THE DEPENDENCE OF REFLECTED RADIANCE AND REFLECTANCE OF THE FOREST VEGETATION — A CASE STUDY OF *CYCLOBALANOPSIS GLAUCA*

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ABSTRACT: This paper used a spectroradiometer, GER 2600, to field measure the reflected radiance of a seedling plant of mountainous vegetation and the incident solar radiance. These two spectral data were then used to calculate the reflectance of the plant. In the experiment the control variables are the incident radiance, leaf pigments and the canopy structure of the plant. All of the measurements were taken under the same sample sets. This experiment aimed to find out if the reflectance of the vegetation is independent or dependent on the incident radiance, and if there are any different features exist among the spectral profiles of the vegetation and how they changes in corresponding to the changes of incident radiation. The results conclude that the Glauca canopy reflected radiance is strongly and linearly proportional to the incident radiance. Especially in the infrared light area, the plant reflected radiance could be estimated exactly by the incident solar radiance in the situations of varying atmospheric conditions, i.e. cloudy to sunny conditions. The plant canopy reflected radiance is not merely dependent on the amounts of incident radiation but also dependent on the factors related to the plant itself, such as the photosynthesis of the plant in the visible light area. But the reflectance of Glauca does not change proportional to the incident solar radiance. This situation could cause an unexpected change of the spectral characteristics of the vegetation and hence make it difficult to detect detail information of mountainous vegetation by the techniques of remote sensing.

1. INTRODUCTION

Remote sensing has been played an important role in detecting or monitoring the land covers of mountainous areas since last two decades. Usually we need to make an atmospheric correction and geometric correction to remove or decrease the influences of the atmosphere and terrain relief on the remotely sensed data (Chavez, 1989; Conese et al., 1993 Price, 1987). Especially in the researches of spectral characteristics of land covers, we are not interested in the digital number but the radiance or reflectance that the objects reflected into the sensor (Lin, 1999; Liu, 1995). For the mountainous area image, we cannot derive the exactly vegetative reflectance because of the atmospheric parameters such as the aerosol density, pressure, temperature etc were not measured for running the atmospheric correction packages. While the gain and offset parameters for radiance restoration could be done exactly. It is therefore we try to field measure the reflected radiance and reflectance of vegetation and analyze them if there is a dependent relationship between those two spectral characteristics. If their relationship could be well defined by a suitable model then the relationship could be applied in the mountainous image processing. That is we can use the radiance instead of the reflectance for vegetation identification. It will make the vegetation spectral characteristics understanding easily and it could also be applied in monitoring of mountainous image. So, our experiment is to understand if the reflectance of the vegetation is independent or dependent on the incident radiance and also to find out if there is any different features exist among the spectral profiles of the vegetation. The experiment is conducted in the field of forest nursery which locates in the middle of Taiwan and managed by the Chiayi department of the Bureau of Taiwan Forest. All of the spectral data of the vegetation is measured by the GER2600 spectroradiometer. The canopy structures of the testing vegetation is always same during the spectral measurement, the only varying variable is the incident radiance.

2. MATERIALS AND METHODS

2.1 Vegetation Samples

Fagaceae and Lauraceae vegetation are native and wild distributed from the elevation between several hundreds meter and more than 2,000 meters in Taiwan (Liu, 1976). They are the most dominant species in such middle elevation and have vigorous ability in native mountainous area and hence become the important plants for reforestation. This study therefore chose one of the Fagaceae species, *Cyclobalanopsis glauca* (abbreviates as Glauca), which grew by the Forest Bureau of Taiwan to be the research samples. We grouped about 30 plants of one-year old seedling *Cyclobalanopsis glauca* to be a sample set and there are two sets of Glauca were used for spectral characteristics measurement. Figure 1 shows such grouped Glauca samples in the forestry nursery.

