfonline.com/doi/abs/10.1080/10106049.2013.848944 (September 13, 2017).

Jensen, J. R. 2009. *Remote Sensing of the Environment: An Earth Resource Perspective 2/e*. Pearson Education India.

Jiang, Z., A. R. Huete, K. Didan, and T. Miura. 2008. "Development of a Two-Band Enhanced Vegetation Index without a Blue Band." *Remote Sensing of Environment* 112(10): 3833–45. http://www.sciencedirect.com/science/article/pii/S0034425708001971 (September 26, 2017).

K. Khorramnia et al. 2014. "OIL PALM LEAF NUTRIENT ESTIMATION BY OPTICAL SENSING TECHNIQUES." *American Society of Agricultural and Biological Engineers* 47(4): 1267–77. http://elibrary.asabe.org.sci-hub.cc/azdez.asp?search=0&JID=3&AID=45044&CID=t2014&v=57&i=4&T=2 (January 11, 2017).

Kamarudin, Norman. 2016. "ENHANCING SUSTAINABLE PALM OIL PRODUCTION." In *Oil Palm Cultivation and Management*, , 59. https://www.researchgate.net/publication/306374969_Oil_Palm_Cultivation_and_Management_ENHANCING_SUSTAINABLE_PALM_OIL_PRODUCTION.

Kamil, Nur Nadia, and Syuhadatul Fatimah Omar. 2016. "Climate Variability and Its Impact on the Palm Oil Industry." *Oil Palm Industry Economic Journal* 16(March): 43.

Khatun, Rahima, Mohammad Imam Hasan Reza, M. Moniruzzaman, and Zahira Yaakob. 2017. "Sustainable Oil Palm Industry: The Possibilities." *Renewable and Sustainable Energy Reviews* 76(December 2016): 608–19.

Khorramnia, Khosro. 2013. "Oil Plm Leaf Nutrient Estimation Using Optical Sensor." Universiti Putra Malaysia.

Kong, Jinling et al. 2015. “An Optimal Model for Estimating Suspended Sediment Concentration from Landsat TM Images in the Caofeidian Coastal Waters.” *International Journal of Remote Sensing* 36(19-20): 5257–72. http://www.tandfonline.com/doi/full/10.1080/01431161.2015.1043159.

Kyratzis, Angelos C. et al. 2017. “Assessment of Vegetation Indices Derived by UAV Imagery for Durum Wheat Phenotyping under a Water Limited and Heat Stressed Mediterranean Environment.” *Frontiers in Plant Science* 8(6): 1–14. http://journal.frontiersin.org/article/10.3389/fpls.2017.01114/full.

Lee, W.S. et al. 2010. “Sensing Technologies for Precision Specialty Crop Production.” *Computers and Electronics in Agriculture* 74(1): 2–33. http://linkinghub.elsevier.com/retrieve/pii/S0168169910001493 (September 13, 2017).

Li, Li, Jinwei Dong, Simon Njeudeng Tenku, and Xiangming Xiao. 2015. “Mapping Oil Palm Plantations in Cameroon Using PALSAR 50-M Orthorectified Mosaic Images.” *Remote Sensing* 7(2): 1206–24. http://www.mdpi.com/2072-4292/7/2/1206/ (September 13, 2017).

Li, Y., D. Chen, C. N. Walker, and J. F. Angus. 2010. “Estimating the Nitrogen Status of Crops Using a Digital Camera.” *Field Crops Research* 118(3): 221–27. http://www.sciencedirect.com/science/article/pii/S0378429010001358 (September 18, 2017).

Liaghat, Shohreh et al. 2014. “Early Detection of Basal Stem Rot Disease (*Ganoderma*) in Oil Palms Based on Hyperspectral Reflectance Data Using Pattern Recognition Algorithms.” *International Journal of Remote Sensing* 35(10): 3427–39. http://www.tandfonline.com/doi/abs/10.1080/01431161.2014.903353 (September 14, 2017).

