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## Measurement of Oil Palm LAI by Manual and LAI-2000 Method\*

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**Abstract:** In this study, accurate Leaf Area Index (LAI) of different palm age groups were determined by manual (direct) method. Optical methods for quantifying variation in LAI of different palm ages were evaluated using LAI-2000 Plant Canopy Analyser (PCA) as an indirect method. In the manual method, LAI values obtained were 0.69, 1.11, 2.38, 2.49, 3.41, 3.83, 4.05 and in the indirect method LAI values obtained were 1.75, 1.4, 1.14, 1.42, 2.87, 1.89, 3.05 for 2, 3, 6, 7, 9, 12 and 16 year old palms, respectively. Results showed that the PCA LAI values were overestimated for immature palms but underestimated for mature palms. The PCA LAI values were overestimated by 30.8-153% for 2 to 3-year old palms and underestimated by 24-52% for beyond 6-year old palms as compared to manual measurement. The relationship between palm age and LAI was also established in this study. A strong linear relationship between direct LAI and palm age was observed with a correlation coefficient,  $R = 0.90$ . However, the relationship between PCA LAI and palm age was weak and not significant. A relationship was observed between PCA LAI and direct LAI with a correlation coefficient of  $R = 0.57$ . The study shows that it was possible to rapidly determine LAI using the LAI-2000 Plant Canopy Analyser. This rapid and non-destructive method saves labour when compared to manual measurements. However, this instrument gave inconsistent of LAI values in respect to oil palm age.

**Key words:** Leaf area index, measurement, plant canopy analyser, manual method, oil palm

## INTRODUCTION

Leaf Area Index (LAI) is one of the most important parameters measured in oil palm physiological studies. It is needed in ecosystem analysis because of the importance of canopy structure in gas, water and carbon and energy exchange. LAI is frequently used for estimating evapotranspiration, net primary productivity and also crop growth model as an important input variable (Sellers *et al.*, 1986). The estimation of LAI and description of the architecture of canopies has been the subject of considerable scientific research involving both experimental and modelling studies (Gardingen *et al.*, 1999). Many direct and indirect methods have been used for measuring the leaf area index. In oil palm, direct methods are time consuming, difficult, laborious and costly. Direct measurement of LAI is only practicable on experimental plots of limited size. Consequently, estimating LAI over large areas is problematic (Gobron *et al.*, 1997).

The plant canopy analyser (PCA) LAI-2000, which is used as an indirect method and LAI obtains on gap fraction at five view angles, is designed to work under diffuse light conditions (Leblan and Chen, 2001). The LAI-2000 has been widely used over a range of plant canopies: coniferous and deciduous species (Gower and Norman, 1991), different pines (Law *et al.*, 2001) and boreal forest in Canada (Chen *et al.*, 1997). Lamade and Setiyo (1996) evaluated the LAI-2000 on oil palms in Indonesia (i.e., 5 and 9 years after field planting) while Roslan *et al.* (2002) evaluated on 5 years old palm in Malaysia.

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Many of these studies showed that the LAI-2000 generally underestimates the LAI from direct measurements. However, indirect LAI measurements are sensitive to a range of external and internal factors such as foliage orientation, measuring time, spatial variation under canopy and weather condition, which often induce errors in the final LAI estimation (Awal *et al.*, 2006). The objectives of this study were i) to determine the LAI of the oil palm by direct and LAI-2000 methods for different ages of the palm and ii) to compare direct and LAI-2000 methods for measuring LAI.

## MATERIALS AND METHODS

### Study Site

Measurements were made at the Malaysian Palm Oil Board (MPOB) research plot in 2004. MPOB is situated about 30 km north from Kuala-Lumpur, Latitude 2° 58' 0.36" N, Longitude 101° 44' 26"E at an average altitude of 66.5 m from sea level. Commercial planting density of 148 palms per hectare and ages of 2, 3, 6, 7, 9, 12 and 16 years old palms were used for this investigation.

### LAI-2000 Plant Canopy Analyzer

The LAI-2000 Plant Canopy Analyser (PCA) is an instrument designed to measure LAI of green canopies (Fig. 1). The instrument's sensor integrates with fisheye optics to project a hemispheric image onto five silicon detectors, arranged in concentric rings. The sensor also contains an optical filter to restrict sensed radiation of wavelengths below 490 nm, in order to minimize the contribution of radiation that has been scattered by foliage (Welles and Norman, 1991).

