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New Approaches in Estimating Rubberwood Standing Volume Using Airborne Hyperspectral Sensing

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Abstract

This paper focuses on mapping and quantifying the rubberwood plantation's volume by using the UPM-APSB's AISA airborne hyperspectral sensor in Lebuh Silikon, Universiti Putra Malaysia, Serdang, Malaysia. The image and field spectral knowledge of the individual standing rubber tree was obtained by image analysis and field work, respectively. The correlations between the different crown area of rubber trees and the diameter at breast height with the ancillary data were obtained. A supervised classification method based on Spectral Angle Mapper (SAM) and spectral matching knowledge was presented and applied to classify the entire image leading towards an estimation of rubberwood volume for the study area. It shows that the rubberwood volume of an old matured unmanaged rubber plantation can easily be predicted with high accuracy obtained through this approach. A total of 20 rubber tree samples were identified, quantified and mapped representing a standing rubberwood volume of 91.44 m^3 /ha and a mapping accuracy of 89.84%. The study demonstrated that UPM-APSB's AISA airborne hyperspectral sensor is capable of mapping individual rubber trees and estimate the standing ruberwood volume with an acceptable accuracy.

Keywords: Rubber (*Hevea brasilieinsis*), Rubberwood volume, Airborne hyperspectral sensing, Mapping, Universiti Putra Malaysia

1. Introduction

Airborne hyperspectral remote sensing has recently become popular in agricultural resources assessment, planning, management and monitoring in Malaysia (Jusoff and Malek, 2008; Jusoff and Pathan, 2009). The system acquires images from airborne remote sensors, pre-processed data on-board and later the images analysed to provide the necessary information and assessment. It enables spatial and temporal assessment of agricultural land use and cover. It has been successfully used not only for assessment and classification of major agricultural resources, but also for mapping and estimating individual plantation tree crop production such as the oil palm (Jusoff and Pathan, 2009; Jusoff, 2009b, 2009c) and rubber plantations. It is very important in the planning, management and sustainable utilization of these agricultural resources.

Inventory of rubber plantation resources in Malaysia is still in an initial phase of development. Ground inventory is rather accurate, but may be costly in time and resources. Remote sensing alone cannot compete with ground methods in accuracy and scope, but can provide an excellent framework for field inventories and can save on cost. In combination with limited field samples, remote sensing can produce excellent results at a reasonable and competitive price (Jusoff and Malek, 2008). It can be especially useful in the monitoring and analysis of rubber cover changes and timber volume estimation and inventory. It is not easy to apply remote sensing techniques to rubber, especially a wild unmanaged old rubber plantation compared with other plantation crop species. Given that the individual crowns of rubber is often scattered and overlapped throughout the plantation, it might be difficult to separate it from other tree crowns and would require field validation.

Malaysia has now become the centre (and model) for the processing and utilization of rubberwood worldwide. In Peninsular Malaysia, about 2.0 mil.m^3 are utilized by the timber and wood-based industries annually even though about 3.2 mil.m^3 are suitable for conversion into sawn timber. This leaves 1.2 mil.m^3 yet to be exploited for processing into sawn timber. In Malaysia the estimated volume available annually up to the year 2005 is between 8-10 mil.m^3. The available wood volume per hectare is dependent upon numerous factors such as clone, site, management etc. In general between 163-185 m^3 / ha for diameter above 15 cm. is obtained. Usable log volume from 9 cultivars studied has been

estimated to range from 52-162 m^3/ha. Although sawn timber recovery from logs is about 25-45% studies on the 9 cultivars have shown a range from 8.9-27.9 m^3 /ha (Gan *et al.*, 1985). Lacking of complete information of rubberwood plantations had urged more research on getting the accurate data about their timber volume. Estimation of standing timber volume is important to obtain the quantitative amounts of various forest products that are available in pre-harvest (Jusoff, 2007; and Jusoff and Lisa, 2009). Nowadays, sales of timber in Malaysia are based on volume. Most of the information of the rubberwood plantations comes from three sources such as National Forest Inventory (NFI), Post-F Inventory and Special Inventory.

