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# A modified chlorophyll absorption continuum index for chlorophyll estimation*

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**Abstract:** There is increasing interest in using hyperspectral data for quantitative characterization of vegetation in spatial and temporal scopes. Many spectral indices are being developed to improve vegetation sensitivity by minimizing the background influence. The chlorophyll absorption continuum index (CACI) is such a measure to calculate the spectral continuum on which the analyses are based on the area of the troughs spanned by the spectral continuum. However, different values of CACI were obtained in this method because different positions of continuums were determined by different users. Furthermore, the sensitivity of CACI to agronomic parameters such as green leaf chlorophyll density (GLCD) has been reduced because the fixed positions of continuums are determined when the red edge shifted with the change in GLCD. A modified chlorophyll absorption continuum index (MCACI) is presented in this article. The red edge inflection point (REIP) replaces the maximum reflectance point (MRP) in near-infrared (NIR) shoulder on the CACI continuum. This MCACI has been proved to increase the sensitivity and predictive power of GLCD.

**Key words:** Continuum, Chlorophyll, Sensitivity, Prediction power
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## INTRODUCTION

Great advance has been achieved in vegetation characterization with remote sensing techniques. Most spectral vegetation indices (VIs) are usually calculated as the combinations of red and near-infrared (NIR) reflectance because the information contained in a single spectral band is insufficient for characterizing vegetation status as vegetation exhibits unique reflectance properties in these bands. These VIs can be generally grouped into ratio indices and orthogonal indices. Later, some indices have emerged that can be considered as hybrid versions of the classic ratio and orthogonal indices (Broge and Leblanc, 2001). An alternative way of utilizing hyperspectral reflectance data is to calculate spectral continuum in which the analyses are based on the area of the troughs spanned by the spectral continuum (Clark and Roush, 1984). The continuum is the beeline between the green peak point (GPP) and the maximum reflectance point (MRP) in the NIR shoulder. More recently, the chlorophyll absorption continuum index (CACI) was defined as the area spanned by the chlorophyll absorption continuum (550~730 nm) and the spectral reflectance curve (Broge and Leblanc, 2001):

$$CACI=\sum_{\lambda_i}^{\lambda_n}(R_i^{\mathrm{c}}-R_i)\Delta\lambda_i, \quad (1)$$

$$R_i^{\mathrm{c}}=R_{\mathrm{GPP}}+i(\mathrm{d}R^{\mathrm{c}}/\mathrm{d}\lambda)\Delta\lambda_i, \quad (2)$$

where $i$ is waveband from GPP to MRP; $n$ denotes

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number of waveband from GPP to MRP; $\lambda$ is the wavelength; $R$ is the reflectance; and 'c' represents the continuum.

CACI can be used to identify and quantify any material that exhibits a discrete absorption feature. However, it is difficult to determine the MRP. Different MRPs are used by different authors. Broge and Leblanc (2001) calculated the continuum between 550~730 nm on the spectrum, and Schmidt and Skidmore (2003) maintained that the end points of the continuum were 600 and 720 nm. These would result in the different continuum. On the other hand, a red edge shift could occur with the changes in green leaf chlorophyll density (GLCD). But the author used the same MRP that could strongly influence the sensitivity of CACI to agronomic parameters.

The objective of this study is to replace the MRP on the red edge with the red edge inflection point (REIP). This could unify the determination of MRP on the red edge. The sensitivity and prediction power of the modified CACI to GLCD was analyzed.

## EXPERIMENT AND MEASUREMENT

To study the characteristics of red edge and relationships between GLCD and red edge, two rice experiments were carried out. The first dataset is used for calibration and the second dataset is used for validation. Each dataset includes canopy spectrum and GLCD. Two rice datasets were collected in an experiment farm of Zhejiang University, China. The study area is characterized by monsoon climate with a hot summer and a cool winter. The soil is sandy loam paddy soil with pH 5.7, organic matter content of 16.5 g/kg and total N of 1.02 g/kg.

A spectroradiometer with range of 350 nm to 2500 nm, manufactured by Analytical Spectral Devices$^{TM}$, was used to collect reflectance data of crops canopy at different growth stage. The measurements were performed between 1100 and 1400 local time (GMT+8).

The canopy reflectance was measured during the growth season. Plants were sampled after the canopy reflectance was measured. An area of 0.088 m$^2$ was cut just above ground and brought to the lab. Leaves and stems were separated. One leaf was randomly selected among developed leaves to carry out the organic extraction of leaf chlorophyll. The GLCD (mg/m$^2$ soil) was calculated by Eq.(3):

$$GLCD = (GLCC \times GLFW) / 0.088 , \qquad (3)$$

where $GLCC$ is the green leaf chlorophyll content (mg/g); $GLFW$ denotes the green leaves fresh weight per square soil meter (g/m$^2$).