This five sensors simultaneously measure the PAR light intensities in five concentric Field Of Views (FOVs) centred at zenith angles of 7, 23, 38, 53 and 68°, respectively referred to as PCA Sensors 1, 2, 3, 4 and 5. Usually, below- and above-canopy readings are simultaneously acquired to calculate the canopy gap fraction, which represents the probability of light penetration. Gap fraction values are then converted to contact frequency values that are used for further analysis (LI-COR, 1992). The LAI-2000 potentially views a full 360° of azimuth, which can be restricted by view cap of 270°, 180°, 90° and 45°, attached onto the sensor head to limit sensor view for special purposes (Welles and Norman, 1991).

### Measurement of Leaf Area and LAI

#### Measurement of Leaf Area by Direct Method

LAI derived from improved direct sampling methods was used for verification of LAI data sets obtained from indirect measurements. An experiment was conducted to determine the leaf area index in the field for 2, 3, 7, 9, 12 and 16 years old palms. As a general rule, the leaf chosen is frond 17, near the middle of the crown, which is assumed to be representative of the crown as a whole (Tailliez and Ballo Koffi, 1992). Therefore, Frond 17 was selected from each palm. A total of five fronds were selected and cut from each palm age groups. After cutting, the fronds were brought back the laboratory for analysis as soon as possible in order to prevent shrinkage. Leaflets from one-side of the frond were cut (Fig. 2) and the leaflet area measured using a portable leaf-area meter (LI-3000A, LICOR, USA) in order to determine true leaf area. The one-sided leaflet area was multiplied by two to obtain the total leaflet area of the frond. Leaf area index was then calculated using the Eq. 1.

According to the conventional method, we used the following equation to determine LAI:

$$\text{LAI} = A_f \times F_n \times \text{PDEN}/10,000 \text{ (m}^2 \text{ m}^{-2}\text{)} \quad (1)$$

Where:

$A_f$  = The leaf area per frond (m<sup>2</sup>)

$F_n$  = The number of frond per palm

PDEN = The planting density (number of palms per hectare)

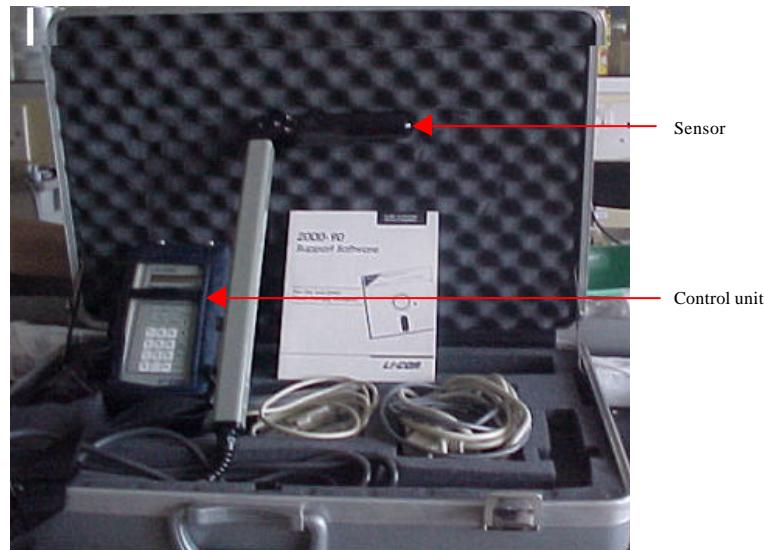


Fig. 1: LAI-2000 plant canopy analyser (LICOR, USA)