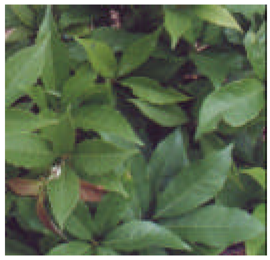


Figure 1. The nadir view of the group of *Cyclobalanopsis glauca* seedling plants for spectral experiment.

2.2 Spectroradiometer Instrument and Spectral Data Measurements

The instrument used for measuring the spectral values of Glauca is portable GER-2600 spectroradiometer. It is a battery-operated field portable spectroradiometer with full real-time data acquisition from 350 nm to 2500 nm. When the reflected radiance enters the instrument, it is split into three spectrometers. One spectrometer incorporates a 512 element silicon detector array and has a wavelength range of 300 nm to 1050 nm with a sampling interval of 1.5 nm. The other spectrometer utilize a 128 PbS detector array and has a wavelength range of 1050 nm to 2500 nm with a sampling interval of 11.5 nm (GER, 2000). We can therefore obtain a 605 band hyperspectral data for a scan. The GER 2600 instrument includes a spectroradiometer head, 3 degree foreoptic, 12 voltage battery and a battery-sensor cable, one computer cable for connecting the notebook PC with the spectroradiometer, spectralon reflectance standard, and a 3 axis headed tripod. In the field operation for spectral measurement, the spectroradiometer head was mounted in the tripod which was first placed over the target area in a sturdy manner. The head is also leveled using the bubble level located on the top of the instrument and the ones located on the tripod. The components, battery, and notebook PC were then well connected. Figure 2 shows the assembly diagram of the spectroradiometer instrument in the field measurements of Glauca spectral reflectance. For best results of measurement, the Glauca samples were located exactly and completely fill the field of view (FOV) of the instrument. Figure 3 shows the FOV diagram in which a sighting laser is used to aid in aligning the instrument to the Glauca to be measured. In our cases, the canopy surface of the grouped Glauca samples covered an area of more than 300 x 300 mm^2 which is almost 36 times of the FOV area in figure 3.

In field measuring the spectral data of the Glauca canopy, a reference scan was always preceding a target scan. This procedure can catch the incident radiance (referred spectralon reflected radiance) and Glauca reflected radiance, and then they were used to determine the Glauca reflectance. In each measurement, each spectral data were automatically averaged from 3 duplicative measurements. We finally made 64 sample measurements for this analysis.

Figure 2. The configuration of the spectroradiometer and components setup for field spectral measurements

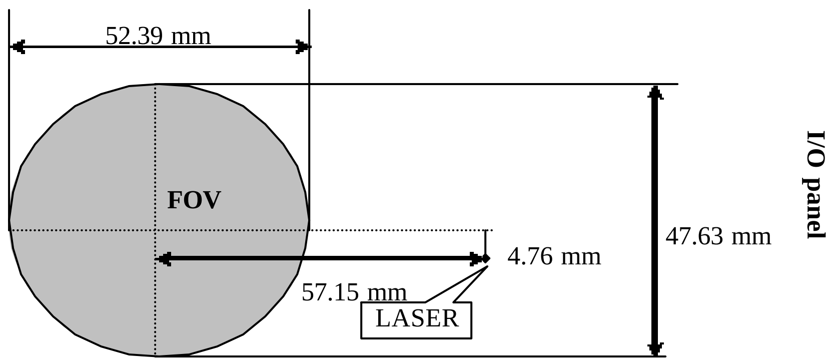


Figure 3. Standard field of view at the position of 47.63 cm above the canopy of Glauca seedlings.