Using airborne hyperspectral imaging gain many advantages such as data collection can be collected on demand with high spatial and spectral resolution, real-times processing of images and GIS ready data (Jusoff and Lisa, 2009; Jusoff and Skidmore, 2009; Jusoff, 2008a; 2008b; 2008c and Jusoff, 2006). Using this technique, one can save the time of monitoring and mapping the crop cover. In addition, it also can be used to estimate the standing timber volume and crown area of the rubber. The objective of this study is therefore to map and estimate the standing rubberwood timber volume in a matured unmanaged rubber plantation in Lebuh Silikon UPM, Selangor.

2. Methods and materials

2.1 Description of study area

Universiti Putra Malaysia's main campus is located in Serdang, Selangor that is approximately 23 km to the south Kuala Lumpur (Figure 1). Serdang Campus covers an area of 1,214 ha and approximately 121 ha are used for administration buildings, lecture halls, student's dormitories, staff housing, sports fields and the rest of the area are used for plantation. The study area is located in Lebuh Silikon, UPM in the state of Selangor Darul Ehsan at latitude 2°59'58"N and longitude 101°43'30"E. The total rubber plantation area of 1 ha was an unmanaged old stand (Figure 2). The climate of Lebuh Silikon, UPM is characterized as humid and hot in the whole year with mean daily temperature of 27° C. The peak temperature could reach 32.3° C and the lowest at 21° C. The hot and humid climate of Lebuh Silikon, UPM is accompanied by an average rainfall of 2,500 mm per annum with the highest of 290 mm per month and the lowest at 130 mm per month. The humidity level is constant at 80% throughout the year.

2.2 Equipments and software

UPM-APSB'S AISA airborne hyperspectral system is a commercial hyperspectral sensor product (15 kg in total weight), a complete push-broom system, consisting of a hyperspectral sensor head, miniature Global Position System (GPS) sensor, and data acquisition unit in a rugged PC with display unit and power supply, operated by Tropical Forest Airborne Observatory (TropAIR)/Forest Geospatial Information & Survey Lab in collaboration with Aeroscan Precision (M) Sdn. Bhd. in Block C3, UPM-MTDC Tech Centre, Lebuh Silikon, Universiti Putra Malaysia. It is a proven hyperspectral system that has been designed to collect accurate and reliable information of the earth surface (Jusoff, 2008a; 2008b; 2008c; 2009a; 2009b; 2009c; Jusoff and Norsuzila, 2008). It is quick to install and remove from any aircraft and provide timely, accurate and reliable information. The systems include an in-flight configuration setting, which allows alterations to be made easily for each exercise. Auxiliary components include a mount to connect the sensor head to the GPS or INS unit, regulated power supply and CaliGeo post-processing software that produces calibrated geo-referenced images and image mosaics of the acquired data with an ENVI header. It is a ready-to-use system to produce radiometrically calibrated and geo-referenced hyperspectral data and measures up to 244 bands of contiguous visible and IR wavelengths at up to 100 images. UPM-APSB's AISA is capable of collecting data within a spectral range of 430 to 900 nm. Although UPM-APSB's AISA is capable of collecting up to 286 spectral channels within this range, the data rate associated with the short integration times (sampling rates) required of the sensor in most operational or flight modes, limits the number of channels. The operational collection configuration used for this study is 20 spectral bands depending on the aircraft speed, altitude and mission goals.

Hyperspectral image of the rubber plantation was acquired using UPM-APSB's AISA hyperspectral sensor. The sensor was flown at an altitude of 1000 m from the ground at a spatial resolution of 1.0 m. The aircraft flying speed was 120 knots or 60 ms^{-1}. The entire image capturing process was taken by the Aeroscan Precision (M) Sendirian Berhad (APSB) which is located at the Tropical Forest Airborne Observatory (TropAIR)/Forest Geospatial Information and Survey Lab, Block C3, UPM-MTDC Tech Centre, Lebuh Silikon, UPM. Image pre-processing was done on-board automatically with the Caligeo software to increase the accuracy and the interpretability of the image prior to image classification. This process involves correcting images to reduce the magnitude of unwanted effects to improve the quality of the image data for subsequent processing in addition to correct for sensor and platform-specific radiometric and geometric distortions of data (Jusoff, 2007). Image enhancement using the contrast and optimum band combinations were later performed using ENVI 4.2 to edit the original image data to increase the amount of information for visually interpreted data to create a "new" image. In order to automatically extract the individual species pixels, the spectral signatures of the individual tree species must be analysed and pixels were then assigned to categories based on similar spectral signatures. A supervised classification using Spectral Angle Mapper (SAM) was finally applied to separate the end members for each tree crown species and later verified on the ground by the field survey team members from Aeroscan