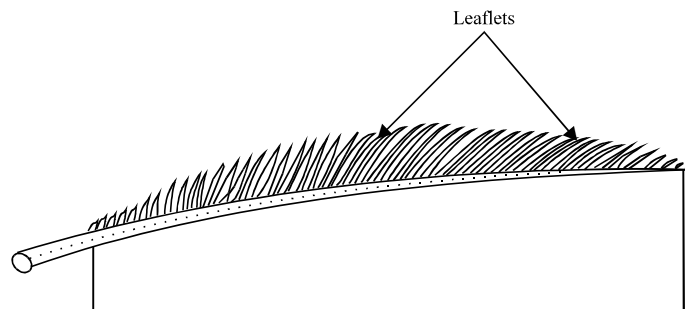


Fig. 2: Leaflet sampled from one side of frond 17

#### LAI Determination Using PCA for Different Palm Age Groups

Six different groups of palm ages (i.e., 2, 3, 7, 9, 12 and 16 year old) were selected for LAI determination by PCA method in the field. Ten locations were selected for each palm age group. Four replications were used to determine the LAI in each age group. The sensor was placed just above the ground level (0 m height from ground) in immature palm (2 and 3 year old palms), whereas one-meter sensor height above the ground was used for mature palm (7, 9, 12 and 16 year old palms). Zigzag method was used for LAI measurement of mature palm age groups (Fig. 3). Four equal measuring points between two adjacent palms were used for zigzag method. The one above and four below method was used for LAI measurement of immature palm age groups. In this method, one above reading and four below reading were taken in North-South and East-West direction (Fig. 4). All PCA LAI-2000 readings were taken with the sensor-facing north at 1.4 meters above ground and with a 180-degree view cap attached. Measurements were taken early in the morning to minimize the direct effect of light on the LAI calculation.

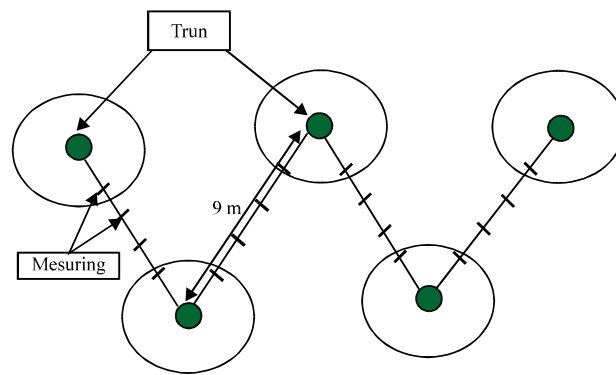


Fig. 3: Designs for taking below canopy reading measurements in mature oil palm

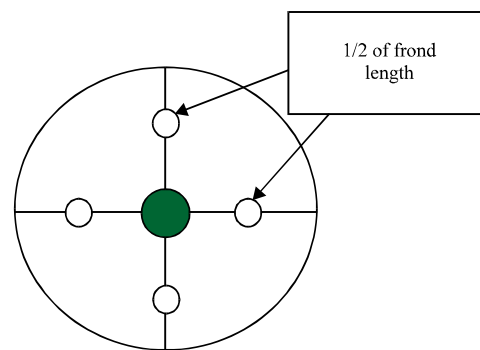


Fig. 4: Designs for taking below canopy reading measurements in immature oil palm

## RESULTS AND DISCUSSION

### LAI Determination for Different Palm Age Groups

#### LAI Determination by Mannal Method

Table 1 shows the average LAI values were lowest for the 2 year old palms, while maximum LAI values were obtained in 16-year old palms. The ranges of the LAI values were 0.57 to 0.79 for the 2-year old palms and 3.12 to 5.02 were for the 16 year old palms, respectively.

Figure 5 shows the linear relationship between direct LAI and palm age. A strong relationship was found between palm age and direct LAI for linear regression analyses ( $R = 0.90$ ). Results indicate a high degree of association ( $R^2 = 0.82$ ) between palm age and true LAI and the standard error of estimation was 0.45. The standard error of estimate of coefficient was 0.037 and the standard error of estimate of constant was 0.01 for linear analyses.

#### LAI Determination by LAI-2000 Method

LAI for oil palm plantation varied with soil fertility, planting density, planting materials and agronomic inputs. However, LAI is expected to vary according to age of palm planting. In this study, PCA LAI was not found to have a linear relationship with palm age (Fig. 6). In immature palms, LAI values were high compared to the mature palm age groups. The range of LAI values in 2-year old palms were 1.591 to 1.922, whereas for the 3 years old palm the range was 1.265 to 1.527 (Table 2).

