ASSESSMENT OF GAP FRACTION BY HEMISPHERICAL PHOTOGRAPH IN OIL PALM PLANTATION

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Abstract

Gap Fraction is a crucial variable that governs interactions between light and vegetation and requires accurate modelling to predict light climate in the canopy, photosynthetic activity or canopy reflectance. It is the amount of open area within a canopy, which is not blocked by wood and foliage. The conventional method used in determining the gap fraction is laborious, difficult and time consuming. Thus an image-based measurement using a camera system with a fisheye lens offers an alternative means for indirect measurement of the gap fraction in oil palms. In this study, a methodology was developed to assess the gap fraction of the oil palms by hemispherical photography as an indirect method and to find the correlation between the gap fraction and Leaf Area Index (LAI). A total of 240 high quality hemispheric photographs were recorded using a Nikon Coolpix 4,500 mega pixel digital camera, (Fuji, Tokyo 100-8331, Japan) with self-levelling mount and SLM2 type tripod (Delta-T Devices Ltd, UK). The study showed that the gap fraction decreased with an increase in the palm age. The gap fractions obtained from the photographic method ranged from 0.51 to 0.18 for palms ranging from 2 to 16 years old. The gap fraction was strongly correlated (r = 0.99) with the LAI. Results indicate that the LAI was negatively correlated with the logarithm of the gap fraction, that is, where the gap fraction decreased with increasing LAI values. A good relationship (r = 0.85) was also found between the gap fraction and palm age. The hemispherical photographic method seems a useful tool, which can confidently be used to estimate the gap fraction of an oil palm plantation.

Keywords: Oil palm, digital camera, gap fraction, measurement, LAI

Introduction

The amount of open area within a canopy is known as the gap fraction, the fraction of view looking up from beneath the canopy, that is not blocked by wood and foliage. These canopy gaps are important, acting as pathways for rainfall, wind and light to penetrate to the underlying surface (Frank *et al.,* 2005). According to Gardingen *et al.* (1999), gap fraction can be defined in terms of the probability of an infinitely narrow probe intersecting with an element of foliage as it penetrates the canopy with a direction defined by zenith and azimuth angles. Gap fraction is a crucial variable that governs interactions between light and vegetation and requires accurate modelling to predict light climate in the canopy, photosynthetic activity or

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canopy reflectance. Gap fraction is determined by the geometrical structure of the canopy, i.e. a data set describing location, orientation, size and shape of the vegetation elements (Ross, 1981). In the photosynthetically active radiation domain, the strong light absorption by leaf pigments allows the approximation of leaves as black. Therefore, the interception efficiency in the photosynthetically active radiation domain may be derived directly from the gap fraction (Bonhomme *et al*., 1974; Lakso, 1980; Baret *et al*., 1993). The light environment beneath a forest or oil palm canopy is essential to the emergence, establishment, survival and growth of understory trees and plants (Nicotra *et al*., 1999), and it has spatially and temporally intensive variations (Nicotra *et al*., 1999; Kato and Komiyama, 2002). Hence, it is important to identify a simple, rapid, and inexpensive method for measuring and/or estimating the environment.