Precision (M) Sdn Bhd using a handheld Global Positioning System (GPS). The supervised classification was done using the Spectral Angle Mapper (SAM), which is a physically-based spectral classification that uses an n-dimensional angle to match pixels to reference spectra. The end-member of the tree crowns were derived from the archived spectral library, which were collected during the ground sampling using a handheld spectroradiometer. The radian used in this study was 0.10, which is the most suitable radian to classify the species-species crowns of trees in the study area. A post classification using the Clump Classes was used to clump adjacent similar classified pixels together using morphological operators. The selected classes were then clumped together by first performing a dilate operation following by erode operation on the classified image using a kernel of the size specified in the parameters dialog. Sieve classes removed isolated classified pixels in classification image using blob grouping. The sieve classes at the neighboring 4 or 8 pixels were to determine that the pixel is grouped with pixels of the same class. The number of pixels in a class that were grouped less than the neighboring pixels value was removed away from the class. For the purpose of mapping accuracy assessment, a ground verification plot of 0.25 ha in size at latitudes $2^{o}59'58.17"$N and $3^{o}00'00.25"$N, and longitudes $101^{o}43'29.16"$E and $101^{o}43'31.91"$E was chosen. The mapping accuracy was calculated using following formula:

$$\% \text{ of Accuracy} = 100\% - \text{error}\%$$

$$= 100\% - \frac{\text{Average of the differences between crown size}}{\text{Average of crown size for each tree at ground truth}} \times 100$$

Finally, an output thematic map of individual rubber tree crowns in UPM Lebuh Silikon was developed. It can be used to estimate the rubberwood standing volume in Lebuh Silikon, UPM and the future sivilcultural prescription to manage the stand for better productivity. This information will definitely aid the rubberwood pre-harvest estimation based industry in Malaysia and elsewhere.

3. Results and discussion

Sobel edge detection filter showed the best effect on the image in detecting edges of canopy of *Hevea brasiliensis* compared to other convolution and morphology filter. The tree crown image (Figure 3) of rubber plantations in the study area was selected randomly from the image to estimate the crown area. Table 1 showed the result of the individual tree crowns of rubber plantation from the image using the ENVI 4.2 software.

Spectral reflectance of *H. brasiliensis* in the study area was selected randomly from the image to check the curve of spectral reflectance. This step was done to confirm the classes that have been mapped out were belonged to the *H. brasiliensis*. Figure 4 showed several similar spectral reflectances of *H. brasiliensis*. Since the pattern and curve of spectral reflectances were almost the same, the spectral reflectances were therefore being concluded to belong to the same species. However, the value of spectral library plots had a different range between 800 – 1000 due to the condition of the age and stress levels of the rubber's leaves. The differences of colour (red, green and yellow) in image were perhaps due to factors of age, healthy or disease affected trees.

In the ground verification, 20 of *H. brasiliensis* were selected for the sample. Ground verification was conducted on 26 March 2007 to define the relationship between the *H. brasiliensis* canopies against their respective rubberwood volumes. Tree diameter, height and crown diameter were measured and data collected were recorded. The rubberwood volume and rubber canopies of all the sampled trees were calculated. Table 2 showed the data collected during the ground verification. From the ground verification data, the calculations of height, basal area, volume, and canopy are shown as below:

$$\text{Height} = (\tan \text{up} + \tan \text{down}) * \text{distance}$$
$$= (\tan 55^{o} + \tan 3^{o}) * 15 \text{ m}$$
$$= 22.21 \text{ m}$$

$$\text{Basal Area} = \pi (\text{DBH})^2 / 4$$
$$= \pi (0.356)^2 / 4$$
$$= 0.0995 \text{ m}^2$$

$$\text{Volume} = \text{Height} * \text{Basal Area}$$
$$= 22.21 \text{ m} * 0.0995 \text{ m}^2$$
$$= 2.21 \text{ m}^3$$

$$\text{Canopy} = \pi (\text{Crown Diameter})^2 / 4$$
$$= \pi (12.4)^2 / 4$$
$$= 121 \text{ m}^2$$

