UNIVERSITI PUTRA MALAYSIA

OIL PALM LEAF NUTRIENT ESTIMATION USING OPTICAL SENSORS

KHOSRO KHORRAMNIA

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By

KHOSRO KHORRAMNIA

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

May 2014

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DEDICATION

I dedicate this thesis to my family, especially…

To my beloved wife, *Raziyeh* whose sacrificial care for me and our children, made it possible to complete this work

To my children, *Mohammad Hassan* and *Yekta*, who are indeed treasures from the Lord

To my loving Dad and Mom whose words of encouragement and push for tenacity ring in my ears

To my brother, *Mojtaba* and my sister *Rouhiyeh*, for their endless love, support and encouragement

To my wife's parent and her brothers for their sincere support and encouragement

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

OIL PALM LEAF NUTRIENT ESTIMATION USING OPTICAL SENSORS

By

KHOSRO KHORRAMNIA

May 2014

Chair: Associate Professor Abdul Rashid Bin Mohamed Shariff, PhD

Faculty: Engineering

Leaf sampling and chemical analysis are common practical methods of assessing the nutrient status of an oil palm leaf. The oil palm foliar analysis technique is expensive and does not provide enough information for individual trees and site-specific fertiliser management. We conducted three experiments in the field and the laboratory, using four different optical sensors. Field measurements were performed three different times at the Universiti Putra Malaysia (2.979917° N, 101.7297833° E), at an agricultural park, and at Sime Darby Co. located at (2.8673° N, 101.3674° E) Carey Island, Malaysia. Specific objectives of this research were to: (i) evaluate the performance of various spectral bands and indices for measuring N, P, K, Mg, Ca and B status in oil palm fronds using four available active sensors (GreenSeeker® RT505, SPAD 502 Plus, Multiplex®3 and Spectroradiometer FieldSpec®3, Hi-Res ASDi) under laboratory conditions; (ii) to compare the performance of developed models using various spectral bands and indices for measuring N, P, K, Mg, Ca and B status in oil palm fronds. Four modeling techniques, partial least square, stepwise multiple linear regression, artificial neural network and linear discriminant analysis, applied to training datasets for leaf N, P, K, Mg, Ca and B prediction analysis; and (iii) assess model performance on test datasets by testing the correlation of four models of predicted nutrient results with measured nutrients. The next step in model assessment is to compare the effectiveness of modeling methods using the receiver operating characteristic (ROC) method for oil palm leaf nutrient predictions. At the first and second measurements, only GreenSeeker® and SPAD502 plus were utilized to develop leaf nutrient estimation models, that was not promising. At the third measurement, spectroradiometer and Multiplex®3 were added. Spectral data and indices processed and screened using stepwise multiple linear regressions (SMLR). Then, feature datasets were analysed using artificial neural network (ANN). The maximum accuracies of estimations were N=77%, using spectroradiometer and ANN, P =100%, using spectroradiometer and ANN, K=75%, using Multiplex®3 and ANN, Mg=77%, using Multiplex®3 and ANN, Ca=98%, using Multiplex®3 and ANN and B=91%, using spectroradiometer and ANN. The reliability assessment of

models using ROCs and according to their AUCs values were N= 0.83, P= 1.0, K= 0.84, Mg= 0.80, Ca= 0.95 and B= 0.95. Linear discriminant analysis (LDA) applied to training datasets of screened spectroradiometer and Multiplex®3 by using entire data for discriminant analysis and using stepwise method, to reduce number of independent variables. Among the three different modeling methods, SMLR, neural network and LDA, neural network models gave higher accuracies to estimate leaf nutrient status. In case of designing and fabricating affordable sensors, LDA could be useful method to develop estimation models using indices (as predictors) provided by Multiplex®3, for B. Using neural network method the minimum predictors to estimate B status was 13 indices. In comparison with neural network model, LDA method needs only three Multiplex®3 indices (YF_R, FRF_R and SFR_R) and NDVI. Correctly classified samples for N, P, K, Mg, Ca and B using LDA were 50% (Multiplex®3), 89% (Spectroradiometer), 70%(Multiplex®3), 68%(Multiplex®3), 75% (Spectroradiometer or Multiplex®3) and 80% (Multiplex®3) respectively.