Lin, Fen Fang et al. 2010. “Investigation of SPAD Meter-Based Indices for Estimating Rice Nitrogen Status.” *Computers and Electronics in Agriculture* 71(5): S60–65. http://www.sciencedirect.com/science/article/pii/S0168169909001847 (September 15, 2017).

Link, A., and S. Reusch. 2006. “Implementation of Site-Specific Nitrogen Application—

status and Development of the YARA N-Sensor.” In *In NJF Seminar*, , 37–41.

Liri, Mohd Tohid bin. 2015. *The Malaysian Fertilizer Market*. Kuala Lumpur.

Magney, Troy S., Jan U H Eitel, and Lee A. Vierling. 2016. “Mapping Wheat Nitrogen Uptake from RapidEye Vegetation Indices.” *Precision Agriculture* 112(4): 1–23.

Mai, Thuy. 2012. “Passive and Active Sensors.” https://www.nasa.gov/directorates/heo/scan/communications/outreach/funfacts/txt_passive_active.html (September 27, 2017).

Mainard, S. Demotes, R. Boumaza, S. Meyer, and Z. G Cerovic. 2008. “Indicators of Nitrogen Status for Ornamental Woody Plants Based on Optical Measurements of Leaf Epidermal Polyphenol and Chlorophyll Contents.” *Scientia Horticulturae* 115(4): 377–85. http://www.sciencedirect.com/science/article/pii/S0304423807003445 (September 15, 2017).

MATRADE. 2017. “Top 10 Major Export Products.” *MATRADE*. http://www.matrade.gov.my/en/28-malaysian-exporters/trade-statistics/3789-top-10-major-export-products-2017.

McDonald, Glenn, William Bovill, Chunyuan Huang, and David Lightfoot. 2013. “Nutrient Use Efficiency.” In *Genomics and Breeding for Climate-Resilient Crops*, Berlin: Springer, 333–96.

McMorrow, J. 2001. “Linear Regression Modelling for the Estimation of Oil Palm Age from Landsat TM.” *International Journal of Remote Sensing* 22(12): 2243–64. http://www.tandfonline.com/doi/abs/10.1080/01431160117188 (September 13, 2017).

Méndez-Barroso, Luis A., Jaime Garatuza-Payán, and Enrique R. Vivoni. 2008. “Quantifying Water Stress on Wheat Using Remote Sensing in the Yaqui Valley, Sonora, Mexico.” *Agricultural Water Management* 95(6): 725–36. http://linkinghub.elsevier.com/retrieve/pii/S0378377408000334 (September 13, 2017).

Miky, Yehia H, and Ahmed F El Shouny. 2013. "Using Space-Borne Hyperspectral Imagery on Mapping Nitrogen Fertilizer Excess to the Environment." *International Journal of Science and Research (IJSR) ISSN (Online Index Copernicus Value Impact Factor* 14611(11): 2319–7064. www.ijsr.net (December 20, 2016).

Mohidin, Hasmah et al. 2015. "Determination of Optimum Levels of Nitrogen, Phosphorus and Potassium of Oil Palm Seedlings in Solution Culture." *Bragantia* 74(3): 247–54.

Mousivand, Alijafar, Wout Verhoef, Massimo Menenti, and Ben Gorte. 2015. "Modeling Top of Atmosphere Radiance Over Heterogeneous Non-Lambertian Rugged Terrain." *Remote Sensing* 7(6): 8019–44.

MPOB. 2016. "Malaysian Oil Palm Statistics 2015." http://www.mpob.gov.my/.

Mulla, David J. 2013. "Twenty Five Years of Remote Sensing in Precision Agriculture: Key Advances and Remaining Knowledge Gaps." *Biosystems Engineering* 114(4): 358–71.

Naito, H. et al. 2012. "Summer-Season Differences in NDVI and iTVDI among Vegetation Cover Types in Lake Mashu, Hokkaido, Japan Using Landsat TM Data." *Environmental Control in Biology* 50(2): 163–71. https://www.jstage.jst.go.jp/article/ecb/50/2/50_163/_pdf (September 27, 2017).

