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Determination of Leaf Area Index for Oil Palm Plantation Using Hemispherical Photography Technique

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ABSTRACT

The present conventional (destructive) 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 an accurate indirect measurement of LAI in oil palm. In this study, a methodology was developed to improve the leaf area index of the oil palm determination using hemispherical photography as an indirect method. A set of true LAI data, collected using the destructive method, were used as a reference to calibrate the LAI measurements obtained by the hemispherical photography. A good relationship (r = 0.85) was found between age of palm and hemispherical photographic LAI. However, the estimated LAI obtained by the hemispherical photographic method was underestimated as compared to the destructive method. Some means of calibration was necessary to determine the relationship between the actual LAI and the hemispherical photographic LAI. It was necessary to multiply the LAI value from 5 years to 16 years, by a clumping factor of 2.14 for 5 to 9 year old palms, 2.33 for 10 to 14-year old palms and 2.37 for above 15-year old palms to calculate the accurate LAI values. For palms which are less than 5 year old (i.e. 2 to 3 years in this study), the photography LAI value was equal to the calculated LAI value. This proposed that correction factors would solve this underestimation effect. In addition, two equations were also proposed to estimate the true LAI from the Photographic LAI for immature and mature oil palm plantation.

Keywords: Oil palm, digital camera, Leaf Area Index, measurement

INTRODUCTION

Leaf area index (LAI) of the oil palm plantation can be described as the ratio of the total leaflet area of the plantation to the total ground area of that plantation. Leaf Area Index (LAI) describes a fundamental property of the oil palm canopy and it is an important index which is related to the growth and metabolism of plant, as well as the accumulation of dry matter and yield (Awal, 2006). A variety of methods have been proposed for ground-based and remote estimation of LAI, and they have led lead to confusion and uncertainty in relation to the selection of methods, experimental design, and instrumentation (Hall, 2003). Destructive methods for the measurement of leaf area index in oil palm plantation are time consuming, difficult, can increase labour cost and are not suitable for tall palms. Several non-destructive methods, which utilize light attenuation through plant canopy to estimate the amount (and in some cases, the orientation of foliage) have been developed (Feldkirchner and Gower, 2001). For optical measurement of the LAI, an indirect method such as the LAI-2000 plant canopy analyzer (LI-COR, USA) is often preferred over

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conventional and laborious destructive methods. However, an increasing number of studies have indicated that the LAI-2000 tends to underestimate the LAI (Stenberg *et al.,* 1994; Nilson, 1999). Hemispherical canopy (fisheye) photography is a technique which has been successfully used under different canopy light regimes in the forest environments to measure the structure of canopy (LAI). This technique has been widely used in crops and forests for more than 40 years. Hill (1924) was the first to design the hemispherical (fisheye) lens to view the whole sky in order to study the formation of clouds. Meanwhile, Evans and Coombe (1959) studied woodland light environments to apply hemispherical photography, and they were probably the first researchers to use this technique for biological purposes. After that, a number of studies (Rich *et al.,* 1993; Easter and Spies, 1994; Breshears *et al*., 1997) have been carried out for the assessment of light environment under forest or plant canopy using hemispherical photography. Among other, Gardingen *et al.* (1999) and Macfarlane *et al.* (2000) successfully used hemispherical photography to estimate the leaf area index of clumped canopies in forest environments. In this study, a fish-eye lens which is incorporated with high pixel digital camera was proposed to be used for estimating LAI in oil palm plantation. Therefore, the main objective of this study was to examine the performance of the new hemispherical photography technique in estimating accurate LAI of oil palm plantation.