Hemispherical photographs, also known as fisheye photographs, are inexpensive and effective tools to describe in a quantitative manner the architecture and radiative regime of plant canopies (Chan *et al*., 1986; Rich, 1990; Jonckheere *et al*., 2004; Weiss *et al*., 2004). Among the various indirect techniques applied for the description of canopy structure, hemispherical photography is becoming increasingly popular due to affordable, high-resolution digital cameras and processing software (Frazer *et al*., 2001; Hale and Edwards, 2002). The analysis of a circular image, taken upwards at ground level with a fisheye lens, enables the calculation of the leaf area index by measuring the canopy gap fractions at various angles. Recently, the development of high-speed personal computers and digital photography has made this technique easier, faster and cheaper (Pontailler *et al.,* 2003). A number of researchers have used photographic techniques for characterizing the canopy architecture and estimation of gap fraction (Rich, 1990; Chen *et al*., 1991; Baret *et al*., 1993). In all these studies, the photographic method was successfully used for a variety of canopy types, i.e. forest canopy, and homogenous crop canopy, including sugar beet and wheat crops. Traditionally, these instruments have been utilized in forested environments to monitor ecosystem productivity (Pierce and Running, 1988; Martens *et al.,* 1993; Cutini *et al.,* 1998). Limited research has been done to study gap fractions in oil palm plantations. Ground-based observations of canopy structural parameters, such as the LAI (total surface area of plant leaf divided by ground area), are essential to calibrate remote observation systems based on satellite data (Wang *et al.,* 2004). These parameters directly affect the absorption of photosynthetically active radiation by the canopy, which is the major driver of the primary productivity of terrestrial ecosystems (Chen, 1996; Cescatti and Niinemets, 2004). The canopy gap fraction is essential for indirect calculation of the LAI. In recent years, advances in instrumentation for measuring the gap fraction in plant canopies and the development of gap fraction inversion models, have enabled canopy characteristics to be determined (Campbell, 1986). Gap fraction can be measured by a proportion of incident radiation transmitted through plant canopy at a given zenith angle. It can be also assessed by the proportion of canopy area in a circular image to the total area of the circle at a given zenith angle. More specifically, the gap fraction can be expressed for a given zenith angle α and azimuth angle β by the following relationship:

$$G_{\alpha\beta} = e^{-k_{\alpha\beta}\, LAI/\mu} \qquad (1)$$

where, G is the gap fraction, k is the extinction coefficient of the canopy and μ is cosine of α. The gap fraction measured at each zenith angle is dependent on the amount, spatial distribution, and orientation of the foliage. However, it is also influenced by the instruments used to measure the gap fractions and the techniques used for their analysis (Macfarlane *et al.,* 2000). The objective of this research was to assess the canopy gap fraction and to find the relationship between the LAI and the gap fraction.

Materials and Methods

Study Locations

A series of hemispherical canopy photographs was obtained to demonstrate the operation of the system under different amounts of canopy cover and clumping. The first set of images was collected of immature and mature (3 year and 7 year old palms) at the research plot of the Malaysia Palm Oil Board (MPOB), Bangi, Kuala Lumpur, Malaysia and the second set of images was collected from the MPOB field plot, Bangi Lama (Latitude 2° 58′ 0.36″ N, Longitude 101° 44′ 26″ E) and at an average altitude of 66.5 m from mean sea level) of both immature and mature palms (2, 9, 12, and 16 year old palms).

Experimental Design

Two types of experimental design were used for two types of palm age groups (immature palm, age < 5 years and mature palm, age > 5 years). Single palm photography (photography taken from every palm) was used for immature planting, whereas equilateral triangle photography (photography taken in between three palms) was used for mature planting. The immature oil palms were situated adjacent to the mature oil palm plantings. All palms were located with the use of the oil palm planting field maps for the study area. A total of six age groups of palm (2, 3, 7, 9, 12, and 16 years) were selected for the investigation. For every age group in the oil palm plantations, four plots were selected for the experiment. From every plot, 10 palms were selected for photography. An oil palm tree within the plot was randomly selected to minimize the variability of open canopy. Palms with uniform growth were selected to minimize variation of the results in each plot. In this investigation, planting materials DxP were used for all age groups of palm. Figures 1 and 2 illustrate the experimental design for immature and mature oil palm plantations, respectively.

