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Estimation of Rubber Tree Canopy Structure Using a Photographic Method

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ABSTRACT

It takes a long period before a rubber tree can be tapped for latex. Following the growth and development of the rubber tree canopy is important. A photographic method may be a suitable indirect way to estimate the canopy structure of individual trees from numbered photographs. This study optimized a photographic method to estimate the canopy structure of two-year-old rubber trees. Two plants of clones RRIM 600 and RRIT251 were photographed from four directions. Plant height, diameter, volume and total leaf area of each tree were estimated using a photographic method and were compared to the measured values. Total leaf area was compared with data measured by a leaf area meter (LI-3100). The estimated crown height and leaf area was 6.4 and 0.17% lower than the measured values, respectively. The estimated tree height, diameter and crown volume was 2.7, 10.6 and 9.1% higher than measured values, respectively. The results indicate that under in-field conditions, a photographic method can be used to estimate the canopy structure of individual rubber trees. A set of tools has been developed for ease and accurate measurements of the required camera parameters. This method could be useful to researchers studying the growth and development of the young rubber tree canopy and for other individual trees.

Key words: photographic method, tree analyzer, canopy structure, total leaf area, rubber tree

INTRODUCTION

Rubber is very important from an agricultural, industrial and economic viewpoint amongst others. Rubber is a product from the latex of rubber trees (*Hevea brasiliensis* Muell. Arg.) and the main rubber tree plantations are located in Southeast Asia (Thailand, Malaysia and Indonesia). The rubber tree needs a long growth period before it can be tapped for latex, with the trunk size being an important parameter determining when tapping can commence. If 50-70% of trees have a trunk diameter greater than 50 cm at a height of 1.25 cm above the ground, they can be tapped (Chandrashekar *et al*., 1998). It can take a normal rubber tree six to seven years to reach this critical size, but it can be ten years or more in unsuitable areas (Vijayakumar *et al*.,

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1998). Higher growth and development of young rubber trees may allow tapping to start one or two years earlier (Krishna *et al*., 1991). Growth and development, measured, for example, by the leaf area index has also been reported to affect latex yield (Righi and Bernardes, 2008). Studying growth and development is important to decrease the period until tapping can commence and to promote latex yield. Growth and development can be measured in terms of parameters associated with the canopy structure, such as canopy size, crown volume and leaf area. However, monitoring the canopy structure of a rubber tree is not easy due to the height of the tree. Direct methods, such as the Stratified–Clipping method can provide estimates of profiles of leaf area density but the tree must be destroyed. Litter trap collection (Dufrene and Breda, 1995) is time consuming and cannot be applied to an individual tree. A 3D digitizing technique is an accurate non-destructive method to measure three-dimensional plant canopy structure (Godin *et al*., 1999), but this technique is time and labor consuming, especially in a big tree. Indirect methods, such as gap fraction (Anderson, 1966) and a hemispherical photograph (Bonhomme and Chartier, 1972) cannot be applied to an individual tree. An LAI 2000 canopy analyzer was used to estimated the plant area index (PAI) of individual olive trees, but this method produced a 30% underestimation (Villalobos *et al*., 1995). For indirect tree crown measurement, Brown *et al*. (2000) introduced a method to characterize the crown architecture using vertical hemispherical photography. This method used several vertical hemispherical photographs to determine crown size, crown volume and projected area. Phattaralerphong and Sinoquet (2005) introduced a photographic method that could be used to estimate tree height, crown diameter and crown volume for an individual tree. This method estimates the canopy structure from a set of photographs taken from several directions around the tree, in association with the camera parameters of: camera distance, camera height, camera inclination, camera direction with reference to the tree and focal length of each photograph. The method has been implemented in software named "Tree Analyzer". Phattaralerphong *et al*. (2006) improved the photographic method to estimate leaf area and the vertical profile of a leaf. The method has been tested in the field on olive and rubber trees. It is fast and nondestructive and can be used to estimate several canopy parameters. As such, it seems to be a suitable tool for following the growth and development of a young rubber tree. However, the method has been developed and optimized for a range of species (including the mango, olive, peach, walnut and rubber tree). For application on rubber trees, the method may need to have some parameters optimized and there is also a need for a tool to be developed for ease of application.