MATERIALS AND METHODS

Study Locations

A series of hemispherical canopy photographs were obtained to demonstrate the operation of the system under different amounts of canopy cover and clumping. The first set of images was collected on 15 April 2004 in immature and semi mature (3-year and 6-year) old palms at ENOVECY research plot, Malaysia Palm Oil Board (MPOB), located in Bangi, Kuala Lumpur, Malaysia, whereas the second set of images was collected from the MPOB field plot, located in Bangi Lama (Latitude 2^{o} 58$^{/}$ 0.36$^{//}$ N, Longitude 101^{o} 44$^{/}$ 26$^{//}$ E), at an average altitude of 66.5m from the sea level for both immature and mature palms (2, 9, 12 and 16-year old palms).

Experimental Design

Two types of experimental design were used for the two palm age groups, namely immature palm (age < 5-years) and mature palm (age > 5 years). Single palm photography (i.e. the photographs taken from every palm) was used for immature planting (Plate 3) as the fronds were too small and not overlapping or touching the neighbouring palms frond. As there was no coverage in between the palms, triangular photography method was therefore not applicable for immature plantation. The equilateral triangle photography method (i.e. photographs taken in between three palms) was used for mature planting (Plate 2). Immature oil palms were situated adjacent to the mature oil palm plantings. All the palms were located with the use of the oil palm planting field maps for the study area. A total of six age groups of palms (2, 3, 6, 7, 9, 12, and 16 years) were selected for the investigation. For every age group of oil palm plantation, four plots were selected for the experiment. The minimum plot size was 1.0 hectare. From every plot, 10 palms were selected for photography. An oil palm tree within the plot was randomly selected to minimize the variability of the LAI. Palms with uniform growth were selected to minimize the variation of the results in each plot. In the investigation of this study, planting materials DxP were used for all age groups of palms. *Figs. 1* and *2* illustrate the experimental design for immature and mature oil palm plantations, respectively.

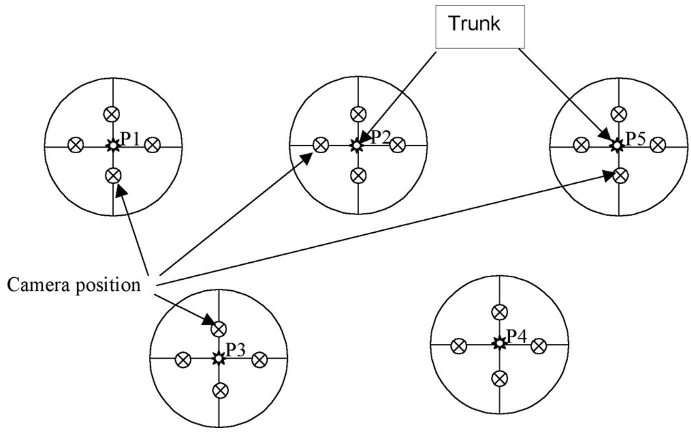

Fig. 1: Experimental design for immature oil palms

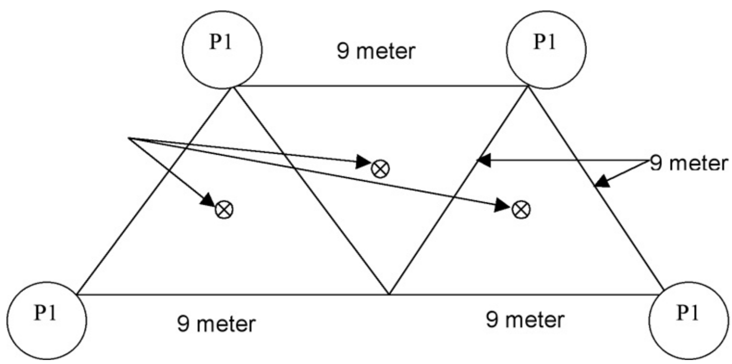

Fig. 2: Experimental design for mature oil palms

Image Acquisition and Analysis

A total of 240 good quality photos with high contrast images were chosen from the field to demonstrate the operation of the system under different amounts of canopy cover and clumping. Two sets of images were taken from two different sites. One set of images was collected in April 2004 at immature oil palm plantation (3-years) and mature oil palm plantation (6-years) at the MPOB research plot in Bangi. Meanwhile, another set of images was collected in May 2004 from the MPOB, UKM Research Station, in Bangi. Sampling locations were chosen to give a range of canopy cover and gap sizes. About 70 to 80 images were captured from each palm age group. Then, 40 best images were selected based on their quality and contrast. It is important to note that sufficient care was taken into consideration when selecting images to ensure that the selected images were free from any kinds of fault.