2.3 Dependence Analysis of the Incident and Reflected Spectral Values

The dependence analysis used in this study is composed with two methods, visual scatter plotting and regression analysis. A scatter plot can depict the data distribution situations in a 2-dimensional space. It always composed by two variables which analyzer is interested. We therefore at first apply the method of scatter plot to visually examine the relationship between the incident radiance and the reflected radiance, the incident radiance and reflectance, and the reflected radiance and the reflectance of the plant. And then we apply a simple regression method to fit the reflectance or reflected radiance of Glauca with the incident radiance, and also to model how the reflectance is dependent on the reflected radiance. Eq. (1) shows the simple linear regression model

$$y = b_0 + b_1 x + e \quad (1)$$

where the intercept b_0 and the slope b_1 are unknown constants and e is a random error. Both parameters of the model were estimated by the method of least squares. And the fitted simple linear regression model comes to the form of $y = b_0 + b_1 x$ (Montgomery and Peck, 1982). Consider the physical meanings of the parameter estimates, the intercept represents the natural states of the dependent variable y in the case of independent variable $x = 0$. This condition would not happen in the view of short wave remote sensing, especial for the visible and middle infrared spectrum. We therefore use the standardized form of $y' = bz$ to mathematically change the intercept as zero to make the fitted linear regression model is corresponding to the physical meaning of remote sensing. Both the standardized variables of the dependent (**y**) and independent variable (x) is derived form their own sample mean, $\bar{x}$ and $\bar{y}$, and sample standard deviation of the spectral data, respectively. Eq. (2) represents the standardized algorithms of variable x (Shen, 1990).

$$z = \frac{x - \bar{x}}{\sqrt{\dfrac{\sum (x_i - \bar{x})^2}{n - 1}}} \quad (2)$$

3. RESULTS AND DISCUSSION

3.1 Spectral Characteristics Curves of *Cyclobalanopsis glauca*

In the 64 available field scan of the canopy of the Glauca plants, we found that the measured reflected radiance for some of the GER2600 hyperspectral bands have an unexpected low radiance value, even less than zero, which will cause the calculated reflectance negatively. This phenomenon is happen when the incident solar radiation comes to a much lower value, such as the heavy cloudy day. The author excluded the bands which have negative radiance and reflectance to avoid their influence. The violet bands whose wavelength is less than 400 nm were also removed. We thus have only 450 bands whose spectrum range from 400.57 nm to 1355.65 nm with the band number from 57 to 506. Figure 4 are the examples of such measured incident radiance image, Glauca canopy reflected radiance, and Glauca reflectance image. From the incident radiance image we had see that the difference atmospheric conditions could cause a large variations of solar radiation. The values of the incident radiance that represented in the range of 400.57nm to 1355.65 nm wavelength could be visually discriminated from figure 5a. The form of these curves were thought to be similar with the solar irradiance measured by the satellite (Tzeng, 1983).

(a) (b) (c)

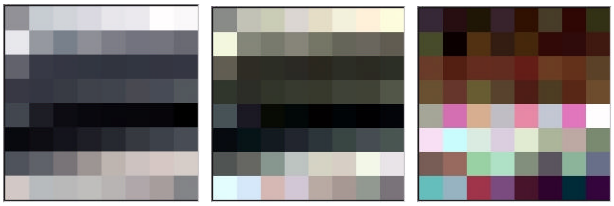


Figure 4. The spectral image of the field measured incident solar irradiance (a), reflected radiance (b) and reflectance (c) of the Glauca samples.

(a) (b) (c)

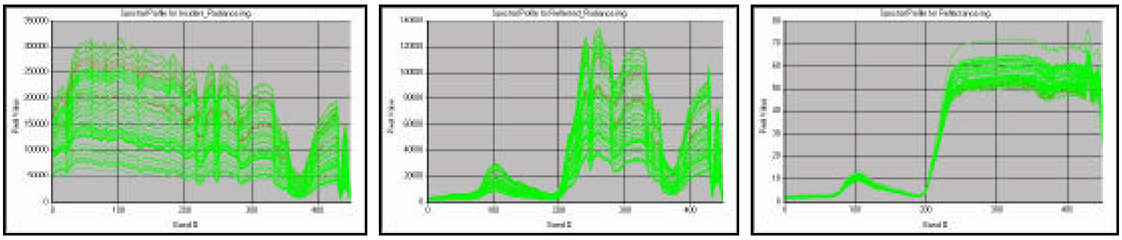


Figure 5. The spectral profiles of the reflected radiance (a) and reflectance (b) curves of the *Cyclobalanopsis glauca* in contrast with the variations of the incident radiance (c).