## IMPROVEMENT OF CACI

The CACI continuum is the beeline between GPP and MRP on the red edge (or on the NIR shoulder). But when the MRP located on the NIR shoulder, the value of CACI would be reduced because the continuum is lower than the reflectance curve (Fig.1). Therefore, NIR shoulder is not optimal for MRP. Some authors lay the MRP on the red edge such as 730 nm (Broge and Leblanc, 2001), so different MRPs are determined by different users; and even by one user, the MRP of all samples is determined at the same wavelength. The red edge of the vegetation spectrum is the steep slope between low reflectance in visible and high reflectance in NIR. The REIP is the wavelength of the maximum slope in the red edge, one of the main parameters for describing the red edge. The shifts of REIP toward the shorter-wave and the longer-wave are called "blue shift" and "red shift", respectively (Figs.1 and 2). The shifts occur corresponding to the changes in GLCD. The increase in vegetation chlorophyll density during the growth cycle causes the REIP red shift (Horler *et al*., 1983a; 1983b). Filella and Peñuelas (1994) found that the position of the red-edge peak was determined by GLCD and green leaf area index (GLAI), and concluded that the red edge is valuable for the assessment of agronomic parameters, even at canopy level. Gitelson *et al*.(1996) reported that REIP is strongly correlated to GLCD. A new technique has been reported for extracting REIP from hyperspectral to mitigate the discontinuity in the relationship between the REIP and the nitrogen content, the discontinuity caused by the existence of double-peak feature on the derivative spectrum (Cho and Skidmore, 2006).

In the present study, REIP was used to replace the MRP of the CACI continuum, the result is as follows:

$$MCACI = \sum_{\lambda_i}^{\lambda_n} (R_i^c - R_i)\Delta\lambda_i, \quad (4)$$

$$R_i^c = \frac{\lambda_i^c - \lambda_{GPP}}{\lambda_{REIP} - \lambda_{GPP}} \times (R_{REIP} - R_{GPP}) + R_{GPP}, \quad (5)$$

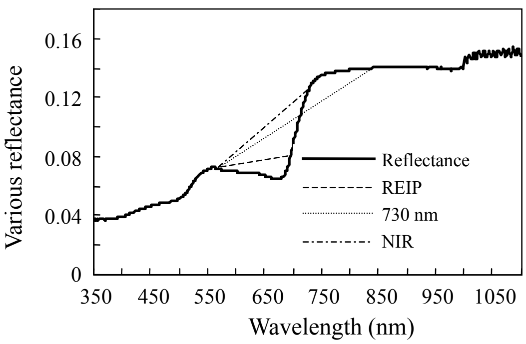


**Fig.1 The continuum of MRP located on the NIR shoulder for rape**

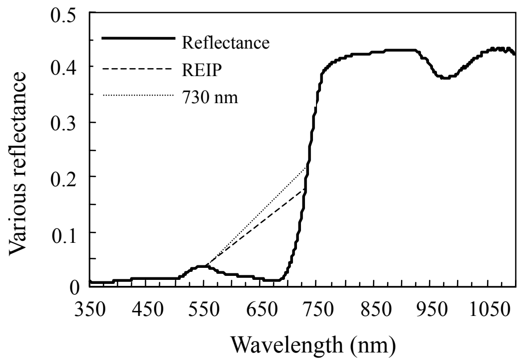


**Fig.2 The different continuums for rice**

RESULTS

**Computation of VIs' continuums**

Continuums of CACI and MCACI were computed for all samples. Only one continuum curve (Fig.3) is presented because it is too numerous for others to be presented here. The continuum of 730 nm is a fixed position that is expanded when GLCD decreases and red edge occurs as a blue shift and is shrunk when GLCD increases and red edge occurs as a red shift. Therefore, the continuum of 730 nm does not represent the chlorophyll absorption characters accurately. In the continuum of REIP, its second point always locates at REIP. REIP is shifted along with the red edge's shift. The position of the red-edge was determined by GLCD. So the REIP continuum can represent the chlorophyll absorption characters accurately. In short, the REIP continuum has relatively high sensitivity to chlorophyll absorption characters.

**Comparison of the sensitivity between MCACI and CACI to GLCD**

The sensitivities of the MCACI and CACI to GLCD are illustrated in Fig.3 showing that the MCACI is 0.6487 and CACI is 2.2052 when rice GLCD is 31.8338. The MCACI is smaller than CACI. MCACI is 17.5803 and CACI is 14.2199 when rice GLCD reaches 3174.5417. MCACI is greater than CACI and is more sensitive to the difference of GLCD than CACI on the whole. So GLCD contributes more than CACI on the variability of MCACI in this study.

As expected, the change of GLCD has stronger influence than CACI on the MCACI. Consequently, MCACI has higher sensitivity than CACI to the change of GLCD.

**Relating the MCACI and CACI to GLCD**

The sensitivity of MCACI to GLCD is characterized by the correlation coefficients ($R$) of the relationship between the VIs and GLCD. What can be concluded from these correlations is that MCACI has higher positive $R$ (0.6764) for GLCD than CACI (0.5497), so MCACI has higher sensitivity to GLCD than CACI. Because REIP has high sensitivity for red edge shift, but 730 nm is only suit to the most medium GLCD, 730 nm will lose its prediction power to GLCD when GLCD are very high or very low. In a word, MCACI could well indicate the change of GLCD.