Images were recorded using a Nikon Coolpix 4500 mega pixel digital camera, (Fuji, Tokyo 100-8331, Japan) with a self-levelling mount and SLM2 type tripod, Delta-T Devices Ltd, UK (Plate 1). All images were taken with a high resolution of 2272 x 1704 pixels. In mature oil

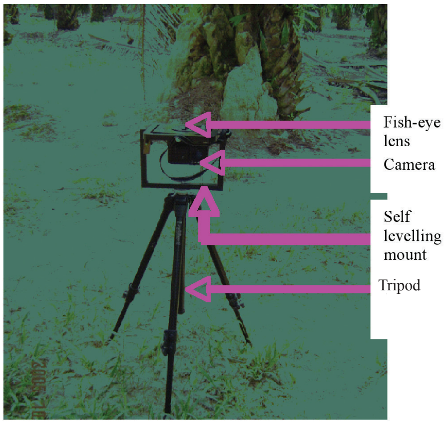

Plate 1

Plate 2

Plate 3

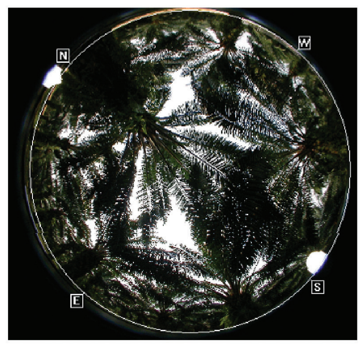

Plate 4

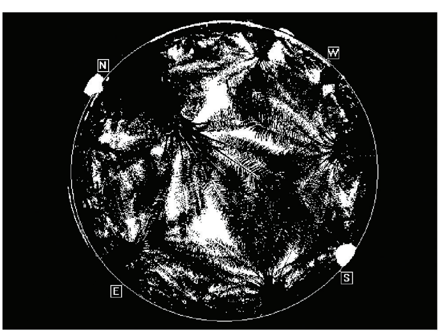

Plate 5

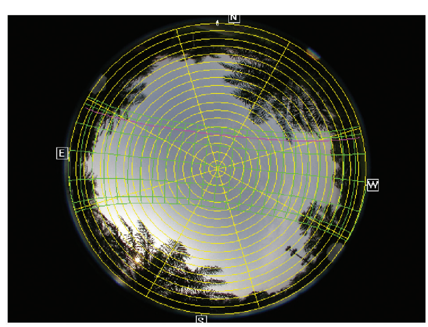

Plate 6

Plate 1: Hemispherical photographic system
Plate 2: Image taken by hemispherical photographics system in mature
Plate 3: Immature oil palm plantation oil palm plantation
Plate 4: Original RGB hemispherical photographics for mature palm
Plate 5: Gray scale (after image processing)
photograph for mature palm
Plate 6: Image processing photograph for mature palm

palm planting, images were taken in the middle position among three adjacent palms, as shown in *Fig. 2*. The camera was set on the tripod at 0.8 meter above the ground level. All images were taken immediately before all the foliage was harvested from the trees for destructive determining of the LAI. In immature oil palm planting, images were captured for each selected palm. Four photographs were taken from each palm oil tree. The self-levelling mount was detached from the tripod before the images were captured. A self-levelling mount with tripod was not used in the immature palm plantation because the lowest fronds of the immature oil palm were situated about 0.2 to 0.4 metre above the ground level. Therefore, the images were captured using the camera with a self-levelling mount which was placed at the ground level. The camera was oriented to magnetic north using integrated compass. Some images were recorded under conditions of diffuse skylight, normally after sunrise or immediately before sunset, and some images were taken in an overcast sky condition. These images were then analysed on a 60 MHz Pentium-IV computer (Dell Computer Corporation, Malaysia) configured with 256 MB RAM. Pictures were analyzed (conversion of the grey image into a binary of 1 bit image) according to a user-defined threshold and LAI calculation using image analysis software Hemi View, (Version 2.1, Delta –T Devices, UK). The LAI was derived from the gap fractions covering zenith angles of 0–90^o. The software was run using Microsoft Windows XP.