Table 2 showed the result of crown area from the image and crown area from the ground verification. The mapping accuracy of this study was 89.84% as calculated below:

$$\% \text{ of Accuracy} = 100\% - \text{error}\%$$

$$= 100\% - \frac{\text{Average of the differences between crown size}}{\text{Average of crown size for each tree at ground truth}} \times 100$$

$$= 100\% - \frac{(162 / 20)}{(1594 / 20)} \times 100$$

$$= 100\% - 10.16\%$$

$$= 89.84\%$$

The mapping accuracy seems to be reasonably accurate and acceptable (over 80%) probably due to the capability of such sensor's spatial resolutions to map rubber canopy in the study area. However, some differences between image and ground measurement exist in this study. Crown size measured on the airborne images are more clearly defined than those measured on the ground, even though crown size measured on the hyperspectral images are smaller than those measured on the ground. This is due to some parts of the overlapping crowns are not resolved on the image. Nevertheless, the airborne hyperspectral sensor measurement is probably a better measure of the functional growing space of a tree and is better correlated with tree and stand volume. Figure 5 showed the relationship between crown area and volume of all the 20 sampled *H. brasiliensis*. The x-axis is crown area (m^2) units and y-axis is timber volume (m^3) units. The equation for regression between crown area and volume is $y = 0.0147x$ with $R^2 = 0.64$. The crown area was increasing proportionally to the volume, and *vice versa*. The estimated standing timber volume of rubber plantations in Lebuh Silikon, UPM was 91.44 m^3 / ha. The calculations are shown as below:

$$\text{Volume/ha} = \frac{\text{Total Timber Volume}}{\text{Total Area}}$$

$$= 22.86 \text{ m}^3 / 0.25 \text{ ha}$$

$$= 91.44 \text{ m}^3 / \text{ha}$$

4. Conclusions

It can be concluded from the study that the UPM-APSB's AISA airborne hyperspectral sensor is capable of quantifying and mapping the individual crowns of the rubber trees with an accuracy of 89.84%. The estimated standing timber volume of rubber plantations in the study area was 91.44 m^3 /ha. It is highly recommended that future work should be tested with a higher spatial resolution image of below 1 m^2 to improve the accuracy of mapping and the tree crown area-volume relationship estimates.

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Table 1. The GPS locations and crown size measurement of the individual *H. brasiliensis* based from the UPM-AOSB's AISA data

Crown No	Latitude	Longitude	Crown Size (m^2)
1	2°59'58.45"	101°43'31.59"	133
2	2°59'58.68"	101°43'31.26"	69
3	2°59'59.11"	101°43'31.36"	99
4	2°59'59.46"	101°43'31.36"	95
5	2°59'59.73"	101°43'30.52"	78
6	3°00'00.08"	101°43'31.66"	112
7	2°59'59.33"	101°43'31.65"	80
8	2°59'58.75"	101°43'31.75"	79
9	2°59'59.07"	101°43'31.04"	121
10	2°59'59.40"	101°43'30.72"	103
11	3°00'00.14"	101°43'29.65"	85
12	2°59'59.73"	101°43'30.17"	81
13	2°59'59.14"	101°43'29.94"	70
14	2°59'59.37"	101°43'29.49"	81
15	3°00'00.05"	101°43'29.33"	92
16	2°59'58.62"	101°43'29.32"	82
17	2°59'58.30"	101°43'29.32"	57
18	2°59'58.26"	101°43'30.49"	55
19	3°00'00.11"	101°43'31.07"	105
20	2°59'59.72"	101°43'30.94"	59

