Algorithms for the Estimation of the Concentrations of Chlorophyll A and Carotenoids in Rice Leaves from Airborne Hyperspectral Data

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Abstract. Algorithms based on reflectance band ratios and first derivative have been developed for the estimation of chlorophyll a and carotenoid content of rice leaves by using airborne hyperspectral data acquired by Pushbroom Hyperspectral Imager (PHI). There was a strong R680/R825 and chlorophyll a relationship with a linear relationship between the ratio of reflectance at 680nm and 825nm. The first derivative at 686 nm and 601 nm correlated best with carotenoid. The relationship between the ratio of R680/R825 and chlorophyll a relationship, the first derivative at 686 nm and carotenoid concentration were used to develop predictive regression equations for the estimation of canopy chlorophyll a and carotenoid concentration respectively. The relationship was applied to the imagery, where a chlorophyll a concentration map was generated in XueBu, which is one of the sites for rice.

1 Introduction

Hyperspectral remote sensing exploits the fact that all material reflect, absorb, and emit electromagnetic energy, at specific wavelengths, in distinctive patterns related to their molecular composition. Hyperspectral imaging sensors in the reflective regions of the spectrum acquire digital images in many contiguous and very narrow spectral bands that typically span the visible, near infrared, and mid-infrared portions of the spectrum. This enables the construction of an essentially continuous radiance spectrum for every pixel in the scene. Thus, Hyperspectral imaging data exploitation makes possible the remote identification of ground materials-of-interest based on their spectral signatures. (D.G.Manolakis & G.Shaw, 2002)

Hyperspectral algorithms for the estimation of the concentrations of chlorophyll A and carotenoids can be developed using statistical approaches. Spectral band in the visible and near-infrared regions of the spectrum have been used to develop a number of indices for estimating chlorophyll. The commonly used normalized difference vegetation index (NDVI) was developed by contrasting the chlorophyll absorption in the red wavelengths. The NDVI has been found to be insensitive to medium and high

chlorophyll concentrations.(Buschman & Nagel,1993) Miller found the concentration of chlorophyll within a vegetation canopy is related positively to the point of maximum slope at wavelengths between 690 and 740 nm in reflectance.(Miller et al.,1990) This point, Known as the Red edge of plant reflectance.(Curran et al.,1991) The Recent studies have developed several new vegetation indices based on other visible wavelength bands instead of the red wavelengths near 670-680nm.The spectral derivative technique has been used to improve characterizing the spectra and estimating accuracy of vegetation biochemical concentrations (Demerriades-Shah & Steven.M.D. et al., 1990, Pu & Gong 1997). Maximum sensitivity of reflectance to chlorophyll content was found in the green wavelengths region at 550 nm and at 708 nm in the far-red wavelengths. The reflectance in the main chlorophyll absorption regions in 400-500nm and 660-690nm proved to be insensitive to variation in chlorophyll content (Bisun.D.,1998). Strong correlation were observed between red edge position and canopy chlorophyll concentration using airborne image (Rosemary.A.J. et al.,1999).

2 Data Acquisition

2.1 Airborne Radiance Data

The hyperspectral image data in this paper are acquired from two airborne flights in 1999 in Changzhou area, Jiangsu province of East China, by using the Push-broom Hyperspectral Imager (PHI), which is developed by the Shanghai Institute of Technical Physics (SITP), Chinese Academy of Sciences (CAS). Table 1 shows the specification of PHI. The flights were carried out in September 9 and October 18 when the rice was in the broom and ripe stages, respectively. 80 bands were selected for recording in a range of 400-850nm for the 244-band PHI with the spectral resolution <5nm. The pixel size or spatial resolution is 2.25m with a flight altitude about 1500m. A 3D stabilized platform was applied for PHI and GPS data was recorded with the image data.