Nicolas Tremblay, Edith Fallon, Noura Ziadi., and Noura Ziadi. 2011. "Sensing of Crop Nitrogen Status: Opportunities, Tools, Limitations, and Supporting Information Requirements." *Hort Technol* 21(3): 274–81. http://horttech.ashspublications.org/content/21/3/274.full (September 14, 2017).

Nikrooz, Bagheri., Ahmadi. Hojjat, Seyed. Kazem. Alavipanah, and Mahmoud. Omid. 2013. "Multispectral Remote Sensing for Site-Specific Nitrogen Fertilizer Management." *Pesquisa Agropecuária Brasileira* 48(10): 1–10.

O'Connell, M., D. Whitfield, and M. Abuzar. 2016. "Satellite Remote Sensing of Vegetation Cover and Nitrogen Status in Almond." *Acta Horticulturae* 1130(17):

559–66.

Ofosu Anim, Desmond, Amos Tiereyangn Kabo-bah, Philip Nti Nkrumah, and Raphinos Tackmore Murava. 2013. "Evaluation of NDVI Using SPOT-5 Satellite Data for Northern Ghana." *Environmental Management and Sustainable Development* 2(1): 167–82. http://www.macrothink.org/journal/index.php/emsd/article/view/3709.

Oil, Palm. 2009. "Palm Oil Industry in Malaysia Skills & Knowledge for Sustained Development Origin of Palm Oil Palm Oil Value Chain & Applications." *Slides* 54(4).

Olfs, Hans Werner et al. 2005. "Soil and Plant Based Nitrogen Fertilizer Recommendations in Arable Farming." *Journal of Plant Nutrition and Soil Science* 168(4): 414–31.

Omer, Galal et al. 2017. "Mapping Leaf Nitrogen and Carbon Concentrations of Intact and Fragmented Indigenous Forest Ecosystems Using Empirical Modeling Techniques and WorldView-2 Data." *ISPRS Journal of Photogrammetry and Remote Sensing* 131(3): 26–39. http://dx.doi.org/10.1016/j.isprsjprs.2017.07.005.

Oza, S. R., S. Panigrahy, and J. S. Parihar. 2008. "Concurrent Use of Active and Passive Microwave Remote Sensing Data for Monitoring of Rice Crop." *International Journal of Applied Earth Observation and Geoinformation* 10(3): 296–304.

Pardon, Lénaïc et al. 2016a. "Key Unknowns in Nitrogen Budget for Oil Palm Plantations. A Review." *Agronomy for Sustainable Development* 36(1): 1–21.

———. 2016b. "Key Unknowns in Nitrogen Budget for Oil Palm Plantations. A Review." *Agronomy for Sustainable Development* 36(1): 1–21. http://dx.doi.org/10.1007/s13593-016-0353-2.

Paul R. Baumann. 2010. "Introduction to Remote Sensing." http://www.oneonta.edu/faculty/baumanpr/geosat2/RS-Introduction/RS-Introduction.html (September 13, 2017).

Penuelas, J., F. Baret, and I. Filella. 1995. "Semi-Empirical Indices to Assess Carotenoids/chlorophyll a Ratio from Leaf Spectral Reflectance." *Photosynthetica* 31(2): 221–30. https://www.researchgate.net/profile/Baret_Frederic/publication/229084513_Semi-Empirical_Indices_to_Assess_CarotenoidsChlorophyll a_Ratio_from_Leaf_Spectral_Reflectance/links/55a5fa2208aef604aa046bd0/Semi-Empirical-Indices-to-Assess-Carotenoids-Chlorophyl (September 27, 2017).

Perry, E. M., and J. R. Davenport. 2007. "Spectral and Spatial Differences in Response of Vegetation Indices to Nitrogen Treatments on Apple." *Computers and Electronics in Agriculture* 59(1-2): 56–65. http://www.sciencedirect.com/science/article/pii/S016816990700138X (September 15, 2017).