RESULTS AND DISCUSSION

Computation of Results

Hemi View software provides a toolbar for a wide range of results calculation. The results of the analysis are the output to a compatible worksheet in Excel 5.0, which can be further analysed within the Hemi View environment. The output obtained from the result of the image analysis are the proportion of visible sky in the sky map sectors, indirect side factor, direct site factors, direct radiation above and below canopy, diffuse radiation above and below canopy, leaf area index, mean leaf angle, etc. The procedures for the computation of results are important task, therefore they require more caution. A wide range of results computation procedures was utilized in this study. All the different oil palm age groups (namely 2, 3, 7, 9, 12, and 16 year) selected in this study were analyzed using the same procedure. Meanwhile, the statistical analysis was performed using the SPSS software, version 11.5. A simple descriptive statistics was also used to characterize the means and standard deviations in the datasets. For this purpose, at least 40 locations were selected from each of the four plots and one photograph was taken for each location. Each photograph was analyzed 4 to 8 times in order to minimize the spatial effects on the results *(Plates 4, 5, and 6)*.

Estimation of LAI by Hemispherical Photography

At least 240 photographs (representing 240 locations) were analyzed for the LAI calculation. Table 1 presents of the results gathered from the statistical analysis performed on the mean LAI. The range of LAI values for the 2 year old palms was 0.59 to 0.76, and this was 1.59 to 1.67 for the 12-year old palms. The maximum average LAI value observed for the 16-year old palms was 1.70, whereas the average LAI values for the 9, 7, and 3 year old palms were 1.59, 1.16 and 1.06, respectively. The largest variation (28%) of mean LAI was observed for the 2 year old palms, while the lowest variation (5%) of mean LAI was detected for the 12 year old palms. These results indicate that the variation of LAI at a particular site, even within a plot, is not dependent on the age of the palms. On the contrary, this variation is usually dependent mainly on the spatial variation of the canopy, physiological vigour of the palm and the management practices. The results also show that the LAI values were underestimated for the mature palm age group,

TABLE 1
Summary of average LAI measured by hemispherical photography

Palm age (Year)	Leaf area index (LAI)	95% Confidence interval	
		Lower	Upper
2	0.680±0.025	0.599	0.761
3	1.065±0.028	0.977	1.154
7	1.161±0.008	1.139	1.184
9	1.594±0.014	1.549	1.636
12	1.635±0.014	1.591	1.679
16	1.710±0.045	1.566	1.854

and this underestimation was closer to that found by Craig *et al*. (2000). As for the immature palm groups, however, the LAI values were found to be the closest to that of the destructive method.

The Relationship between Photographic LAI and Palm Age

Fig. 3 shows the relationship between hemispherical photographic LAI and the age of palm trees. A strong relationship ($R^2 = 0.73$) was found between the age of palm trees and hemispherical photographic LAI through a linear regression analysis. The results indicate a high degree of association ($r = 0.85$) between age of palm and photographic LAI with a standard error of estimation of 0.19. The standard error of estimate of coefficient was 0.01, whereas the standard error of estimate of constant was 0.21 for the linear analysis.