Table 2. GPS readings and crown size variations between image and ground truth

No.	Latitude	Longitude	Crown Size (Image) (m^2)	Crown Size (Ground Truth) (m^2)	Differences Crown Size (m^2)
1	2°59’58.45”	101°43’31.59”	133	121	12
2	2°59’58.68”	101°43’31.26”	69	64	5
3	2°59’59.11”	101°43’31.36”	99	100	1
4	2°59’59.46”	101°43’31.36”	95	83	12
5	2°59’59.73”	101°43’30.52”	78	72	6
6	3°00’00.08”	101°43’31.66”	112	104	8
7	2°59’59.33”	101°43’31.65”	80	75	5
8	2°59’58.75”	101°43’31.75”	79	68	11
9	2°59’59.07”	101°43’31.04”	121	109	12
10	2°59’59.40”	101°43’30.72”	103	95	8
11	3°00’00.14”	101°43’29.65”	85	74	11
12	2°59’59.73”	101°43’30.17”	81	72	9
13	2°59’59.14”	101°43’29.94”	70	66	4
14	2°59’59.37”	101°43’29.49”	81	69	12
15	3°00’00.05”	101°43’29.33”	92	95	3
16	2°59’58.62”	101°43’29.32”	82	88	6
17	2°59’58.30”	101°43’29.32”	57	50	7
18	2°59’58.26”	101°43’30.49”	55	48	7
19	3°00’00.11”	101°43’31.07”	105	88	17
20	2°59’59.72”	101°43’30.94”	59	53	6
Total				1594	162