Pittman, A. M., K. Carlson, L. M. Curran, and A. Ponette Gonzalez. 2013. "NASA Satellite Data Used to Study the Impact of Oil Palm Expansion across Indonesian Borneo." *The Earth Observer* 25(5): 12–15.

Poffenbarger, H. J., Barker, D. W., Helmers, M. J., Miguez, F. E., Olk, D. C., Sawyer, J. E., ... & Castellano, M. J. (2017). Maximum soil organic carbon storage in Midwest US cropping systems when crops are optimally nitrogen-fertilized. *PloS one*, *12*(3), e0172293.

Qi, J. et al. 1994. "A Modified Soil Adjusted Vegetation Index." *Remote Sensing of Environment* 48(2): 119–26. http://www.sciencedirect.com/science/article/pii/0034425794901341 (September 26, 2017).

Qiang, Caoa et al. 2013. "Non-Destructive Estimation of Rice Plant Nitrogen Status with Crop Circle Multispectral Active Canopy Sensor." *Field Crops Research* 154: 133–44. http://www.sciencedirect.com/science/article/pii/S037842901300275X?via%3Dihub (September 26, 2017).

R.N. Roy A. Finck G.J. Blair H.L.S. Tandon. 2006. "Plant Nutrients and Basics of Plant Nutrition. A Guide for Integrated Nutrient Management." In *FAO*, Rome: FAO, 25–42.

Rankine, I.R., and T.H. Fairhurst. 2000. *Field Handbook: Oil Palm Series*. 2nd ed. Singapore: Potash & Phosphate Institute (PPI).

Reimer, Adam et al. 2017. "Moving toward Sustainable Farming Systems: Insights from Private and Public Sector Dialogues on Nitrogen Management." *Journal of Soil and Water Conservation* 72(1): 5A – 9A. http://www.jswconline.org/lookup/doi/10.2489/jswc.72.1.5A.

Rendana, Muhammad et al. 2015. "A Review of Methods for Detecting Nutrient Stress of Oil Palm in Malaysia." *J. Appl. Environ. Biol. Sci. Journal of Applied Environmental and Biological Sciences* 5(6): 60–64. www.textroad.com (December 27, 2016).

Robert, P. C. 2002. "Precision Agriculture: A Challenge for Crop Nutrition Management." *Plant and Soil* 247(1): 143–49.

Rondeaux, G., M. Steven, and F. Baret. 1996. "Optimization of Soil-Adjusted Vegetation Indices." *Remote Sensing of Environment* 55(2): 95–107. http://www.sciencedirect.com/science/article/pii/0034425795001867 (September 26, 2017).

Rotta, Luiz H.S. et al. 2016. "Atmospheric Correction Assessment of SPOT-6 Image and Its Influence on Models to Estimate Water Column Transparency in Tropical Reservoir." *Remote Sensing Applications: Society and Environment* 4(7): 158–66. http://dx.doi.org/10.1016/j.rsase.2016.09.001.

Roujean, J. L., and F. M. Breon. 1995. "Estimating PAR Absorbed by Vegetation from Bidirectional Reflectance Measurements." *Remote Sensing of Environment* 51(3): 375–84. http://www.sciencedirect.com/science/article/pii/0034425794001143 (September 26, 2017).

Rouse Jr, J. W. 1974. *Monitoring the Vernal Advancement and Retrogradation (green Wave Effect) of Natural Vegetation*. United States . https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740008955.pdf (September 26, 2017).

Rouse, W, R H Haas, and D W Deering. 1974. "Monitoring Vegetation Systems in the Great Plains with ERTS." *NASA. Goddard Space Flight Center* 1(12): 309–17. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19740022614.pdf (September 26, 2017).

S., Anbazhagan, Anbazhagan S., and Paramasivam C.R. 2016. "Statistical Correlation Between Land Surface Temperature (LST) and Vegetation Index (NDVI) Using Multi-Temporal Landsat TM Data." *International Journal of Advanced Earth Science and Engineering* 5(1): pp. 333–46. http://scientific.cloud-journals.com/index.php/IJAESE/article/view/409.