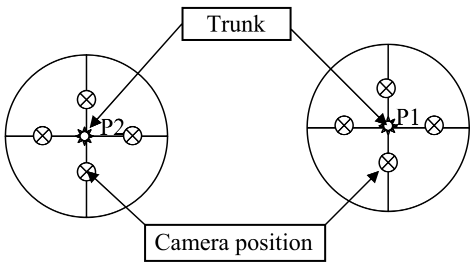

Figure 1. Experimental design for immature oil palms

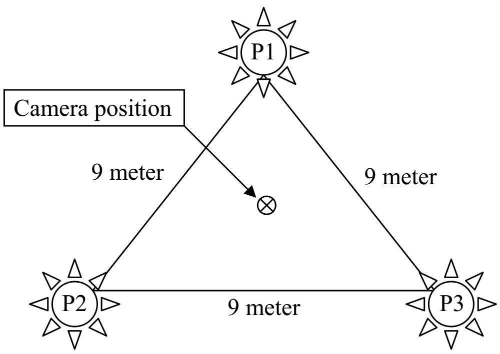

Figure 2. Experimental design for mature oil palms

Image Acquisition and Analysis

A total of 240 good quality, high contrast images were chosen from the fields to demonstrate the operation of the system under different amounts of canopy cover and clumping. Two sets of images were taken from two sites. One set of images was collected on 15th April 2004 in the immature oil palm plantation (3 years) and the mature oil palm plantation (7 years) at the MPOB research plot in Bangi. Another set of images was collected on 20th May 2004 from the MPOB, Universiti Kebangsang Malaysia (UKM), Research Station, 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 the best 40 images were selected based on their quality and contrast. Sufficient care was taken during image selection to ensure that the selected images were free from any kinds of fault.

Images were recorded using a Nikon Coolpix 4,500 mega pixel digital camera, (Fuji, Tokyo 100-8331, Japan) with self-levelling mount and SLM2 type tripod (Delta-T Devices Ltd, UK). All images were taken with a high resolution of 2,272 × 1,704 pixels. In the mature oil palm planting, images were taken in the middle position among three adjacent palms (Figure 2). The camera was set on the tripod at 0.8 m above ground level. All images were taken immediately before all the foliage was harvested from the trees for direct determination of the gap fraction. In the immature oil palm planting, images were captured for each selected palm. Four photographs were taken from each oil palm tree. The self-levelling mount was detached from the tripod before image capture. The tripod was not used in the immature palm plantation, because the lowest fronds of the immature oil palm were situated 0.2 m to 0.4 m above the ground level. Therefore, images were captured by the camera with the self-levelling mount put at ground level. The camera was oriented to magnetic north using an 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. The images were analysed on a 60 MHz Pentium-IV computer (Dell Computer Corporation, Malaysia) configured with 256 MB RAM. Pictures were analyzed (conversion of a grey image into a binary (1 bit) image according to a user-defined threshold and a gap fraction calculation) using Hemi View, Version 2.1 image analysis software (Delta –T Devices, UK). The LAI was derived from the gap fractions covering zenith angles of 0 to 90°. The software was run under Microsoft Windows XP.

Calculation of Gap Fraction

Measurements of the gap fraction depend upon dividing the sky into several sectors and calculating the gap fraction for each sky sector (Figure 3(a) and 3(b)). A gap fraction of zero (0) means the sky is completely blocked (obscured) in the particular sky sector, whereas a gap fraction of one (1) means the sky is completely visible (not obscured).

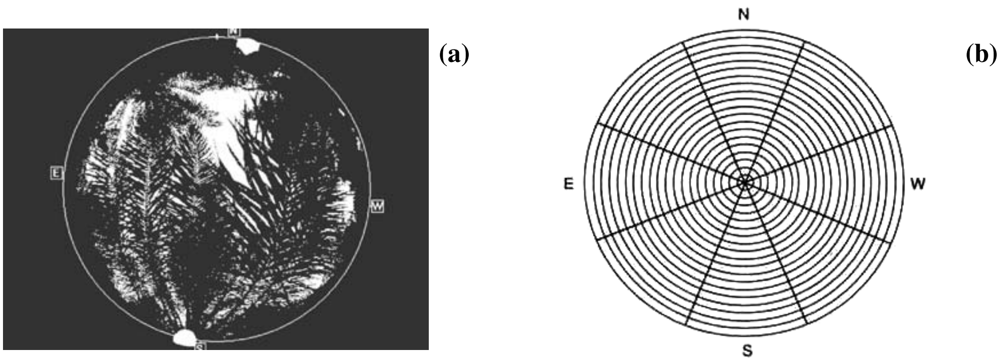

Figure 3. (a) Image with alignment (b) An example of divisions of the sky with 160 sectors, with 20 equal ranges of zenith angles and 8 ranges of azimuth angles

Segmentation of Images

Image segmentation is the process by which a grey image is converted into a binary image with an appropriate threshold. After image classification, the next critical job is to select a suitable threshold value. The Hemi View system provided a ‘Threshold’ toolbar, which can be easily used to select the image threshold. The intensity of the threshold varied from 0 to 256. A threshold intensity of 0 means no vegetation and the image is completely white (or clear), whereas a threshold intensity of 256 means no clear space and the image is completely dark. This means more intensity of threshold is classified as obscured and less intensity of thresholds is classified as visible. So, determination of the threshold is critical and important for image classification. During classification of the image, the threshold value was increased or decreased until the edges of the classified image best matched with the visible or obscured sky edges of the original image (Figure 4(a) and 4(b)). This process was repeated until an appropriate matching between the original and classified image is achieved.