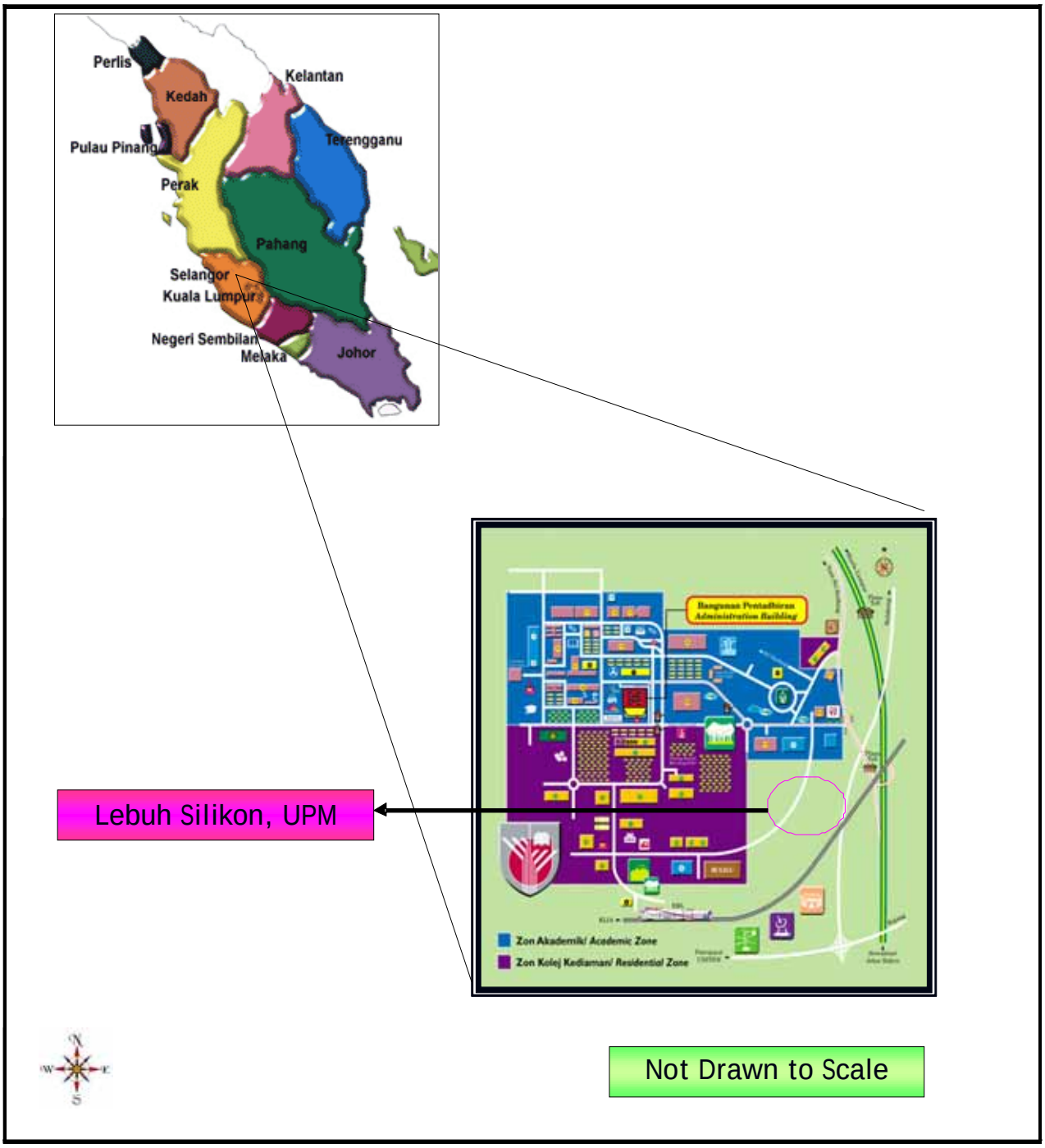

Figure 1. A map of Peninsular Malaysia showing the study area

Figure 2. The unmanaged old rubber plantation under study

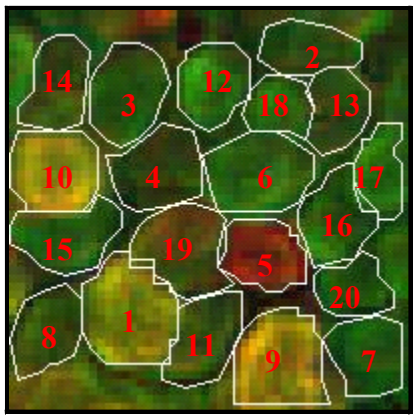

Figure 3. Tree crown image delineation of rubber plantations, Lebuh Silikon