Table 1. Specification of the PHI

FOV	0.36rad(21 ⁰)
IFOV	1.0mrad (vertical to flight line)
S/N	300
No. of bands	244
Spectral Range	VIS-NIR(400nm--850nm)
Spectral Resolution	<5nm
Number of Pixels/scan	367pixels/line
Weight	9Kg
Frame Frequency	60Fr/sec
Data Rate	7.2Mb/Sec.

The field spectra are measured by the 252-channel SE590 spectrometer with a spectral resolution about 2-3nm in the range of 0.4-1.1 μ m.

The PHI image was pre-processed for radiometric, spectral and geometric calibration then was transformed to a reflectance image by field calibration using empirical line method.

2.2 Field Site

Night field sites were selected to analyzed chlorophyll concentration. There are four sites for rice within the nine. Unfortunately the PHI imagery was acquired on 18 October 1999 was deflected one field site for rice. Three sites were used to analyze rice samples. Nine study plot were located three sites which to be ensure were larger than one 2.25m*2.25m PHI pixel. Field reflectance and samples of different rice species for biochemical analyses were collected at the nine study areas.

2.3 Canopy Biochemical Concentration Data

Chlorophyll a, chlorophyll b, and carotenoid of rice leaves have been measured in Sep.1 1999 and Oct.18, 1999 in the study area of Changzhou.

The concentration of chlorophyll a, chlorophyll b, and total chlorophyll was calculated by the following equations. The unit is microgram per milliliter.

$$C_a = 12.7A_{663} - 2.69A_{645} \quad (1)$$

$$C_b = 22.9A_{645} - 4.68A_{663} \quad (2)$$

$$C_{a+b} = 20.2A_{645} + 8.02A_{663} \quad (3)$$

$$C_K = 4.7A_{440} - 0.27C_{a+b} \quad (4)$$

Where C_a is the concentration of chlorophyll a; C_b is the concentration of chlorophyll b, C_{a+b} is the concentration of the total chlorophyll and C_K is the concentration of carotenoid (mg/ml) A_{663} and A_{645} are the absorption value of leaves where wavelengths are 663nm and 645nm respectively. These values were measured by 721 spectrophotometer.

From the C_a , C_b , and C_{a+b} , the concentration of chlorophyll a, chlorophyll b, and carotenoid can be got from the following equations.

$$X_a = C_a \times V/W \quad (5)$$

$$X_b = C_b \times V/W \quad (6)$$

$$X = C_{a+b} \times V/W \quad (7)$$

$$Y = (4.7A_{440} - 0.27C_{a+b}) \times V/W \quad (8)$$

Where X_a , X_b , X , and Y are the concentration of the chlorophyll a, chlorophyll b, chlorophyll a and b, and carotenoid respectively. (mg/g). And A_{440} is the absorption value of the leaf where wavelength equals 440 nm. W (g) is the weight of the samples and V (ml) is the volume of the sample liquor.

3 Develops Algorithms for Estimating the Concentrations of Vegetation Biochemical

The image, which transformed into reflectance was used to produce the first derivative image. In order to develop better algorithms for estimating the concentrations of vegetation biochemical, the wavelength bands with maximum and minimum sensitivities to the concentrations of vegetate were identified from correlogram plots

Fig. 1. The correlation coefficients between reflectance, first derivative of reflectance and the concentrations of chlorophyll at all wavelengths

Table 2. Correlation of vegetation indices with pigment content

	Chlorophyll a	Chlorophyll b	Chlorophyll a+b	Carotenoids
R680/R550	-0.633286(S)	-0.027519	-0.567520	0.303747
R680/R700	-0.597131(S)	0.012407	-0.527937	0.356874
R680/R825	-0.901990(S)	-0.376614	-0.871511(S)	-0.148244
R760/R550	-0.101527	0.146617	-0.062699	-0.380614
R760/R700	-0.240858	0.214545	-0.173705	-0.401802
R825/R550	0.791722 (S)	0.406786	0.779243 (S)	0.058519
NDVI	-0.051386	0.175014	-0.012855	-0.286543
GNDVI	-0.099975	0.135721	-0.063361	-0.352727
Red edge Position	-0.121271	0.444960	-0.024358	-0.231216
Red edge slope	0.497118	0.266054	0.491274	0.625607 (S)