This work studied the canopy structures of young rubber trees using a photographic method and compared the quality of estimations with digitized data. A set of tools was introduced for ease of accurate measurements of camera angle, camera direction and camera distance from the tree. The photographic method was also demonstrated under field conditions. The results of this study could be useful for researchers to study the growth and development of the young rubber tree canopy.

MATERIALS AND METHODS

Plant materials

Eight rubber trees cultivar (four trees from each cultivar RRIM600 and RRIT251), were chosen from the germplasm plot at the Surat Thani Rubber Research Center (SRRC), Surat Thani Province, 560 km south of Bangkok, Thailand (9° 40' 24.7" N, 99° 6' 19.94" E). Trees were two-years-old and planted at 3 × 7 m spacing. Photographs of the trees were taken for the estimation of canopy structure and then digitized as described later.

Taking photographs

The photographic method uses a set of photographs of a tree to estimate canopy structure. The method also needs parameters associated with the photograph, that is, camera elevation, camera azimuth around the tree, camera height, distance between the camera and the tree trunk and focal length (Phattaralerphong and Sinoquet, 2005). Each tree was photographed from four directions around the tree and the camera azimuths were recorded using a digital compass. Photographs were taken using a Konica-Minolta DiMAGE A2 with a 2560 × 1920 (5 Megapixel) resolution in JPEG format with an Extra Fine image quality at ISO 200. The camera was placed on a tripod, so the camera parameters could be measured after taking photographs. For fast and accurate measurements, a digital inclinometer (Smart Tool™, M-D Building Products®, USA, measuring range of 0 to 90° accuracy ± 0.1°) was used to measure camera inclinations. Tools were fixed on a ball head that was equipped with a custom-designed holder, with two tubular vial levels and a quick-release camera mount (Figure 1). The compass holder could be turned 360° horizontally, to allow the digital compass to calibrate while sitting on the holder. It also could twist vertically, to allow the digital compass to be leveled before each measurement. For measuring camera height, a laser-leveling tool was used to level the camera position with the trunk and a measuring tape was used to measure the height of camera (at the leveling point) to the tree base (Figure 2). A laser distance meter (Leica DISTO™ A2, Leica Geosystems, Switzerland, measuring range of 0.05 to 60 m, accuracy ±1.5 mm) was used for fast and accurate measurements of the camera distance to the tree trunk. The focal length of the lens for each photograph was automatically stored in EXIF data (Exchangeable Image File format for Digital Still Cameras, Japan Electronic Industry Development Association, JEIDA).

A red cloth (about 3 × 5 m) was used as background for the background separation process. To setup the background, one side of the cloth was tied to a bamboo stick with a rope at each end of the stick. The cloth was pulled up to the top of the canopy supported by two bamboo sticks equipped with pulleys (Figure 3). All photographs were processed manually to the black and white bitmap file format (see Phattaralerphong *et al.*, 2006) using GIMP for Windows Version 2.2.9 (GNU Image Manipulation Program, http://www.gimp.org).

Canopy structure estimation

Processed black and white photographs from the previous step were used to estimate

Figure 1 Ball head equipped with the custom-designed tool holder.

Figure 2 Leveling technique using laser leveling tools.

Figure 3 Setup of red background for photographs.

canopy structure parameters. Tree height, canopy height, canopy width, crown volume, leaf area and the vertical profile of the leaf area for each tree were estimated by the photographic method using Tree Analyser software (Phattaralerphong *et al*., 2006).