Saberioon, Mohammadmehdi, Mohd S M Amin, Asa Gholizadeh, and Mohd H. Ezri. 2014. "A Review of Optical Methods for Assessing Nitrogen Contents during Rice Growth." *Applied Engineering in Agriculture* 30(4): 657–69.

Sabri, Mohamed Ali. 2009. "Evolution of Fertilizer Use by Crops in Malaysia: Recent Trends and Prospects." In *IFA Crossroads Asia-Pacific*, , 1–39.

Sahu, Pradip Kumar. 2013. "Research Design." In *Research Methodology: A Guide for Researchers In Agricultural Science, Social Science and Other Related Fields*, India: Springer India, 25–33. http://link.springer.com/10.1007/978-81-322-1020-7_4 (September 11, 2017).

Santoso, Heri, Hiroshi Tani, and Xiufeng Wang. 2016. "A Simple Method for Detection and Counting of Oil Palm Trees Using High-Resolution Multispectral Satellite Imagery." *International Journal of Remote Sensing* 37(21): 5122–34. https://www.tandfonline.com/doi/full/10.1080/01431161.2016.1226527 (September 13, 2017).

Savci, Serpil. 2012. "An Agricultural Pollutant : Chemical Fertilizer." *International Journal of Environmental Science and Development* 3(1): 11–14.

Savoy, Hugh. 2015. 12 *Fertilizers and Their Use*. The University of Tennessee Institute of Agriculture. http://trace.tennessee.edu/utk_agexfora.

Schelling, K. 2010. "Approaches to Characterize Chlorophyll/Nitrogen Status of Crop

Canopies." In *Auswertung von Fernerkundungsdaten*, Hannover: DPGF Workshop Analysis of Remote Sensing Data. http://www.dgpf.de/src/ak/rsd/Vortraege-int/Schelling.pdf (September 20, 2017).

Schlerf, M., C. Atzberger, and J. Hill. 2005. "Remote Sensing of Forest Biophysical Variables Using HyMap Imaging Spectrometer Data." *Remote Sensing of Environment* 95(2): 177–94. http://www.sciencedirect.com/science/article/pii/S0034425705000143 (September 26, 2017).

Seelan, Santhosh K., Soizik Laguette, Grant M. Casady, and George A. Seielstad. 2003. "Remote Sensing Applications for Precision Agriculture: A Learning Community Approach." *Remote Sensing of Environment* 88(1-2): 157–69.

Selvaraja, S, S K Balasundram, G Vadamalai, and M H A Husni. 2013. "Use of Spectral Reflectance to Discriminate between Potassium Deficiency and Orange Spotting Symptoms in Oil Palm (Elaeis Guineensis)." *Life Science Journal* 10(4). http://www.lifesciencesite.com (September 16, 2017).

Sen, Avijit, and Panjab Singh. 2015. *Nutrient Use Efficiency : From Basics to Advances*. eds. Amitava Rakshit, Harikesh Bahadur Singh, and Avijit Sen. Springer US.

Serrano, L, J Serra, and J Peñue. 1995. "Evaluating Wheat Nitrogen Status with Canopy Reflectance In Dices and Discriminant An Alysis." *Crop Science* 1405(5): 1400–1405.

Shafri, Helmi Z. M., Nasrulhapiza Hamdan, and M. Iqbal Saripan. 2011. "Semi-Automatic Detection and Counting of Oil Palm Trees from High Spatial Resolution Airborne Imagery." *International Journal of Remote Sensing* 32(8): 2095–2115. http://www.tandfonline.com/doi/abs/10.1080/01431161003662928 (September 13, 2017).

Shaver, T. M., R. Khosla, and D. G. Westfall. 2011. "Evaluation of Two Crop Canopy Sensors for Nitrogen Variability Determination in Irrigated Maize." *Precision Agriculture* 12(6): 892–904. http://link.springer.com/10.1007/s11119-011-9229-2 (September 16, 2017).