Results and Discussion

Computation of Results

The Hemi View software provided a toolbar for a wide range of results calculations. The results of the analysis are output to a compatible worksheet in Excel 5.0, which can be further analysed within the Hemi View environment. The output of the image analysis results are the proportion of visible sky in sky map sectors, indirect side factor, direct site factors, direct radiation above and below canopy, diffuse radiation above and below canopy, leaf area index, and mean leaf angle etc. The procedures for the results computation are as important task which need more caution. A wide range of the results computation procedure was utilized in this study. All the different oil palm age groups (2, 3, 7, 9, 12, and 16 years) selected in this study were analyzed using the same procedure.Statistical analysis was performed using the SPSS 11.5 software. Simple descriptive statistics were used to characterize the means and standard deviations in the datasets. At least 40 locations were selected from each of four plots and one photograph for each location. Each photograph was analyzed 4 to 8 times in order to minimize the spatial effects on the results.

Estimation of Gap Fraction by Hemispherical Photography

Gap fraction was estimated using an overlay defining the number of annuli (circles) covering the hemispherical image, as shown in Figure 5. The Hemi View system can work with up to ninety annuli (1 degree division). The position of the annuli can be determined by a range of zenith angles from 0° to 90°. Table 1 presents the gap fraction results of six different oil palm age groups. The largest mean gap fraction of 0.508 was observed for the 2 year old palms.

(a) (b)

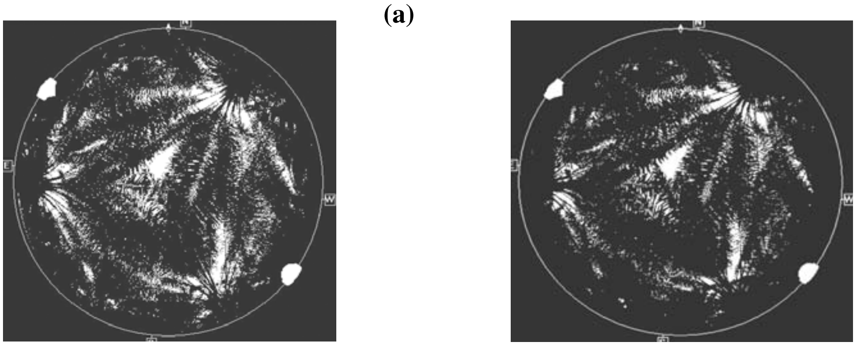

Figure 4. (a) Segmented image with threshold level 110 (b) Segmented image with threshold level 210

Relationship Between Gap Fraction and Palm Age

A good relationship with multiple correlation coefficient, r = 0.90 was found between the gap fraction and the palm age. The relationship between the gap fraction and the palm age was found to be non-linear relationship as illustrated in Figure 6. Results show that the palm age was negatively correlated with the gap fraction, which implies that the gap fraction decreases with increasing palm age. However, variation of the gap fraction depends not only on the palm age but also on the physical shape, pruning practices and planting density of the oil palm.

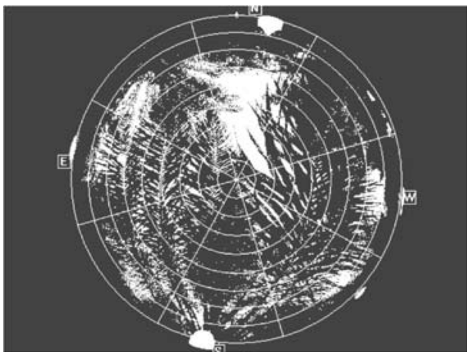

Figure 5. Segmented image analysis with overlay

Relationship Between Gap Fraction and LAI

A good relationship was found between the gap fraction and LAI. The plotted gap fraction and the LAI show a high degree of correlation coefficients (0.98). Figure 7 show that the LAI was negatively correlated with the log of the gap fraction, which implies that the gap fraction decreases with increasing LAI values.