Canopy structures: tree height, vegetation height, crown diameter and crown volume, were estimated from sets of four photographs. Four trees were digitized and then each tree was photographed from four directions to estimate the canopy structure using 25 cm × 25 cm × 25 cm voxel size.

Leaf area was estimated from the set of four photographs. Eight trees were each photographed from four directions, then leaf area was measured by removing all leaves and measuring them using a leaf area meter. Leaf area was estimated using 25 cm × 25 cm × 25 cm voxel size. A binomial-law inversion method was used for estimation. Measured mean leaf inclination and average leaf area were used as parameters for four digitized trees and the average value for each cultivar was used for the other four trees. Other parameters in the software were set to default values.

Measurement of canopy structure

Canopy structures were measured after photographs had been taken. Leaf position and orientation were measured using a digitizing technique (Phattaralerphong and Sinoquet, 2005; Phattaralerphong *et al*., 2006). Due to the time and labor required for the digitizing technique, two trees for each cultivar were digitized, (each tree required about 2-3 days of measurement). Tree height, canopy height, canopy width, crown volume and the vertical profile of leaf area for each tree were calculated from the digitized data. Total leaf area of all trees was measured by cutting off all the leaves and measuring them directly with a leaf area meter (LI-3100 Leaf Area Meter; LI-COR(1992)).

RESULTS

Canopy structures

Table 1 shows variations in the rubber tree canopy structure parameters analyzed from digitized data. For the two trees sampled from RRIM600, mean leaf inclination was 28.62 and 27.27, tree height was 4.85 and 4.26 m, crown height was 2.88 and 1.7 m, crown diameter was 2.55 and 1.24 m and crown volumes were 6.45 and 2.16 m^2, respectively. For the two trees sampled from RRIT251, mean leaf inclination was

Table 1 Canopy structure parameters of 3D-digitized rubber trees.

Rubber trees	Mean leaf inclination (degree)	Tree height (m)	Vegetation height (m)	Diameter (m)	Volume (m^3)
RRIM600-1	28.62	4.85	2.88	2.55	6.45
RRIM600-2	27.27	4.26	1.70	1.24	2.16
RRIT251-3	30.23	5.33	2.92	3.72	16.88
RRIT251-4	30.84	3.80	3.25	2.32	5.03

30.23 and 30.84, tree height was 5.33 and 3.8 m, crown height was 2.92 and 3.25 m, crown diameter was 3.72 and 2.32 m and crown volume was 16.88 and 5.03 m^2, respectively.

Table 2 shows the variation in leaf size, leaf area and average leaf area of rubber trees measured by leaf area meter. Average leaf area ranged from 31.72 to 39.03 cm^2 for RRIM600 and 29.4 cm^2 to 43.95 cm^2 for RRIT251; whereas the number of leaflets ranged from 693 to 1564 for RRIM600 and 1203 to 3053 for RRIT251. Total leaf area ranged from 2.2 to 5.03 m^2 for RRIM600 and 4.89 to 12.97 m^2 for RRIT251.

Estimation of canopy structures

Tree height was slightly overestimated by 2.7% (SD=5.7) compared with the measurement values (Figure 4A). Crown height was underestimated by 6.4% (SD=21.4) (Figure 4B). Crown diameter was overestimated by 10.6% (SD=11.1) (Figure 4C). Crown volume was overestimated by 9.1% (SD=23.9) (Figure 4D).

Figure 5 shows the comparison between leaf area estimated by the photographic method and measured by the leaf area meter. The leaf area of all trees was overestimated by 15.7% (ranged from 5.1 to 24.2%).

Figure 6 shows the comparison of the vertical profile of leaf area estimated using the photographic method compared with the digitized data. The vertical profile of leaf area was calculated from four digitized trees using a 25 cm interval. RRIM600 (Figures 6A and 6B) showed a good relationship between estimated and digitized values. The crown heights of both RRIM600 sample trees were slightly lower than the digitized data (Figure 4B). RRIT251 (Figures 6C and 6D) have slightly difference patterns in vertical profile. The crown height of RRIT251 (Figure 6C) was lower than for the digitized data.