Sheil, D et al. 2009. Africa *The Impacts and Opportunities of Oil Palm in Southeast Asia*. International Forestry Research.

Shou, Lina et al. 2007. “Using High-Resolution Satellite Imaging to Evaluate Nitrogen Status of Winter Wheat.” *Journal of Plant Nutrition* 30(10): 1669–80. http://www.tandfonline.com/doi/abs/10.1080/01904160701615533 (September 19, 2017).

Silalertruksa, Thapat, Sébastien Bonnet, and Shabbir H. Gheewala. 2012. “Life Cycle Costing and Externalities of Palm Oil Biodiesel in Thailand.” *Cleaner Production* 28(4): 225–32.

Sinfield, Joseph V., Daniel Fagerman, and Oliver Colic. 2010. “Evaluation of Sensing Technologies for on-the-Go Detection of Macro-Nutrients in Cultivated Soils.” *Computers and Electronics in Agriculture* 70(1): 1–18.

Soroker, Victoria, and Stefano Colazza. 2017. *Handbook of Major Palm Pests : Biology and Management*.https://books.google.com.my/books?hl=en&lr=&id=K1QQDgAAQBAJ&oi=fnd&pg=PA39&dq=Oil+palm+physiology+botany&ots=un0ZkC2_pJ&sig=a4Zydn7xFpDWahBU8qu1QNNF4X4&redir_esc=y#v=onepage&q&f=false (July 7, 2017).

Soudani, Kamel et al. 2006. “Comparative Analysis of IKONOS, SPOT, and ETM+ Data for Leaf Area Index Estimation in Temperate Coniferous and Deciduous Forest Stands.” *Remote Sensing of Environment* 102(1-2): 161–75.

Sun, Yan et al. 2015. “Standardization of Leaf Sampling Technique in Jackfruit Nutrient Status Diagnosis.” *Agricultural Science* 6(1): 232–37.

Taiz, Lincoln, Eduardo Zeiger, I. M. (Ian Max) Møller, and Angus S. Murphy. 2015. *Plant Physiology and Development*. Sinauer Associates, Incorporated. http://www.forskningsdatabasen.dk/en/catalog/2262296489 (September 15, 2017).

“The World Bank Group Framework and IFC Strategy for Engagement in the Palm Oil

Sector." 2011. https://www.ifc.org/wps/wcm/connect/159dce004ea3bd0fb359f71dc0e8434d/WBG+Framework+and+IFC+Strategy_FINAL_FOR+WEB.pdf?MOD=AJPERES (September 12, 2017).

Tian, Y. C. et al. 2011. "Assessing Newly Developed and Published Vegetation Indices for Estimating Rice Leaf Nitrogen Concentration with Ground- and Space-Based Hyperspectral Reflectance." *Field Crops Research* 120(2): 299–310. http://dx.doi.org/10.1016/j.fcr.2010.11.002.

Tiit, Kutser. 2012. "The Possibility of Using the Landsat Image Archive for Monitoring Long Time Trends in Coloured Dissolved Organic Matter Concentration in Lake Waters." *Remote Sensing of Environment* 123: 334–38. http://www.sciencedirect.com/science/article/pii/S0034425712001666?via%3Dihub (September 26, 2017).

Tilling, Adam K. et al. 2007. "Remote Sensing of Nitrogen and Water Stress in Wheat." *Field Crops Research* 104(1-3): 77–85.

Tilman, David et al. 2002. "Agricultural Sustainability and Intensive Production Practices." *Nature* 418(8): 671–77. http://dx.doi.org/10.1038/nature01014.

Torres-Olivar, Vicente et al. 2014. "Role of Nitrogen and Nutrients in Crop Nutrition." *Journal of Agricultural Science and Technology.B* 4(1B): 29–37. http://sfxhosted.exlibrisgroup.com/cpu?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%3Aagriculturejournals&atitle=Role+of+Nitrogen+and+Nutrients+in+Crop+Nutrition&title=Journal+of+Agricultural+Science+and+Techn.