Conclusions

The light environment beneath an oil palm canopy is essential to the emergence, establishment, survival and growth of understory trees and plants. The gap fraction is an important variable, which allows light and rain-fall for the understory crop and also requires accurate modelling to predict light climate in the canopy, photosynthetic activity or canopy reflectance. It is the amount of open area within a canopy, which is not blocked by wood and foliage. The conventional method used in determining the gap fraction is laborious, difficult and time consuming. Thus an image-based measurement using a camera system with a fisheye lens offers an alternative means for indirect measurement of the gap fraction in oil palms. Strong relationships were found between the gap fraction and the LAI and between the gap fraction and the palm age. Results indicate that the LAI was negatively correlated with the logarithm of the gap fraction, that is, where the gap fraction decreased with increasing LAI values. In

Table 1. Average gap fraction measured by hemispherical photography

Palm age	Gap fraction	95% confidence interval	
		Lower	Upper
2	0.509±0.013	0.468	0.510
3	0.348±0.010	0.317	0.379
7	0.316±0.002	0.310	0.323
9	0.208±0.001	0.197	0.204
12	0.208±0.009	0.196	0.208
16	0.187±0.006	0.167	0.206

commercial oil palm plantations using the same planting practice, palms are planted in a triangular method. The gap fraction is strongly azimuth dependent, and it will be different for the same plant structure and foliage amount, but with a different planting pattern. Neverthe-less, a sufficient description of the spatial variation of LAI and leaf angle orientation, or information on leaf distribution appears to be the major requirement for describing the gap fraction in oil palm plantation with a strong row structure.

In an assessment of the gap fraction by the hemispherical photographic method, thresholding is one of the crucial steps in image processing. Thresholding is the process where the image segmentation needs to separate the foreground (canopy) from the background (sky). Some important factors that affect image grey levels are such as camera resolution, lens criteria, gamma correction, and heterogeneity of sky irradiance, etc., and with current thresholding procedures the estimation of the canopy gap fraction is rather uncertain. Both manual and automatic segmentation methods are highly dependent on exposure, operator experience or assumptions of thresholding algorithms. However, hemispherical photography seems to be a useful technique for measuring percentage canopy openness, gap formation and closure, and other physical properties of plant canopies.

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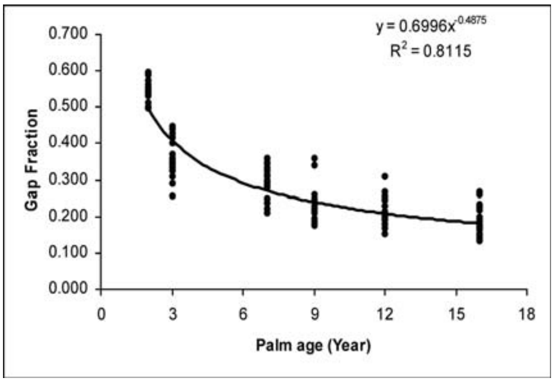

Figure 6. Relationship between gap fraction and palm age

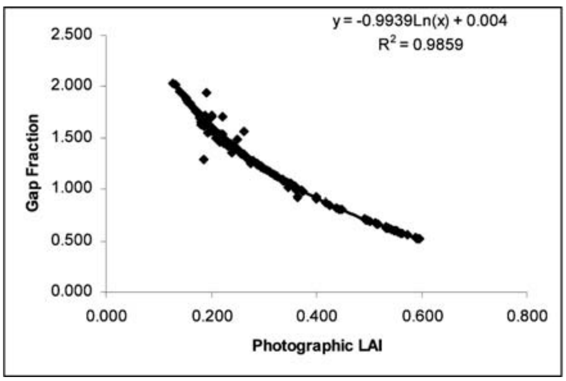

Figure 7. Relationship between gap fraction and photographic LAI

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