(S) = significant at 0.05 level

Fig. 2. The correlation coefficients between reflectance, first derivative of reflectance and the concentrations of carotenoid at all wavelengths

showing the correlation coefficients between reflectance, first derivative of reflectance and the concentrations of vegetation biochemical at all wavelengths. The correlogram for chlorophyll is shown in Figure 1. The similar correlogram for cartooned is demonstrated in Figure 2. The reflectance is insensitive to chlorophyll. The first derivative at 735 nm correlated best with chlorophyll. The reflectance and the first derivative were well correlated with the carotenoid contents at many wavelength bands. The first derivative at 601 nm and 686 nm correlated best with carotenoid.

Chlorophyll a, b, a+b, and carotenoid content were related to the vegetation indices R680/R550, R680/R700, R680/R825, R760/R550, R760/R700, R825/R550, NDVI, GNDVI, the Red edge Position and the Red edge slope. The correlation coefficients between these indices and pigment are given in Table 2.

The NDVI is normalized difference vegetation index, defined as $(R760-R670)/(R760+R670)$.

A “green” NDVI defined as $GNDVI=(R760-R550)/(R760+R550)$, by using the green wavelength band near 550nm.

Red edge position is the point of maximum slope at wavelengths between 690 nm and 740 nm in reflectance. This point characterizes the effective boundary between the strong absorption of red radiation by chlorophyll and the increased multiple scattering of radiation in near-infrared wavelengths (Curran et al., 1991).

Red edge slope is the slope of red edge and is the maximum slope at wavelength between 690 nm and 740 nm.

R680/R550, R680/R700, R680/R825 and R825/R550 are sensitive to chlorophyll a, and R680/R825 is correlated best with chlorophyll a.

R680/R825 and R825/R550 are well correlated with chlorophyll a+b. The red edge slope is sensitive to carotenoid.

4 Algorithms for Estimates of Canopy Chlorophyll and Carotenoid from Image Spectra

There was a strong R680/R825 – chlorophyll a relationship with a linear relationship between the ratio of reflectance at 680nm and 825nm.. There was a statistically significant correlation between R680/R825 and chlorophyll a at the 99% confidence level. ($r = -0.90$)

The relationship between R680/R825 and chlorophyll a concentration was used to develop a predictive regression equation for the estimation of canopy chlorophyll a concentration. The algorithms equation had the form of Equation (9).

$$\text{Chl a} = -2.657\text{R680/R825} + 1.8029 \quad (9)$$

Where Chl a is the concentration of chlorophyll a (mg/g). R680 and R825 are the reflectance at 680nm and 825nm.

This relationship was applied to the imagery, where a chlorophyll a concentration map (Figure 3) was generated in Xuebu, which is one of the sites for rice.

The first derivative at 686 nm correlated best with. There was a very strong first derivative-carotenoid relationship with a linear relationship between the first derivative at 686nm. There was a statistically significant correlation between the first derivative at 686 nm and carotenoid at the 99.9% confidence level. ($r = 0.99$)

The relationship between the first derivative at 686 nm and carotenoid concentration was used to develop a predictive regression equation for the estimation of canopy carotenoid concentration. The algorithm equation was the Equation (10).

Fig. 3. Chlorophyll concentration map (Xuebu, Oct.18)

$$CK = 0.9527D_{686} + 0.1955 \quad (10)$$

Where CK is the concentration of carotenoid (mg/g). D_{686} is the first derivative at 686nm.