Tremblay, Nicolas et al. 2009. "A Comparison of Crop Data Measured by Two Commercial Sensors for Variable-Rate Nitrogen Application." *Precision Agriculture* 10(2): 145–61. http://link.springer.com/10.1007/s11119-008-9080-2 (September 16, 2017).

Tremblay, Nicolas, Zhijie Wang, and Zoran G. Cerovic. 2012. "Sensing Crop Nitrogen Status with Fluorescence Indicators. A Review." *Agronomy for Sustainable Development* 32(2): 451–64. http://link.springer.com/10.1007/s13593-011-0041-1

(September 16, 2017).

Turner, P. D., and R. A Gillbanks. 2003. *Oil Palm Cultivation and Management.* Kuala Lumpur: Incorporated Society of Planters. http://www.cabi.org/isc/abstract/19750328044 (September 11, 2017).

"United Nations Environment Programme UNEP/GRID-Sioux Falls." https://na.unep.net/ (July 7, 2017).

Verheye, Willy. 2010. Soils, Plant Growth and Crop Production "Growth and Production of Oil Palm." University of Ghent, Belgium.

Viña, Andrés, Anatoly A. Gitelson, Anthony L. Nguy-Robertson, and Yi Peng. 2011. "Comparison of Different Vegetation Indices for the Remote Assessment of Green Leaf Area Index of Crops." *Remote Sensing of Environment* 115(12): 3468–78. http://dx.doi.org/10.1016/j.rse.2011.08.010.

Wang, Ning. 2016. "13 Worksite Management for Precision Agricultural Production." In *Agricultural Automation: Fundamentals and Practices*, , 343.

Watanabe, Fernanda et al. 2015. "Estimation of Chlorophyll-a Concentration and the Trophic State of the Barra Bonita Hydroelectric Reservoir Using OLI/Landsat-8 Images." *International Journal of Environmental Research and Public Health* 12(9): 10391–417. http://www.mdpi.com/1660-4601/12/9/10391/ (September 26, 2017).

Wesley, J.Moses et al. 2012. "Estimation of Chlorophyll-a Concentration in Turbid Productive Waters Using Airborne Hyperspectral Data." *Water Research* 46(4): 993–1004. http://www.sciencedirect.com/science/article/pii/S0043135411007603?via%3Dihub (September 26, 2017).

Wielaard, N. 2011. *Impact of Oil Palm Plantations on Peatland Conversion in Sarawak 2005–2010*. ed. Summary Report: SarVision. http://ckpp.wetlands.org/Watchread/tabid/865/mod/1570/articleType/ArticleView/articleId/2760/Default.aspx (September 13, 2017).

Wilcove, David S., and Lian Pin Koh. 2010. "Addressing the Threats to Biodiversity from Oil-Palm Agriculture." *Biodiversity and Conservation* 19(4): 999–1007.

William W. Casady, and Harlan L. Palm. 2002. "Precision Agriculture: Remote Sensing and Ground Truthing." *MU Extension, University of Missouri-Columbia* 5(13). http://extension.missouri.edu/explorepdf/envqual/eq0453.pdf (September 13, 2017).

Woittiez, Lotte Suzanne et al. 2016. *Smallholder Oil Palm Handbook Module 4: Fertiliser Application*. 3rd ed. Wageningen University, Wageningen, and SNV International Development Organisation.

World Bank. 2017. "World Bank." http://www.worldbank.org/ (July 11, 2017).

Wright, Dennis L. et al. 2003a. "Managing Grain Protein in Wheat Using Remote Sensing." *Online Journal of Space Communication, Available* 33(7): 13. http://citeseerx.ist.psu.edu/viewdoc/summary;jsessionid=707213A0D85C96DDAD88961CC2B45F20?doi=10.1.1.531.4922.

———. 2003b. "Managing Grain Protein in Wheat Using Remote Sensing." *Journal of Space Communication* 33(7): 13. http://citeseerx.ist.psu.edu/viewdoc/summary;jsessionid=707213A0D85C96DDAD88961CC2B45F20?doi=10.1.1.531.4922.