The pixel density of the reflected radiance image of Glauca listed in the middle of figure 4 is almost identical to the incident radiance image, the left of figure 4. It gives us a hint that the plant reflected radiance might have a functional relationship with the incident radiance. Compare the incident ad reflected radiance image with the reflectance image, the right one of figure 4, we can not visually find out any relationship between the reflected radiance and reflectance or between the reflectance and incident radiance. Basically the all of the curves of the reflected radiance and reflectance of Glauca canopy have same trends in the spectral profile listed in figure 5. The reflectance profiles in different incidence situations are similar except their height in pixel values. This plot depicts clearly the spectral characteristics of plant. In the visible light area, plant reflects more green light than the blue and red wavelength, while as it reflects large percentages of infrared light. The same features of both reflected radiance and reflectance plots are limited in the visible area, but in the infrared area the reflectance is far from the reflected radiance.

3.2 Relationships of the Spectral Characteristics of Glauca Canopy and the Incident Radiance

3.2.1 Dependence of the reflected radiance on the incident radiance.

Scatter plot of the reflected radiance vs. incident radiance revealed that they both have a linear relationship (figure 6). The fitted regression linear models of both variables are also perfect for each of the 450 bands. The minimum and maximum coefficient of determination (R^2) of the linear model is 0.80 and 0.99 respectively. It means that the amounts of Glauca canopy reflected radiance is strongly related with the incident radiance, and also can be estimated precisely by the incident radiance. In consequence of the positive slopes of the linear models depicts the relationship of the reflected radiance (denoted as "*Ref'd.Rad*") and the incident radiance (denoted as "*In.Rad*"), we can conclude that the larger incident radiance, the higher radiance the Glauca reflected. Figure 7a shows model's R^2 varies with the band number or wavelength. It is obviously lower R^2 for the visible area while higher R^2 exists in the infrared area. And the root mean square error (RMSE) of the linear model of each band plotted in figure 7b reveals the equivalent meanings as the R^2 of the models. The RMSE profile acted against with the R^2 profile, that is a model with larger R^2 then it could predicts the reflected radiance of Glauca more precisely by the incident radiance.

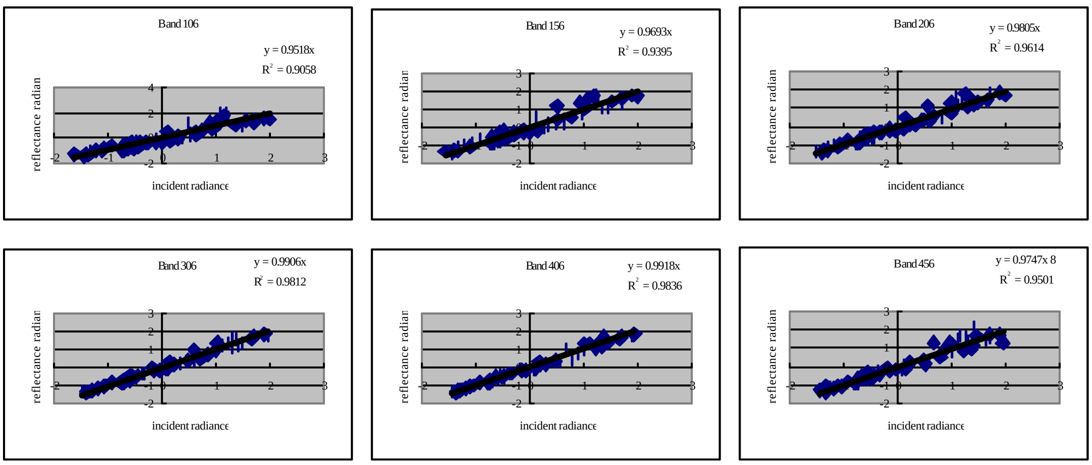


Figure 6. Examples of the scatter plot of the Glauca reflected radiance (*Re.Rad*) versus the incident radiance (*In.Rad*).