Table 1: Summary of average LAI values for 2 to 16 year old palms

Palm age (year)	Leaf Area Index (LAI)	95% confidence interval	
		Lower	Upper
2	0.69±0.040	0.570	0.795
3	1.06±0.031	0.977	1.154
6	2.38±0.111	2.076	2.694
7	2.52±0.139	2.137	2.914
9	3.43±0.254	2.730	4.145
12	3.81±0.133	3.441	4.184
16	4.05±0.343	3.121	5.027

Table 2: Summary of PCA LAI values for 2 to 16 year old palms

Palm age (year)	Leaf Area Index (LAI)	95% confidence interval	
		Lower	Upper
2	1.75±0.081	1.591	1.922
3	1.39±0.064	1.265	1.527
6	1.60±0.067	1.468	1.743
7	1.78±0.133	1.512	2.051
9	2.82±0.101	2.615	3.025
12	1.79±0.067	1.660	1.934
16	3.05±0.119	2.798	3.281

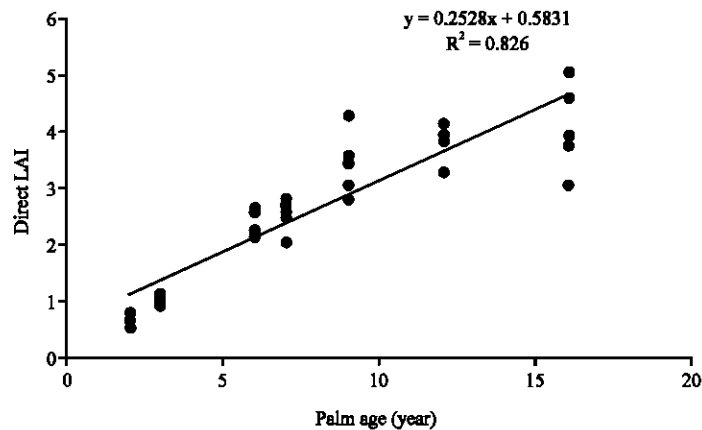


Fig. 5: Relationship between palm age and direct LAI

Maximum LAI values were observed in the 16 year old palms (2.798-3.281). Average LAI value of 9 years old palm was 2.82, whereas for the 12 year old palms the average LAI value was 1.79. This indicates that the LAI-2000 value does not depend on palm age.

Figure 6 shows the linear relationship between indirect LAI and palm age. Results show that the relationship between palm age and indirect LAI was weak and not significant ( $R = 0.52$ ). In oil palm plantations, LAI measurement by LAI-2000 method depends mainly on the density of foliage, arrangement of canopy and height and position of sensor.

**Comparison of LAI from Manual Method and LAI-2000 Method**

Table 3 shows the LAI values for the different palm age groups for the two methods. The measured LAI values using LAI-2000 was higher for immature palm and lower for mature palm compared to manual method. In the 2 year old palms, the indirect LAI value as overestimated by 153% as compared to the manual method. In the 3 year old palms, the indirect LAI value as also

Table 3: Mean LAI values obtained from the manual method and LAI-2000 method

Palm age (year)	LAI	
	Direct method	Indirect (LAI-2000) method
2	0.69	1.75
3	1.06	1.39
6	2.38	1.60
7	2.52	1.78
9	3.43	2.82
12	3.81	1.79
16	4.05	3.05