Effect of picture zone area

Picture zone area (PZA) is the parameter used to estimate the leaf area in the photographic method. The default PZA used in the photographic method is 17 (Phattaralerphong *et al*., 2006) but this value produced an over estimation of leaf area for all rubber trees. Test results using different PZA values from 10 to 300 are shown in Figure 7. For a PZA value of 10, the overestimation of leaf area ranged from 10 to 30%. With a PZA range of 150 to 270, the estimation of leaf area was ±10%. The error of estimation value for linear regression analysis of the estimated leaf area for PZA values from 60 to 300 showed that a PZA value of 207 gave the best value of estimated leaf area. For eight trees, Figure 8 shows the comparison with measured data of the estimated leaf area using a PZA value of 207. The estimated leaf area of small trees showed a good relationship (R^2=0.9943) with the measured data and the estimated leaf area error ranged from -6.9 to 5.7% (average = 0.17%). The vertical profile of leaf area with a PZA value of 207 also showed better correlation (Figure 9).

Table 2 Leaf parameters of rubber trees measured with a leaf area meter.

Rubber trees	No. of leaflet	Total leaf area(m^2)	Average leaf area(cm^2/leaf)
RRIM600-1	1564	5.03	32.16
RRIM600-2	693	2.20	31.72
RRIM600-3	700	2.73	39.03
RRIM600-4	731	2.47	33.78
RRIT251-1	1216	5.06	41.59
RRIT251-2	1664	4.89	29.40
RRIT251-3	3053	12.97	42.50
RRIT251-4	1203	5.28	43.95

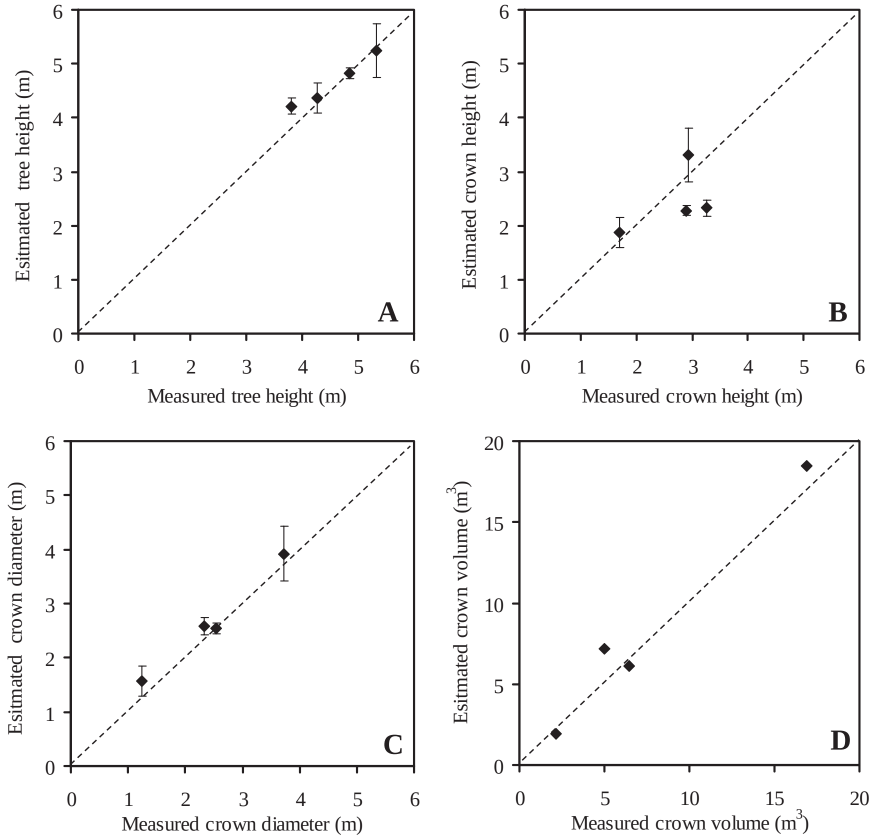

Figure 4 Comparison between canopy parameters of four rubber trees, as determined from 3D-digitizing data and estimated by the photographic method. (A) tree height, (B) crown height, (C) crown diameter from a mean value of N-S and E-W direction and (D) crown volume.

