UNIVERSITI PUTRA MALAYSIA

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MD. ABDUL AWAL.

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By

MD. ABDUL AWAL

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

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Dedicated to

My Dear Parents
And
My Beloved Wife & Son

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

IMAGE-BASED MEASUREMENT OF LEAF AREA INDEX ANDRADIATION INTERCEPTION FOR MODELLING OF OIL PALM

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MD. ABDUL AWAL

December 2005

Chairman: Professor Ir. Wan Ishak Wan Ismail, PhD

Faculty: Engineering

Leaf area index (LAI) is an important parameter for precise characterization of the plant canopy structure. LAI describes a fundamental property of the plant canopy that has often been used as a critical variable to simulate the growth and yield models. The present conventional method used in determining LAI is laborious, difficult and time consuming. Thus an image-based measurement using camera system with fish eye lens offers an alternative means for accurate indirect measurement of LAI in oil palm. In this study leaf area index was determined by direct and indirect methods. The LAI-2000 plant canopy analyser (PCA), fish eye lens with charge couple device (CCD) camera and radiation sensor were used as indirect methods. Results show that the LAI value was overestimated (30.8%-153%) for immature palm and underestimated (24%-52%) for mature palm as compared to direct measurement. The LAI-2000 PCA reading varies according to the condition of sky, measuring technique, view cap, height of the measuring point and shade. Four models (leaflet shape factor model, frond area model, leaflet dry weight model and leaflet area model) were tested for accurate estimation of leaf area. Results show that the leaflet dry weight was strongly correlated (r = 0.98) with leaflet area.

Light interception by a canopy is a fundamental requirement for crop growth and important for biomass production and plant growth modelling. In this study, two operational methods for estimating the amount of photosynthetically active radiation intercepted by a canopy of the oil palm were developed, i.e. "Triangular" method and "Circular" method. Results show that both methods were suitable for oil palm PAR measurement. A non-linear relationship was found between radiation interception and LAI. Results show that the radiation interception decreased with increasing distance from the frond base to frond tip.

Hemispherical photography was used in this study to estimate the leaf area index and gap fraction in oil palm plantation. Photographs were taken from different palm ages i.e. 2, 3, 6, 7, 9, 13 and 16-year old after field planting. The average LAI values obtained from photography method were 0.68 to 1.71 for 2 to 16-year old palms. The average LAI value was underestimated as compared to destructive method. The LAI values need to be multiplied by a conversion factor to get the accurate LAI as obtained from the photography method. For palms less than 5-year olds, the photographic method gave the accurate LAI value. The gap fractions obtained from photographic method ranged from 0.51 to 0.18 for palm age range from 2 to 16-year old palms. The gap fraction was linearly correlated (r = 0.99) with leaf area index.

Computer simulation models have become powerful tools to enhance information derived from costly and laborious field experiments. Particularly in oil palms where field experiments are expensive, time consuming and labours intensive. A computer simulation model was developed using Visual C++ computer language for simulation of leaf area index and yield of oil palm. The simulated results were reasonably comparable to the field data for both LAI and yield. The LAI data was collected by field experiment for 2 to16-year old palms, whereas yield data was obtained from Malaysian Palm Oil Board (MPOB). A strong linear relationship was found between the measured LAI and the simulated LAI with correlation coefficient r of 0.96. A good linear relationship (r = 0.95) was found between the simulated LAI and the simulated yield. Also a strong relationship (r = 0.98) was found between the simulated yield and observed yield.

The proposed photographic method for LAI estimation, different regression models, methodology for PAR measurement as well as computer program for LAI and yield simulation have potential application in oil palm sector, oil palm R&D and also as teaching tools.

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

PENGUKURAN INDEK LUAS DAUN DAN INTERSEPSI RADIASI BERPANDUKAN IMEJ UNTUK PERMODELAN KELAPA SAWIT

Oleh

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Indek Luas Daun (ILD) merupakan parameter yang penting dalam menentukan struktur kanopi pada sesuatu pokok. ILD ialah sifat utama dalam daun pokok, banyak digunakan sebagai pembolehubah yang digunakan secara kritikal dalam simulasi permodelan untuk tumbesaran dan hasil pertanian. Kaedah penggunaan ILD secara konvensional masakini adalah adalah tidak sistematik yang beroperasi dengan kos yang tinggi. Dalam kajian ini, ILD ditentukan secara kaedah terus dan tidak langsung. Kaedah tidak langsung yang digunakan dalam pengukuran ILD adalah dengan menggunakan LAI-2000 'Plant Copy Analyser' (PCA), 'Charge Couple Device' (CCD) kamera bersama *fish eye lens* dan sensor radiasi. Pelbagai kaedah optikal digunakan bersama LAI-2000 'Plant Canopy Analyser' (PCA). Keputusan mendapati nilai ILD akan terlebih anggaran (30.8-153%) untuk pokok yang belum matang manakala untuk pokok yang sudah matang nilai ILD adalah dalam nilai anggaran. Anggaran untuk nilai ILD dengan menggunakan perisian PCA adalah diantara 24% hingga 52% berbanding pengukuran secara terus. Pembacaan untuk LAI-2000 PCA berubah-ubah