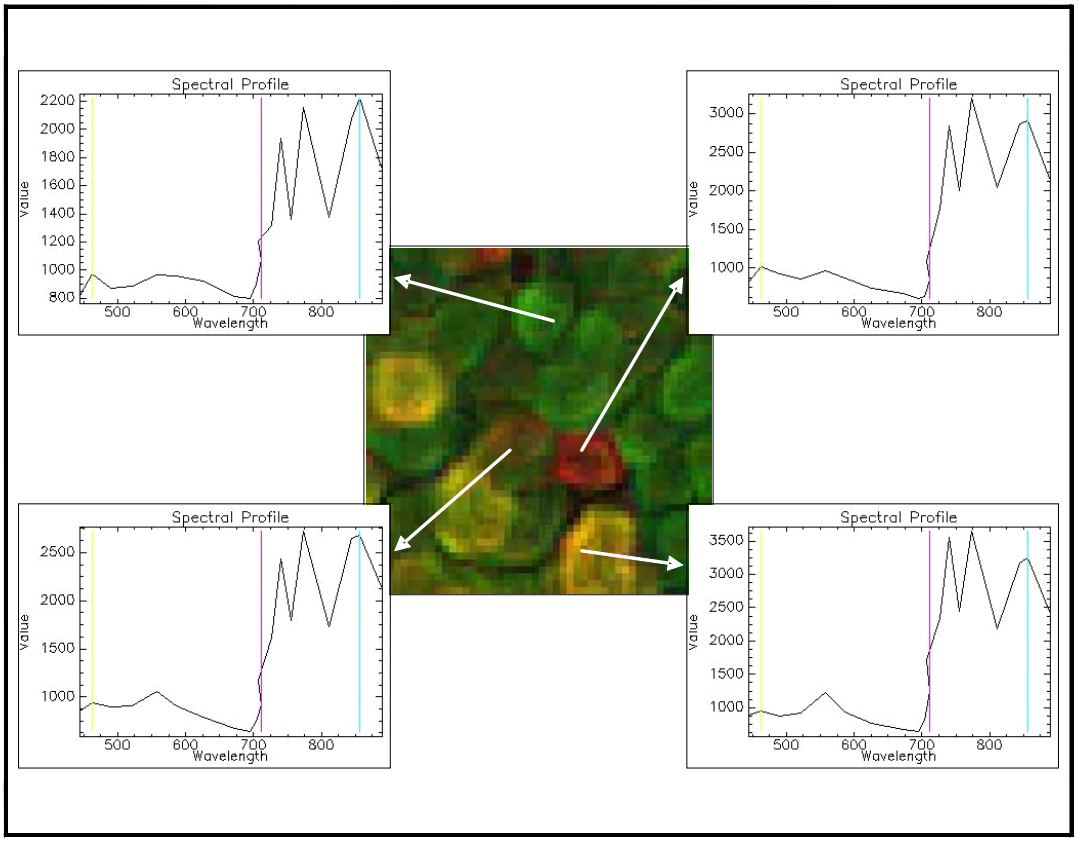

Figure 4. Spectral reflectance of *H. brasiliensis* in study area

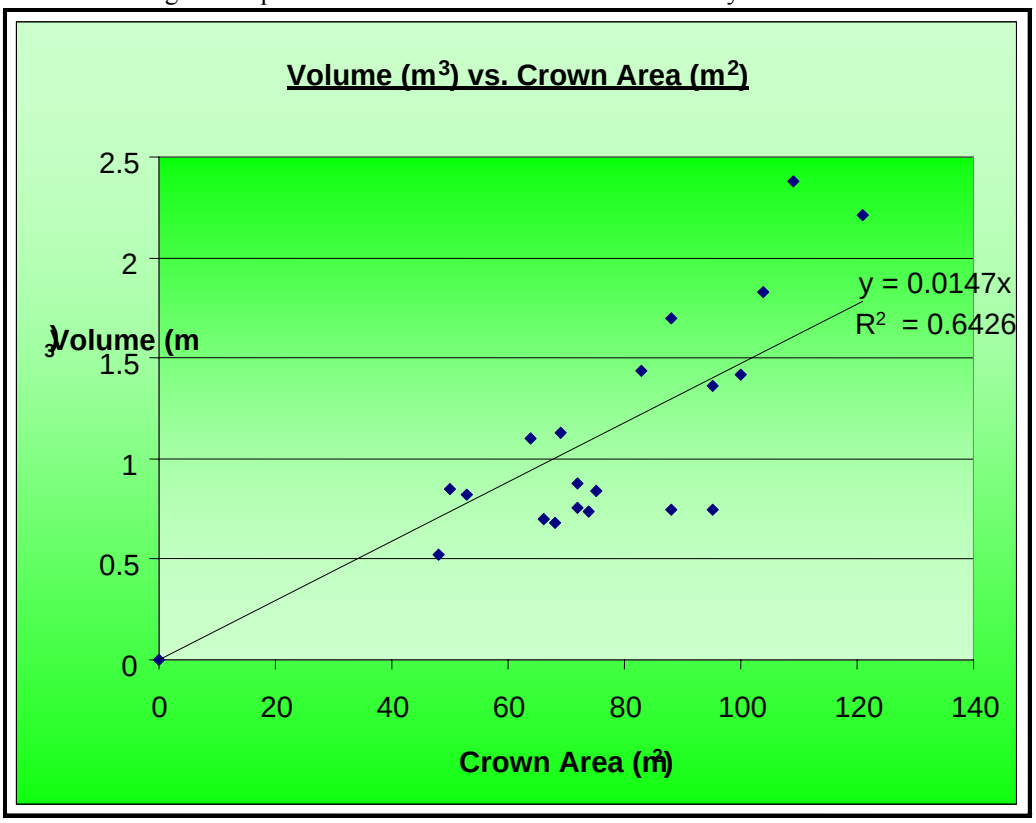

Figure 5. Relationship between crown area and volume of the 20 sampled *H. brasiliensis*