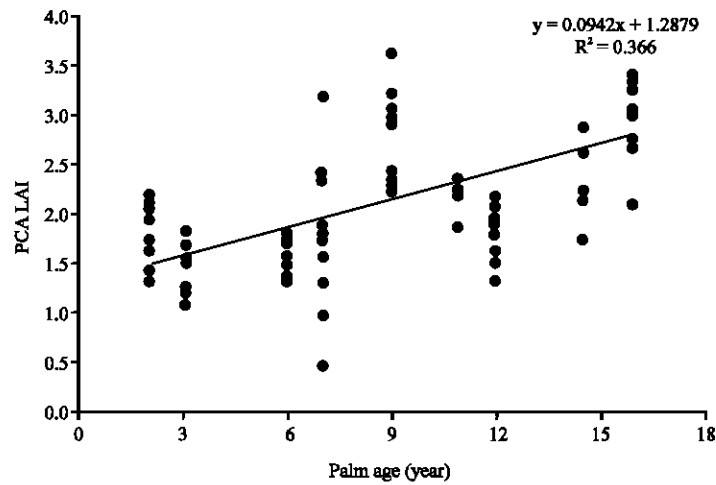


Fig. 6: PCA LAI value against palm age

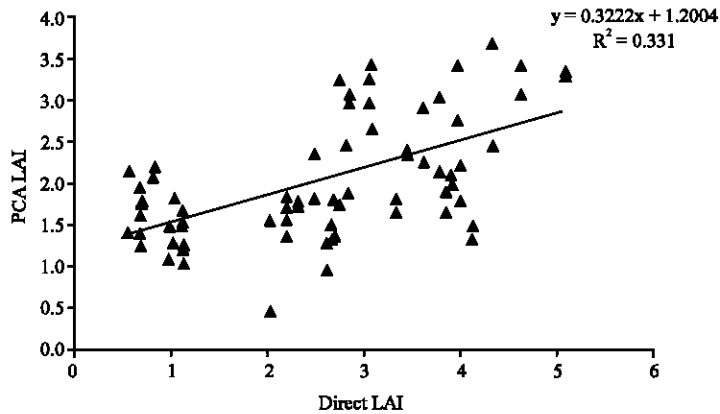


Fig. 7: Relationship between the direct and indirect LAI values

overestimated by about 30.8%. For palm age above six year old, the indirect LAI values were underestimated at about (24-52%) compared to the manual method. Lamade and Setiyo (1996) carried out an experiment on 10 year old palms using the LAI-2000 measurement technique and found that the LAI value was 40% less than the LAI obtained by direct measurement.

Figure 7 shows the relationship between the indirect and direct LAI values for 2 to 16 year old palms. A poor relationship observed with correlation coefficient,  $R = 0.57$  between LAI-2000 method

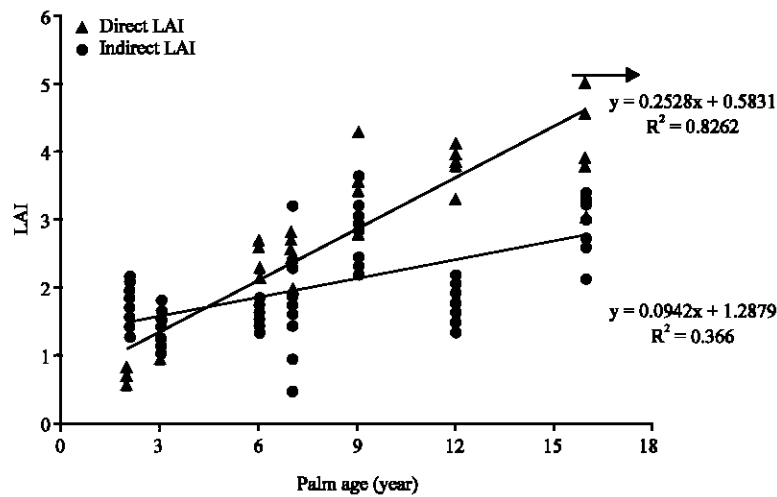


Fig. 8: Relationship between direct and indirect LAI with palm age

and direct method. Figure 8 shows the comparison LAI values for the different palm age groups for the two methods. Results show that in the 2 and 3 year old palms, the indirect LAI value was overestimated as compared to the direct method, while for the palm age above six year old, the indirect LAI values were underestimated as compared to the direct method.

Lamade and Setiyo (1996) carried out an experiment on 10 year old palms using the LAI-2000 measurement technique and found that the LAI value was 40% less than the LAI obtained by direct measurement. Villalobos *et al.* (1995) also carried out study on olive orchards (where leave contribute 91% to the total area) and took measurements of LAI by LAI-2000 PCA and found an underestimation of LAI of around 30%. Chason *et al.* (1991) found an underestimation of the LAI of an oak-hickory forest by about 45%, where a random spatial distribution of leaves was assumed. All of the above study showed that LAI-2000 generally underestimate LAI from direct measurement, which strongly supported present findings.

## CONCLUSIONS

An obvious goal of using indirect techniques to estimate LAI was to compare with manual measurements, which are usually assumed to be more accurate and are typically the standard for comparison. However, manual methods are time consuming, laborious and destructive and often not permitted in oil palm plantation and also not suitable for tall palms. Compared to the manual methods, the LAI-2000 PCA is more rapid, non-destructive and can be used over wide areas and tall palms. The study shows that it was possible to rapidly determine LAI using the LAI-2000 Plant Canopy Analyzer. This rapid and non-destructive method saves labour when compared to manual measurements. The main disadvantage of the LAI-2000 PCA was inconsistency of LAI measurement. The indirect LAI values were underestimated by 45-50% for mature (above 6 year old) palms and overestimated by 153% for immature (2 to 3 year) Palms. In conclusion, LAI-000 PCA could be useful only for measuring relative variation in LAI rather than accurate LAI, where the main objective will be to monitor growth of the palm and LAI variation with season.



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