Wu, J. 2006. "Validation and Application of High Resolution Remote Sensing in Agricultural Fields." *ProQuest* 15(4). https://www.laas.umn.edu/sites/laas.umn.edu/files/Validation and Application of High Resolution Remote Sensing in Agricultural Fields.pdf (September 19, 2017).

Xu, G H, X Fan, and A J Miller. 2012. "Plant Nitrogen Assimilation and Use Efficiency." *Annual Review of Plant Biology* 63(1): 153–82. http://www.annualreviews.org/doi/abs/10.1146/annurev-arplant-042811-105532.

Xue, Lihong et al. 2004. "Monitoring Leaf Nitrogen Status in Rice with Canopy Spectral Reflectance." *Agronomy Journal* 96(1): 135–42. https://dl.sciencesocieties.org/publications/aj/abstracts/96/1/135 (09, 2017).

Yan, Zhu et al. 2008. "Analysis of Common Canopy Vegetation Indices for Indicating Leaf Nitrogen Accumulations in Wheat and Rice." *International Journal of Applied Earth Observation and Geoinformation* 10(1): 1–10. http://www.sciencedirect.com/science/article/pii/S0303243407000165 (September 16, 2017).

Yu, Weifeng et al. 2012. "Evaluating Different Methods of Using Chlorophyll Meter for Diagnosing Nitrogen Status of Summer Maize." In *2012 First International Conference on Agro- Geoinformatics (Agro-Geoinformatics)*, Shanghai, China: IEEE, 1–4. http://ieeexplore.ieee.org/document/6311633/ (September 15, 2017).

Zhang, Jin Heng, Ke Wang, J. S. Bailey, and Ren Chao Wang. 2006. "Predicting Nitrogen Status of Rice Using Multispectral Data at Canopy Scale." *Pedosphere* 16(1): 108–17.

Zhang, Naiqian, Maohua Wang, and Ning Wang. 2002. "Precision Agriculture—a Worldwide Overview." *Computers and Electronics in Agriculture* 36(2-3): 113–32.

Zhao, Duli, K. Raja Reddy, Vijaya Gopal Kakani, and V. R. Reddy. 2005. "Nitrogen Deficiency Effects on Plant Growth, Leaf Photosynthesis, and Hyperspectral Reflectance Properties of Sorghum." *European Journal of Agronomy* 22(4): 391–403.

Zhao, Yu, Xingan Hu, Wenbin Zheng, and Shuwen Wang. 2017. "Diagnosis Method for Corn Nitrogen Status Measurement Based on Multispectral Imaging." In *In Instrumentation and Measurement Technology Conference (I2MTC)*, IEEE, 2–6.

Zhu, Juanjuan, Nicolas Tremblay, and Yinli Liang. 2011. "A Corn Nitrogen Status Indicator Less Affected by Soil Water Content." *Agronomy Journal* 103(3): 890. https://www.agronomy.org/publications/aj/abstracts/103/3/890 (September 16, 2017).

Zhu, Linqing et al. 2016. "Comparision of Diurnal Temperature Cycle Model and Polynomial Regression Technique in Temporal Normalization of Airborne Land Surface Temperature." *(IGARSS)*, China: IEEE International, 4309–12.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : ____________________

TITLE OF THESIS / PROJECT REPORT :

MULTISPECTRAL REMOTE SENSING FOR NITROGEN FERTILIZER MANAGEMENT IN OIL PALM

NAME OF STUDENT: MOHAMMAD YADEGARI KHOUZANI

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	CONFIDENTIAL	(Contain confidential information under Official Secret Act 1972).
☐	RESTRICTED	(Contains restricted information as specified by the organization/institution where research was done).
☐	OPEN ACCESS	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	PATENT	Embargo from ____________ (date) until ____________ (date)

Approved by:

(Signature of Student)
New IC No/ Passport No.:

Date :

(Signature of Chairman of Supervisory Committee)
Name:

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]