***Keywords*:** Precision agriculture, oil palm, sensors, spectroradiometer, Multiplex, Nutrient status.

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

ANGGARAN NUTRIEN PADA DAUN KELAPA SAWIT MENGGUNAKAN SENSOR OPTIK

Oleh

KHOSRO KHORRAMNIA

May 2014

Pengerusi: Profesor Madya Abdul Rashid Bin Mohamed Shariff, PhD

Fakulti: Kejuruteraan

Cara yang biasa digunakan bagi menentukan kandungan nutrient pada daun kelapa sawit adalah melalui pengambilan sampel daun dan analisis menggunakan bahan kimia. Teknik penganalisaan foliar bukan hanya mahal, malah tidak memberi maklumat yang secukupnya bagi setiap pokok untuk menjalankan pengurusan baja tapak tertentu. Kami telah menjalankan tiga ekspermen di ladang dan makmal dengan menggunakan empat sensor optik yang berbeza. Pengambilan data telah dijalankan di tiga ladang berbeza iaitu diladang Univertiti Putra Malaysia (2.979917° N, 101.7297833° E), Taman Pertanian dan diladang Sime Darby Co. (2.8673° N, 101.3674° E) di Carey Island Malaysia. Objektif penyelidikan ini termasuk (i) penilaian dan perbezaan prestasi pelbagai jalur spectrum dan indeks bagi penentuan kandungan N, P, K, Mg, Ca dan B pada daun kelapa sawit mengunakan empat jenis sensor aktif (GreenSeeker® RT505, SPAD 502 Plus, Multiplex®3 and Spectroradiometer FieldSpec®3, Hi-Res ASDi) di dalam makmal. Empat teknik permodelan termasuk 'partial least square', regrasi linear berganda langkah (SMLR), rangkaian neural buatan (ANN) dan model analisis diskriminan linear (LDA) serta aplikasinya terhadap set data ujian bagi meramal kadar nutrient N, P, K, Mg, Ca dan B; (ii) menilai prestasi model dengan set data ujian dengan menguji korelasi empat model bagi meramalkan keputusan nutrient dengan nutrient yang telah diukur. Langkah seterusnya dalam menilaian prestasi model adalah perbandingan keberkesanan cara permodelan, dengan menggunakan teknik 'receiver operating characteristics' (ROC), bagi meramalkan kadar nutrisi pada daun kelapa sawit. Bagi ukuran pertama dan kedua, hanya GreenSeeker® dan SPAD502 plus digunakan bagi pembangunan model penentuan nutrisi daun, tetapi didapati kurang memuaskan. Maka, pada pengukuran ketiga, spectroradiometer dan Multiplex®3 ditambah, data spectrum dan indeks telah di proses dan ditayangkan menggunakan regrasi linear berganda langkah (SMLR). Kemudiannya, data ciri dianalisa menggunakan rangkaian neural buatan (ANN). Ketepatan maksimum anggaran adalah seperti berikut; N=77% menggunakan spectroradiometer dan ANN, P =100% menggunakan spectroradiometer dan ANN, K=75% menggunakan Multiplex®3 dan ANN,

Mg=77% menggunakan Multiplex®3 dan ANN, Ca=98% menggunakan Multiplex®3 dan ANN, dan B=91% menggunakan spectroradiometer dan ANN. Penilaian kebolehpercayaan model menggunakan ROCs dan mengikut nilai AUCs adalah N= 0.83, P= 1.0, K= 0.84, Mg= 0.80, Ca= 0.95 and B= 0.95. Aplikasi analisis diskriminan linear (LDA) terhadap data latihan menggunakan spectroradiometer dan Multiplex®3 tertapis dengan mengunakan semua data untuk DA dan kaedah langkah demi langkah untuk mengurangkan bilangan pempolehubah bebas. Diantara tiga kaedah model yang berbeza, (SMLR, rnagkaian neural dan LDA) didapati model rangkaian neural yang memberikan ketepatan tertinggi bagi penentuan kadar nutrient didalam daun. Bagi kes mereka bentuk dan mereka-reka sensor berpatutan, LDA boleh menjadi kaedah yang berguna untuk membangunkan model anggaran berdasarkan indeks (sebagai peramal) yang disediakan oleh Multiplex®3, untuk B. Dengan menggunakan kaedah rangkaian neural, peramal minimum untuk menganggarkan status B adalah 13 indeks. Sebaliknya, kaedah LDA memerlukan hanya tiga Multiplex®3indeks (YF_R, FRF_R dan SFR_R) dan NDVI. Sampel betul diklasifikasikan untuk N, P, K, Mg, Ca dan B menggunakan LDA adalah 50% (Multiplex ® 3), 89% (Spectroradiometer), 70% (Multiplex®3), 68% (Multiplex®3), 75% (Spectroradiometer atau Multiplex®3) dan 80% (Multiplex®3), masing-masing.

Kata-kata kunci: Pertanian ketepatan, kelapa sawit, sensor,spectroradiometer, Multiplex, status nutrien.

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I certify that a Thesis Examination Committee has met on 29 May 2014 to conduct the final examination of Khorramnia Khosro on his thesis entitled "Oil Palm Leaf Nutrient Estimation using Optical Sensors" 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 Doctor of Philosophy.

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

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DECLRATION

Declaration By Graduate Student

I hereby confirm that:

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Declaration by Members of Supervisory committee

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