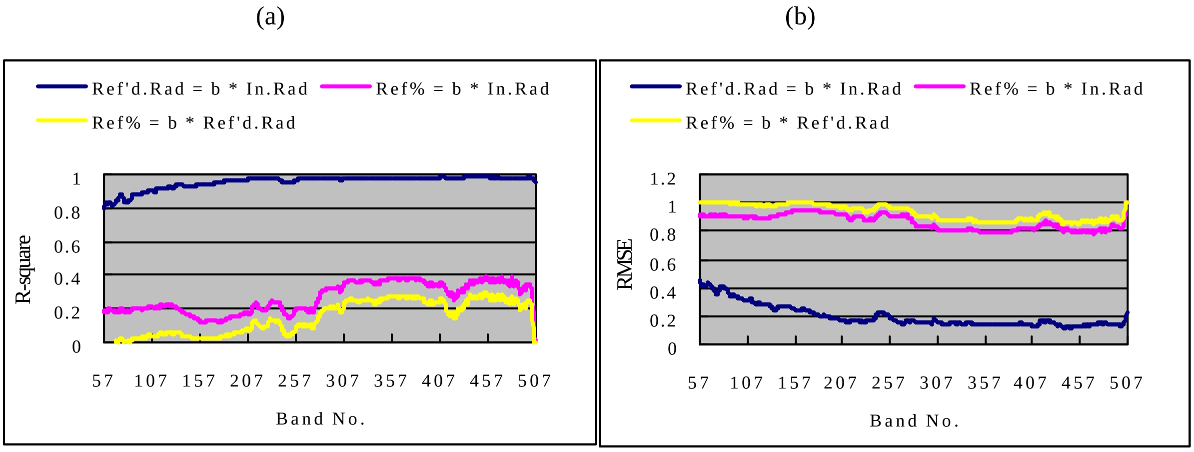
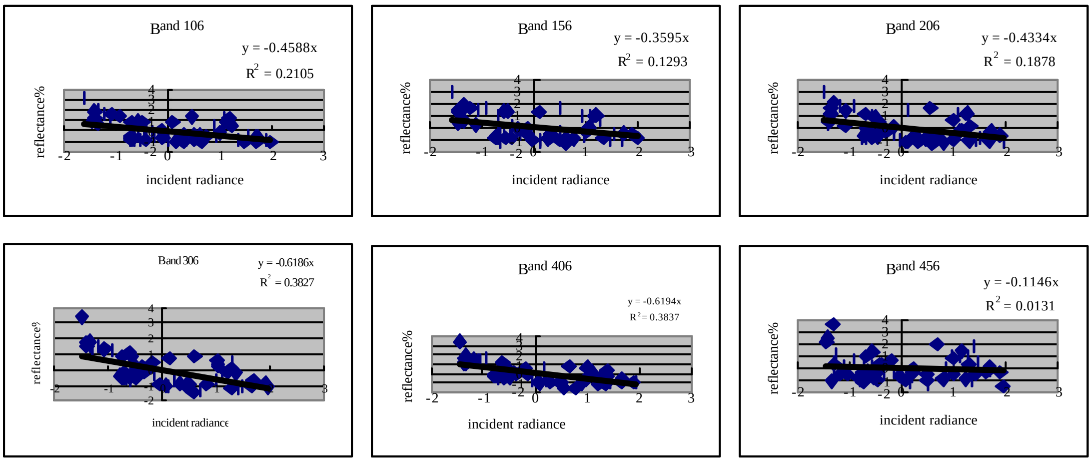


Figure 7. The coefficient of determination (a) and RMSE (b) curves of the fitted regression models for each band of Glauca data.