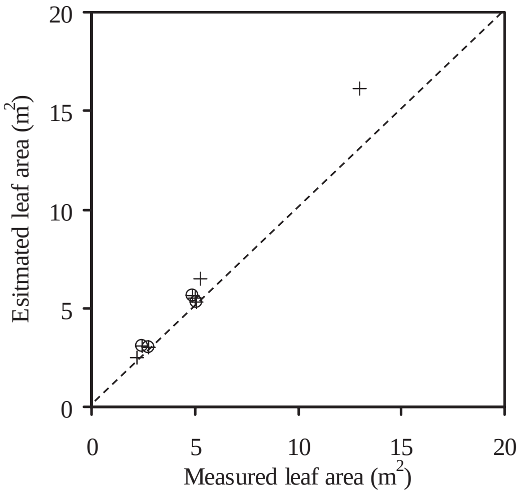

Figure 5 Comparison of the leaf area from eight rubber trees, as measured by leaf area meter (Li-3100) and estimated by the photographic method. (○ and + represent values of RRIM600 and RRIT251, respectively)

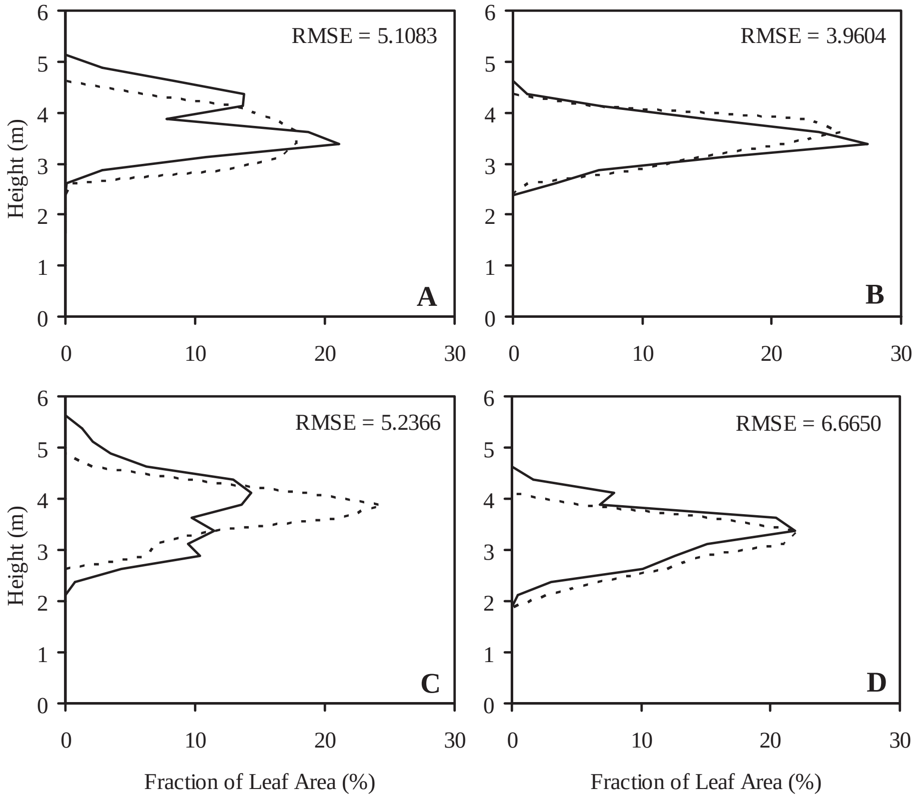

Figure 6 Comparison of a vertical profile of leaf area from four rubber trees, measured from 3D-digitizing data (—) and estimated by the photographic method (—), cultivar RRIM600 (A) and (B), and cultivar RRIT251 (C) and (D).