5 Discussion

Analysis of visible/infrared reflectance and biochemical concentration data for rice leaves has revealed some new information on the quantification of chlorophyll and carotenoid by airborne hyperspectral data. PHI data, by means of its continuous, high resolution spectral image, have been found useful for the estimation of chlorophyll a and carotenoid content of rice leaves. It was found that the indices R680/R550, R680/R700, R680/R825 and R825/R550 correlate well with chlorophyll a. R680/R825 and R825/R550 showed the more sensitivity to chlorophyll a+b. It was also found red edge slope correlate well with carotenoid. The new index R680/R825 is the best indicator of chlorophyll a. The reflectance ratio is the simple transformation, which removes irrelevant information from reflectance spectra, and highlights subtle variations in reflectance caused by chemical absorptions (B.Datt, 1999). The R680/R825 is calculated from wavelengths that is not affected by leaf structure (M.L.Adams, W.D.Philpot and W.A.Norvell, 1999), and also be unaffected by leaf water content (Bowman, W.D.1989).

The reflectance and the first derivative of reflectance at many wavelengths are more sensitive to the carotenoid content of rice leaves. The phase of the airborne hyperspectral data acquisition is October 18, which is complete maturity period of rice. The rice color is yellow and the carotenoid content is more than the others growth stages of rice.

The algorithms developed in this paper have been found to accurately predict the chlorophyll and carotenoid content in rice leaves in maturity period. They are needed to be compared with more data sets. The applicability to the other growth stages and other crops will need to be evaluated by further experiments.

The employed ground-truth was found to be limited due to some constraints. Despite these limitations however, optimistic chlorophyll and carotenoid content of rice for the PHI was clearly established.

References

- Adams M.L., Philpot W.D., Norvell W.A.: Yellowness Indexes: an Application of Spectral Second Derivatives to Estimate Chlorophyll of Leaves in Stressed Vegetation. *International Journal of Remote Sensing*, 20(1999) 3663-3675
- Bagheri S., Stein M., Dios R.: Utility of Hyperspectral Data for Bathymetric Mapping in a Turbid Estuary. *International Journal of Remote Sensing*, 19(1998) 1179-1188
- Bisun, D.: Remote Sensing of Chlorophyll A, Chlorophyll B, Chlorophyll A+B, and Total Carotenoid Contenting Eucalyptus Leaves. *Remote Sensing of Environment*, 66(1998) 111-121
- Bowman, W.D.: The Relationship between Leaf Water Status, Gas Exchanges, and Spectral Reflectance in Cotton Leaves. *Remote Sensing of Environment*, 30(1989) 249-255

- Buschman, C., Nagel, E.: In Vivo Spectroscopy and Internal Optics of Leaves as a Basis for Remote Sensing of Vegetation. *International Journal of Remote Sensing*, 14(1993) 711-722
- Curran, P.J., Dungan, J.L., Macler, B.A., Plummer, S.E.: The Effect of a Red Leaf Pigment on the Relationship between Red Edge and Chlorophyll Concentration. *Remote Sensing of Environment*, 35(1991) 69-76
- Datt B.: Visible/Near Infrared Reflectance and Chlorophyll Content in Eucalyptus Leaves. *International Journal of Remote Sensing*, 20(1999) 2741-2759
- Demetriades-Shah, T.H., Steven, M.D., Clark, J.A.: High Resolution Derivative Spectra in Remote Sensing. *Remote Sensing of Environment*, 33(1990) 55-64
- Manolakis D.G., Shaw G.: Detection Algorithms for Hyperspectral Imaging Applications. *IEEE Signal Processing*, 19(2002) 29-43
- Miller, J.R., Hare, E.W., Wu, J.: Quantitative Characterization of the Vegetation Red Edge Reflectance I. An Inverted-Gaussian Reflectance Model. *International Journal of Remote Sensing*, 11(1990) 1755-1773
- Pu, R., Gong, P.: Relationships between Forest Biochemical Concentrations and CASI Data along the Oregon Transect. *Journal of Remote Sensing*, 1(1997) 115-123 (in Chinese)
- Rosemary, A.J., Mark, E.J.C., Paul, J.C.: Estimating Canopy Chlorophyll Concentration from Field and Airborne Spectra. *Remote Sensing of Environment*, 68(1999) 217-224