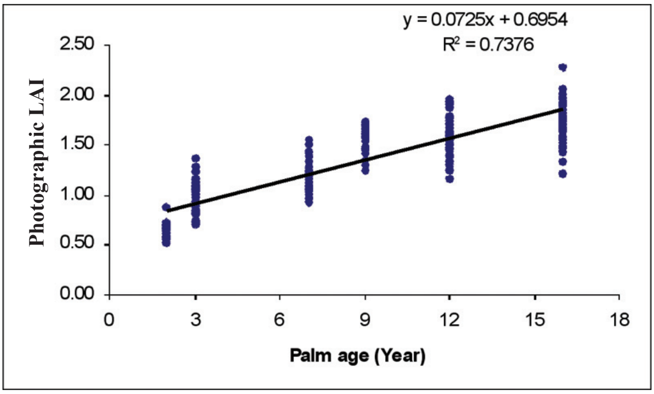

Fig. 3: Relationship between palm age and photographic LAI

A Comparison between Destructive LAI and Photographic LAI

Table 2 shows the LAI values for the different age groups of palms for both the destructive and photographic methods. For the 2 and 3 year old palms, the photographic LAI values were much closer to the true LAI (calculated by the destructive method). The observed photographic LAI values for the immature palms were less than 0.5% underestimated, as compared to the LAI values obtained by the destructive method. As for the mature palm groups (age ranging from six years and above), the photographic LAI values were found to be underestimated when compared to the destructive method.

TABLE 2
LAI values obtained from the destructive method and the photographic method

Palm age (Year)	LAI	
	Destructive method	Photographic method
2	0.69	0.68
3	1.07	1.06
7	2.49	1.16
9	3.41	1.59
12	3.83	1.64
16	4.05	1.71

The Relationship between Photographic LAI and Destructive LAI

The relationship between the photographic LAI and the destructive LAI (obtained using the destructive method) can be established using a linear regression analysis. *Fig. 4* illustrates the relationship between the photographic LAI and destructive LAI for all age groups of palms (i.e. mature and immature). A strong linear relationship was found between the destructive LAI and the photographic LAI using the linear regression analysis. The results show that the data fitted strongly in the linear regression model. The linear regression analysis indicated a high degree of association between the destructive LAI and the photographic LAI with r = 0.93 and a low standard error of estimate of 0.43. Meanwhile, the standard error estimation of coefficient was 0.47. The following equation was proposed for estimating the true LAI from the photographic LAI:

$$LAI_t = 0.2555 * LAI_p + 0.6432 \qquad (1)$$

Where, LAI_t is the true LAI and LAI_p is the photographic LAI obtained using the hemispherical photography. This model could be used to estimate the LAI for both mature and immature palms.

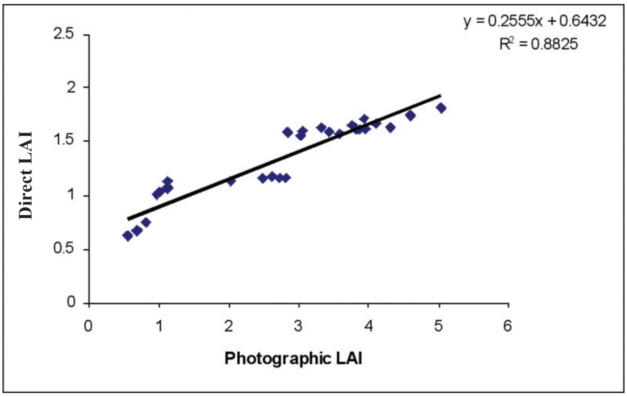

Fig. 4: The relationship between the photographic LAI and the destructive LAI for both mature and immature palms (2 to16 year old palms)