(a) Examples of the scatter plots of *Ref%* vs. *In.Rad*



(b) Examples of the scatter plots of *Ref%* vs. *Re.Rad*

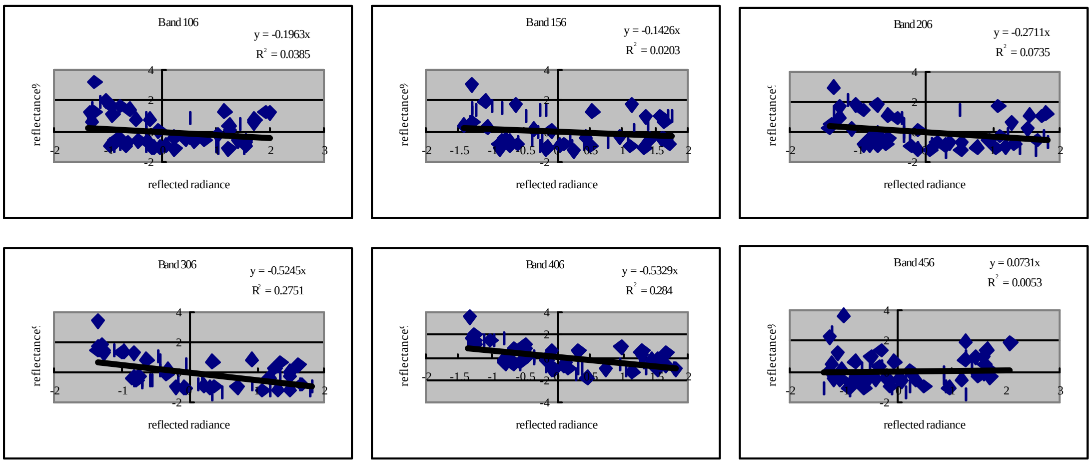


Figure 8. Scatter plot of the reflected radiance, and reflectance versus with the incident radiance.

3.2.2 The dependence of the reflectance on the reflected radiance or on the incident radiance

Scatter plot of the reflectance vs. incident radiance (figure 8a) and that of the reflectance vs. reflected radiance (figure 8b) suggests that their relationship should be linear and there are no any other better relationships exists between these variables. While the regression analysis results show that although the reflectance (denoted as *Ref%*) of Glauca is statistically significant dependent on the incident radiance and the reflected radiance but their relationship is not stronger as the relationship of reflected radiance and incident radiance (Ref'd.Rad-In.rad). The maximum coefficient of determination of the fitted models for the cases of *Ref%-In.Rad* and *Ref%-Re.Rad* is 0.40 and 0.30, respectively (figure 7a). The ill fitness of the *Ref%-In.Rad* and *Ref%-Re.Rad* models are also obviously poor than the fitness of *Ref'd.Rad-In.rad* models in the sense of root mean square error (RMSE) (figure 7b).

4. CONCLUSION

From the results of this study, we can conclude that the Glauca canopy reflected radiance is strongly and linearly related to the incident radiance. Especially for the infrared light area, the plant reflected radiance could also be estimated using the incident radiance even in the conditions of varying atmosphere. Since the canopy structure of the samples was kept as constant in this study, we therefore can also conclude that the plant canopy reflected radiance in the visible area is not merely depend on the incident radiance but also depends on the inner factors of the plant. The physiological activity, especially the photosynthesis should be the key factor in determine the variations of reflected radiance, and we believe the photosynthesis effects would less then 10% in related to the coefficient of determination because the photosynthetic rate is varying with the light intensity. While in the sense of reflectance of Glauca, it does not change proportional to the incident radiance and the same sample sets of the plant indeed have different reflectance when the incident radiance changes. This phenomenon can explain why the classification performance of the remote sensing were not good enough for detecting sophisticated vegetation species in the mountainous area. How to simulated the changes of plant reflectance to overcome the spectral variation effects caused by the changes of solar incidence should be one of the major subjects of remote sensing research.

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