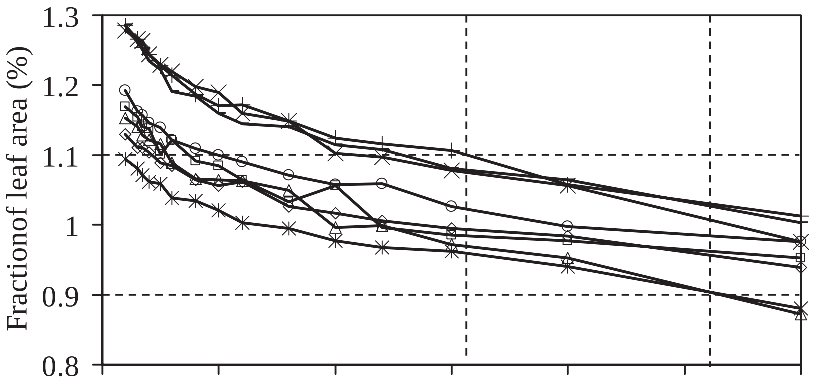

Figure 7 Effect of picture zone area (PZA) on leaf area estimated by a binomial model using eight rubber trees.

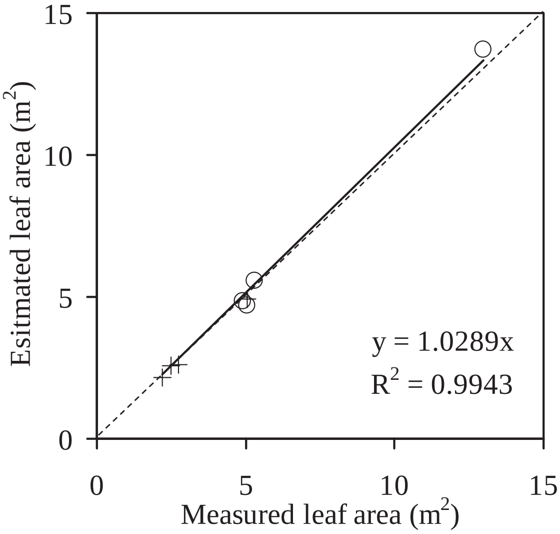

Figure 8 Comparison of leaf area of eight rubber trees, measured from data and estimated from the photographic method using picture zone area (PZA) = 207. (○ and + represent values of RRIM600 and RRIT251, respectively).