bergantung kepada keadaan cuaca, teknik pengukuran, pandangan cap (cap review) ketinggian titik pengukuran dan bentuk. Untuk kaedah terus purata indek Laus daun adalah sebanyak 0.69 hingga 4.05 untuk 2 hingga 16 tahun umur pokok kelapa sawit. Bagi kaedah secara tidak langsung ,purata index keluasan daun adalah didapati sebanyak 1.75 hingga 3.05 bagi pokok kelapa sawit berumur 2 hingga 16 tahun. Empat *model* pengukuran (model factor kecerunan daun, model keluasan pelepah, model berat daun kering, model keluasan daun) digunakan dalam menentukan keluasan daun. Keputusan menunjukkan berat daun kering berkait rapat (r = 0.98) dengan keluasan daun.

Pencerapan cahaya oleh pokok adalah penting dalam tumbesaran dan pengeluaran biomass serta pemodelan penumbuhan tanaman. Dalam kajian ini , dua kaedah digunakan dalam penganggaran jumlah *'photosynthetically active radiation' (PAR)* yang diserap oleh pokok kelapa sawit iaitu kaedah 'triangular' dan 'circular'. Keputusan menunjukkan dua kaedah ini sesuai untuk menentukan PAR bagi tanaman kelapa sawit. Hubungan tidak linear didapati diantara pencerapan radiasi dan nilai ILD. Keputusan menunjukkan cerapan radiasi akan berkurangan dengan pertambahan panjang pelepah.

Photography Hemisferical telah digunakan dalam kajian ini untuk menggangar indek luas daun dan pecahan jarak dalam penanaman kelapa sawit. Foto telah diambil dari umur kelapa sawit yang berbeza-beza iaitu 2,3,6,7,9,13 dan 16 tahun selepas penanaman. Purata nilai ILD yang terdapat dalam kaedah foto adalah 0.68 hingga 1.71 untuk pokok kelapa sawit berumur 2 hingga 16 tahun. Purata nilai ILD dalam anggaran seperti yang dibandingkan pada kaedah destructive. Nilai ILD yang diperlukan akan didarabkan dengan factor penukaran 2.14 untuk pokok 5 hingga 9 tahun, 2.33 untuk 10 hingga 14 tahun, dan 2.37 untuk 15 tahun umur pokok kelapa sawit dan untuk mendapatkan nilai ILD yang tepat, kaedah fotografi digunakan. Untuk pokok kelapa sawit dibawah umur 5 tahun, nilai ILD didapati dengan tepat jika kaedah fotografi digunakan. Jarak pecahan diperolehi dari kaedah fotografi dengan nilai dari 0.51, hingga 0.18 bagi pokok kelapa sawit berumur 2-16 tahun. '*Gap fraction'* didapati berhubung terus (r = 0.99) dengan '*leaf area index'*.

Model simulasi komputer merupakan alat terbaik dalam menghasilkan maklumat yang tepat berbanding dengan kaedah eksperimen yang berorientasikan tenagakerja disamping kosnya yang tinggi. Ini terutamanya untuk penggunaan di perladangan kelapa sawit yang memerlukan eksperimen diladang yang mahal, masa yang panjang serta berinsentifkan pekerja. Program bahasa komputer *Visual C++* telah digunakan bagi pembangunan model simulasi komputer untuk pengukuran indek keluasan daun dan penganggaran hasil tanaman kelapa sawit. Hasil simulasi menunjukan data eksperimen antara ILD and hasil pertanian adalah serupa. Maklumat untuk nilai ILD telah diperolehi hasil dari kajian tapak untuk pokok kelapa sawit yang berumur antara 2-16 tahun sementara maklumat untuk hasil petanian telah diperolehi dari maklumat simpanan MPOB. Perhubungan yang kukuh telah diperolehi diantara nilai ILD yang diukur berbanding nilai simulasi ILD dengan pekali korelasi r adalah 0.96. Begitu juga perhubungan yang kukuh didapati diantara nilai simulasi ILD berbanding nilai simulasi hasil pertanian (r = 0.95) dan perhubungan yang kuat (r = 0.98) diperolehi antara simulasi hasil pertanian berbanding nilai hasil pertanian yang diukur.

Penggunaan perisian yang dibangunkan dengan kaedah fotografi ini sesuai digunakan untuk penganggaran nilai ILD, perbezaan model regression, kaedah pengukuran PAR dan simulasi hasil pertanian dan ia mempunyai potensi yang luas dalam penggunaan di sektor perladangan, di sector penyelidikan dan pembangunan kelapa sawit serta sesuai untuk digunakan sebagai alat bantu pengajaran.

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I certify that an Examination Committee met on 15th December 2005 to conduct the final examination of Md. Abdul Awal on his Doctor of Philosophy thesis entitled "Image-Based Measurement of Leaf Area Index and Radiation Interception for Modeling of Oil Palm" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the supervisory committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MD. ABDUL AWAL

Date: 19/02/06

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