Studies show that there exists an exponential relationship between the VIs and GLCD (Baret and Guyot, 1991). Fig.4 presents the fitted results between VIs and GLCD. The coefficient of determination ($R^2$) between GLCD and MCACI is 0.6125. But the $R^2$ between GLCD and CACI is only 0.5516. The fitted result between GLCD and MCACI is better than that between GLCD and CACI.

From the fitted results, MCACI has a higher value than CACI according to the $R^2$, but the $R^2$ statistic is defined as the proportion of variance of the response that can be explained by the repressor variables. However, the $R^2$ statistic can be misleading when comparing results of experiments on the same

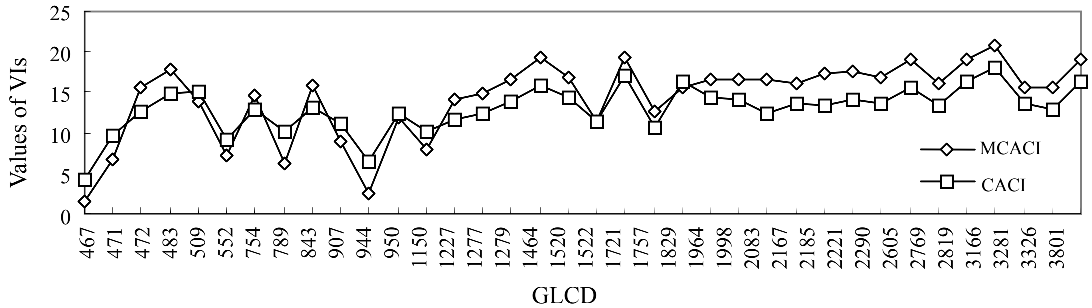


**Fig.3 The sensitivity of two VIs to GLCD**

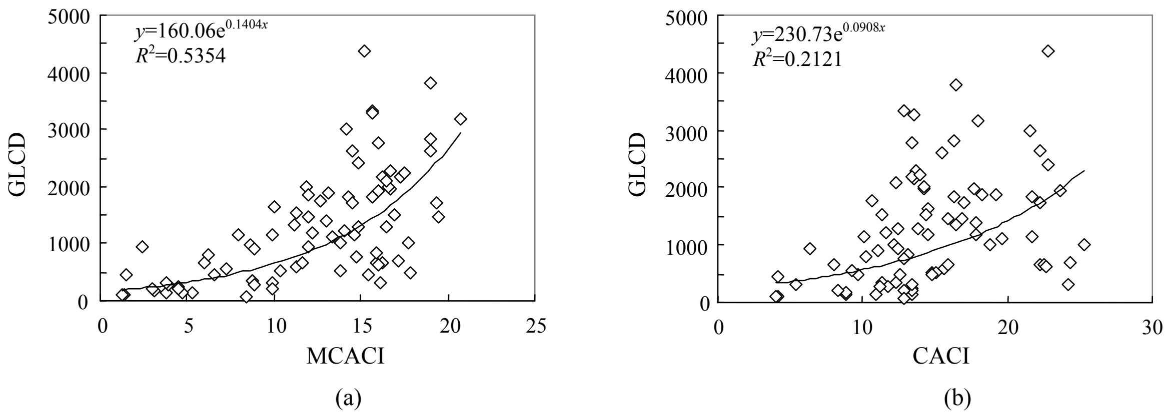


**Fig.4 Comparison regression results. (a) Between MCACI and GLCD; (b) Between CACI and GLCD**

variable but with different ranges for the repressors, such as the experiment reported herein. RMSE and NRMSE give the expected error for future predictions based on the fitted model. The results showed that the fitted model for GLCD using MCACI as independent variable has a lower RMSE value (909.2705) than that using CACI (1191.691). The NRMSE of fitted model using MCACI as independent variable also has a lower value (44.00403) than that of CACI (64.98197). This indicates that MCACI has a higher prediction power for GLCD than CACI.

## CONCLUSION AND DISCUSSION

Continuum technique, applied to hyperspectral across the chlorophyll absorption band, leads to the development of CACI based on the area of the convex hull spanned. But CACI has no unified continuum calculation method for every user, this could certainly result in the difference of VIs for diverse users. Consequently, the author presents the MCACI to solve these problems.

The performance of MCACI is then compared with the performance of CACI. First, the MCACI has a faster change rate than CACI along with the changes of GLCD. It also has higher $R$ than CACI. Therefore, MCACI has higher sensitivity to GLCD than CACI. Because the MRP of the 730 nm continuum has been replaced by the REIP, it could improve the sensitivity of CACI on the shift of the red edge. Second, the prediction power of MCACI to GLCD is best described by low RMSE and NRMSE. Altogether, MCACI is a good prediction index for GLCD.

The MCACI proposed is based on the CACI in this paper. The MCACI has strong potential for predicting GLCD in precision agriculture. MCACI has higher sensitivity to the change of GLCD. But the extent to which GLCD can be estimated from reflectance measurements at canopy need further study. Much work must be done to scale those greenness estimation relationships between various canopies and larger scale remote sensing applications.

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