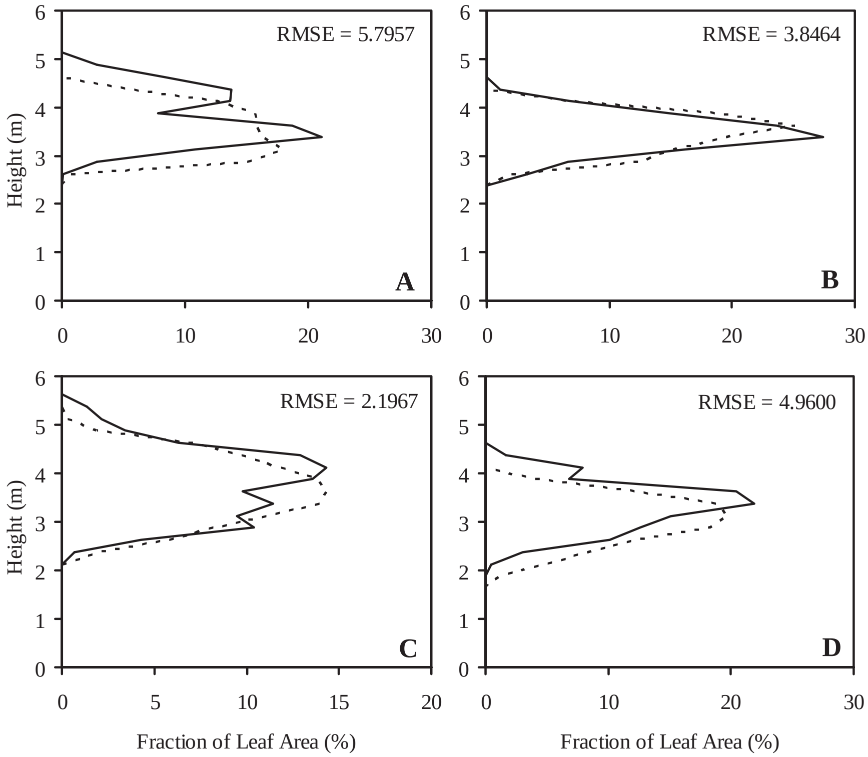

Figure 9 Comparison of the vertical profile of leaf area from four rubber trees, measured from 3D-digitizing data (—) and estimated by the photographic method (—) using picture zone area (PZA) = 207, cultivar RRIM600 (A) and (B), and cultivar RRIT251 (C) and (D).

DISCUSSION

The photographic method can be used to estimate the canopy structure of a rubber tree. Taking photographs using a digital camera equipped with a custom-designed tool holder was convenient. The custom-designed tool holder allowed the user to adjust camera inclination without affecting the camera's horizontal plane. This tool also made the readout of camera inclination and camera direction to the tree trunk more convenient. Taking photographs with the red background possibly helped in the background separation process. The red color gave clear separation of the targeted tree from other trees and objects behind it. The background separation process could be done manually using any photo editing software. The background separation process was still time consuming but this step could be improved. The Tree Analyser software can import and analyze the photographs using the background separation process normally.

Comparing the estimated canopy structures from the photographic method with calculated canopy structures from digitized data, it was found that the estimated tree height, crown height, crown diameter and crown volume were slightly overestimated (Figure 4). The overestimation of tree height and crown height may have been caused by the non-uniformity of the canopy shape (Phattaralerphong and Sinoquet, 2005). It may be due also to the distance of the camera from the tree trunk. If some branches at the top or the bottom of the crown are bent out of the crown and hence mask the real top and bottom points, then the tree height and crown height will be overestimated. The distance of the camera from the trunk also affects the estimation. When photographs are taken too close to the tree, the edge of the crown will mask the real top and bottom point of the canopy. To avoid this error, increasing the distance between the camera and the trunk or changing the direction of the camera can avoid masking in that direction (Phattaralerphong and Sinoquet, 2005).

The overestimation of the crown diameter may have been caused by the shape of the crown and the direction of photographs. When the crown shape was not round, photographs taken from different directions gave different crown diameter values. The overestimation of crown diameter can be reduced by using more photographs from different directions (Phattaralerphong and Sinoquet, 2005). The overestimation of crown volume may have resulted from the overestimation of crown height and crown diameter. The voxel size chosen also affects the estimation of crown volume (Phattaralerphong and Sinoquet, 2005).

Estimation of total leaf area using the photographic method with the default PZA value (PZA=17) produced higher total leaf area than the actual measurement in all rubber trees (Figure 5). The error in estimation of the total leaf area may have been caused by picture discretization, leaf inclination and leaf size, but voxel size does not affect the estimation of total leaf area (Phattaralerphong *et al.*, 2006). In this experiment, leaf inclination and leaf size estimates were derived from actual measurement. The error in the estimation of total leaf area should thus have been caused by the picture discretization. Picture discretization is the size of the picture zones used to compute the gap fraction. Instead of using size of the picture zones directly, Phattaralerphong *et al.* (2006) represented the picture zone area (PZA) as the unit of the zone area compared to the actual leaf area within the canopy. A PZA value equal to 17 was optimized for a wide range of species (mango, olive, walnut and peach). This value gave an overestimate of up to 5% for rubber trees. In this experiment, rubber tree total leaf area also was overestimated, but it ranged from 5.1 to 24.2%. This showed that the default PZA for rubber trees needed to be refined. The results of the current study suggested that a default PZA value of 207 for rubber trees gave an error within ±10% (-6.9 to 5.7% for this experiment).