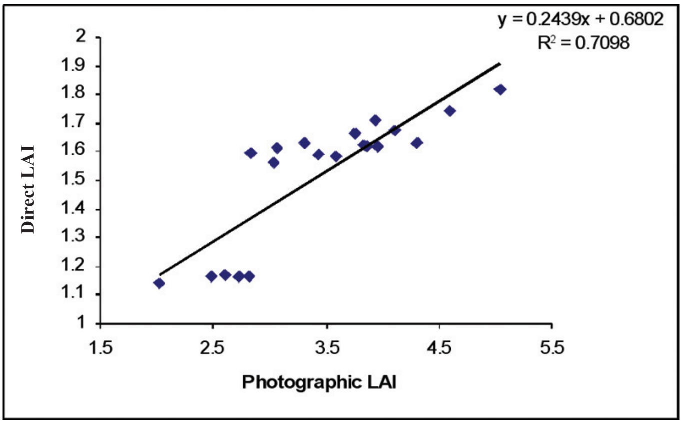

Fig. 5: The relationship between the photographic LAI, and the destructive LAI for mature palms

Fig. 5 shows the relationship between the photographic LAI and the destructive LAI for the mature palm groups (> 6 year old). A strong linear relationship was found between direct LAI and photographic LAI for the mature palms. The results show that the data fitted strongly in a linear regression model. The linear regression analysis indicates a high degree of association between the destructive sampling LAI and the photographic LAI, with r = 0.83 and a low standard error of estimate of 0.18. Meanwhile, the standard error estimation of coefficient was 0.43. Based on this observation, the following equation was proposed to be used in estimating the true LAI from the photographic LAI:

$$LAI_t = 0.2439 * LAI_p + 0.6802 \qquad (2)$$

Where, LAI_t is the true LAI and LAI_p is the photographic LAI obtained by the hemispherical photography. The relationship between the photographic LAI and the destructive LAI was observed as linear with slope of 1:1, implying that the hemispherical photographic method could be useful for estimating the true LAI without calibration. Therefore, the model (Equation 2) is useful for estimating the true LAI for mature palms.

Determination of Correction Factor

As other photographic method of the LAI estimation, hemispherical photography generally gives an underestimation of the LAI values as compared to the destructive method. This underestimation was mainly observed for multiple canopy layers (clumping of the foliage) of oil palms. Thus, it was necessary to determine the correction factor for the true LAI estimation using the hemispherical photographic method. The application of a simple correction factor presumes a linear relationship between the true (destructively estimated) LAI and the indirect estimate of LAI provided by the hemispherical photography. Therefore, linearity between destructive and indirect LAI estimates could be useful, even without knowing the correction factor. Hence, observation on the changes of LAI is more important than knowing the absolute amount of leaf area presents at some specific age of the oil palms in monitoring their growth. The following approach was used to estimate of the correction factor:

$$LAI_t = LAI_p * C_f \tag{3}$$

$$C_f = \frac{LAI_t}{LAI_p} \tag{4}$$

Table 3 presents the numerical calculation of the correction factor for 2 to16 year old palms.

TABLE 3
Factor calculation of the photographic LAI measurement

Palm age (year)	Correction factor
2	1.007299
3	1.004695
7	2.146552
9	2.144654
12	2.335366
16	2.368421

CONCLUSION

LAI has often been used as a critical variable to simulate the growth and yield models, but it is difficult to measure destruction for oil palms. The present conventional method used in determining LAI is rather laborious, difficult and time consuming. Thus, an image-based measurement using a camera system with fish eye lens offers an alternative means for an accurate indirect measurement of LAI in oil palm. In this study, a new methodology was developed to improve the leaf area index of the oil palm determination using the hemispherical photography as an indirect method. A set of the true LAI data, which were collected using the destructive method, were used as a reference to calibrate the LAI measurements obtained by hemispherical photography.

The LAI values obtained by the hemispherical photographic method were underestimated as compared to the destructive method. However, the underestimation was systematic, indicating that some means of calibration were necessary to determine the relationship between the actual LAI and the hemispherical photographic LAI. The proposed correction factors are used to solve this underestimation effect. Once again, the two proposed equations could be used to estimate the true LAI from the photographic LAI. Finally, the hemispherical photographic method can be concluded as a useful tool which can confidently be used to estimate the LAI of oil palms. Moreover, it can also be used to estimate the leaf area index (LAI), apart from being reliable as compared to those which were obtained from other indirect methods.

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