Vertical profiles of the leaf area of the trees estimated by the photographic method were slightly different (Figure 9); the density of leaf area at each height was different. This error may have occurred when the layer calculated from the digitized data was not at the same starting height of the estimated data. This error also comes from non-uniform leaf distribution within the canopy. The under estimations were also due to the under estimation of tree height and crown height, if photographs were taken only a short distance from the tree trunk. This resulted from taking photographs horizontally to estimate the vertical profile of leaf area. If the tree were tall and the camera too close to the tree, horizontal photographs of the canopy could not be obtained (Phattaralerphong *et al*., 2006). With a non horizontal photograph, the vertical profile is computed with the path of the beam not being horizontal. This will cause the merging of the vertical profile from the layer above or layer under the target layer.

There are some limitations in taking photographs of a rubber tree canopy in the field. Trees near by and trees behind the target tree are always visible in the photograph and this can make background separation difficult to perform. To avoid including the unwanted subjects, an artificial background needs to be inserted in every photograph. Red cloth was chosen to use as a background because of the good contrast it provided. Red can be separated easily from the green color of leaves. To setup a good background behind the tree, the background size should be bigger than the tree canopy. Red cloth can be attached to a stick and pull up to the top of the canopy using two other sticks (Figure 3). With this method, the target tree can be separated from the other trees and objects behind it. The photographic method uses photographs taken from different directions around the tree. These photographs need to be precisely positioned so that: 1) the photograph must be aligned in the horizontal plane, 2) the base of the tree must be aligned to the middle of the photograph and 3) the photograph must contain as much as possible of the canopy area. Using these criteria, the equipment designed for the photographic method should allow the camera to be easily adjusted to the horizontal. This equipment also allows the alignment of the frame to be in the middle of the tree base while taking canopy photographs. For camera inclination and azimuth measurements, the angle meter and compass can be attached to the tripod and move together with the camera. The camera height and distance from the tree trunk should be recorded independently, as the camera is moved around the tree.

All photographs were processed manually using GIMP software for Windows Version 2.2.9 to remove the background and convert the photographs into black and white bitmap files. The red background was removed using the “Select regions by color” tool. This tool selects pixels that contain the nominated color value and allows the user to adjust the range of color depth so that a range of colors will be selected instead of only one color. The red color removal started with a wide range of colors, which was decreased until all red color had been removed, even the very light red color around the leaf edge. Secondly, other tree parts, such as the main stem, main branches and unwanted objects in the photographs were manually removed using the “Eraser” tool. Thirdly, the photographs were converted to “Gray Scale” mode and were “Brightness-Contrast” adjusted until the color of the leaves in the photographs was black and the background was white. Finally, the photographs were converted to black and white (index color conversion) without a dithering option and saved as bitmap files.

The photographic method can be used to estimate tree height, crown height, crown diameter, crown volume, total leaf area and a vertical profile of leaf area of an individual rubber tree. This method can be used to measure different canopy structures in different clones of rubber trees and to assess the growth and development during growth periods.

CONCLUSION

The photographic method was a fast and non-destructive way to measure changes in the canopy structure of individual rubber trees. This method can be used to estimate tree height, crown height, crown diameter, crown volume, total leaf area and the vertical profile of leaf area. Furthermore, this method can be applied using a normal digital camera. The background separation method was still time consuming and needs to be improved.

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