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A comparative analysis of broadband and narrowband derived vegetation indices in predicting LAI and CCD of a cotton canopy

Dehua Zhao [a,b], Liangmei Huang [a,b], Jianlong Li [a,b,*], Jiaguo Qi [c]

[a] The State Key Laboratory of Pollution Control and Resources Reuse, Nanjing University, Nanjing 210093, PR China
[b] Department of Biological Science and Technology, Nanjing University, Nanjing 210093, PR China
[c] Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI48823, USA

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Abstract

Remote sensing is a powerful tool for obtaining important agronomic information about field crops. Many spectral vegetation indices (VIs) have been developed in the past three decades to provide more sensitive measurements of plant biophysical parameters and to reduce external noise interferences such as those related to soil and the atmosphere. Some VIs were developed based on narrowband spectral data and others on broadband sensors. Therefore, although the mathematical equations defining VIs are the same, their calculated values are different, thus affecting their stability in predicting agronomic variables such as total green leaf area index. The objective of this study was to compare the ability of VIs derived from broad and narrowbands and to determine the optimum red–NIR bands for VIs used in predicting leaf area index (LAI) and canopy chlorophyll density (CCD) of cotton canopies. A completely randomized experiment was conducted in a cotton (*Gossypium hirsutum* L. cv. Sumian 3) field treated with four nitrogen application rates: 0%, 50%, 100% and 200% of the recommended rate. Hyperspectral reflectance was measured at 2.3 m above the cotton canopy on July 15, August 14 and October 1, 2002 using a FieldSpec® FR spectroradiometer. Corresponding leaf area index values and CCD were also measured on these dates. A large number (i.e. 22,500) of two-band combinations in the Normalized Difference Vegetation Index $(\lambda_2-\lambda_1)/(\lambda_1+\lambda_2)$ and the Ratio Vegetation index λ_2/λ_1 was used for a linear and exponential regression analysis against LAI and CCD values. Moreover, traditional broadband vegetation indices based on simulated spectra were compared with their narrowband versions in predicting LAI and CCD. The results suggest that 640–660 nm and 800–870 nm, the centers of the red and NIR channels of several multi-spectral sensors on the current generation of earth-orbiting satellites, were not always the optimum wavelength position of red–NIR bands for VIs. Although different in formula, both the NDVI (normalized difference vegetation index) and RVI (ratio vegetation index) calculated from narrowbands at 690–710 nm and 750–900 nm were closely correlated with LAI ($R^2>0.8$) and CCD ($R^2>0.85$). The red–NIR band position was more important than band width for modeling LAI and CCD. In summary, hyperspectral remotely sensed data provide more alternative red–NIR bands compared to multi-spectral data and, therefore, can provide greater flexibility in predicting LAI and CCD.

Keywords: Hyperspectral remote sensing; Cotton; Broadband vegetation indices; Narrowband VIs; Leaf area index (LAI); Canopy chlorophyll density (CCD); Bandwidth and wavelength selection

* Corresponding author. The State Key Laboratory of Pollution Control and Resources Reuse, Nanjing University, Nanjing 210093, PR China. Tel.: +86 25 3592715; fax: +86 25 3302728.
E-mail address: jlli2008@nju.edu.cn (J. Li).

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1. Introduction

Remote sensing in agricultural research over the past three decades has focused on the use of spectral data to characterize the status of plants. However, information contained in a single spectral band is usually not sufficient to characterize crop properties fully or to identify causal factors and their relationships with the host or the environment. So far, the most common technique to extract information content from spectral measurements is the computation of spectral vegetation indices (VIs). The normalized difference vegetation index (NDVI) and ratio vegetation index (RVI) have been used extensively in correlating remote sensing observations with the characteristics of vegetation (Myneni and Williams, 1994; Carlson and Ripley, 1997; Serrano et al., 2000; Tottrup and Rasmussen, 2004). In particular, these vegetation indices were found to be quantitatively and functionally related to several vegetation parameters such as leaf area index (LAI), percent vegetation cover, intercepted photosynthetically active radiation (IPAR), and green biomass (Myneni and Williams, 1994; Elvidge and Chen, 1995; Carlson and Ripley, 1997). Many VIs were developed in the past three decades with the primary purposes of (1) enhancing their sensitivities to green vegetation signals and (2) reducing external effects such as those from soil and atmospheric variations (Pearson and Miller, 1972; Rouse et al., 1974; Baret et al., 1989; Demetriades-Shah et al., 1990; Major et al., 1990; Qi et al., 1994; Gitelson and Merzlyak, 1996; Sims and Gamon, 2002).

The reflectance of plants in the blue, green and red regions of the spectrum is primarily determined by pigments, often chlorophyll concentration and, therefore, has been widely used to quantify vegetation physiological properties (Jago et al., 1999; Gitelson et al., 2002, Sims and Gamon, 2002). The reflectance of plants in the near-infrared (NIR) region is mainly determined by the arrangement of cells within the mesophyll layer of leaves and by canopy structure (Kumar et al., 2001; Mutanga et al., 2003). Vegetation indices constructed with red and NIR spectral measurements have been shown to be significantly correlated with crop agronomic variables such as LAI, above ground biomass, and chlorophyll content. Previous research has demonstrated their usefulness and potential for agricultural applications such as estimating and forecasting crop yields, monitoring crop conditions, classifying and mapping crop types, and assisting precision farming activities (Plant et al., 2000; Serrano et al., 2000; Shanahan et al., 2001; Chang et al., 2003; Dobermann and Ping, 2004).

Broadband and narrowband based vegetation indices have been compared for their ability to estimate crop agronomic variables such as green vegetation cover, LAI and CCD ((Elvidge and Chen, 1995; Broge and Leblanc, 2001; Broge and Mortensen, 2002). In general, the narrowband VIs may be slightly better than their broadband versions for estimating crop variables (Elvidge and Chen, 1995; Thenkabail et al., 2000; Hansen and Schjoerring, 2003), although some reported no difference between them (Broge and Leblanc, 2001; Broge and Mortensen, 2002).

The objectives of this study were to i) compare VIs derived from narrow and broadband red–NIR spectral data in estimating LAI and CCD of a cotton canopy, ii) select the best performing spectral bands in vegetation indices, and iii) compare their linear and exponential models in predicting LAI and CCD.

2. Materials and methods

2.1. Experimental design and treatments

A randomized experiment containing four replicates was conducted in a cotton (*Gossypium hirsutum* L. cv. Sumian 3) field at Zhangjiagang, Jiangsu province, China (31°50′N, 120°49′E). Treatments included four nitrogen application rates: 0%, 50%, 100% and 200% at

Table 1
Different versions of broad and narrowbands of red and NIR spectra used to calculate VIs modeled from ASD FieldSpec hyperspectral data (nm)

Codes [a]	(Simulated) sensors [b]	Red channel		NIR channel	
		CW [c]	FWHM [d]	CW [c]	FWHM [d]
B1	TM	660	60	825	150
B2	ASTER	660	60	830	80
B3	SPOT	645	70	835	110
B4	AVHRR-14	640	140	865	290
B5	MODIS	645	50	855	30
B6	TM-T	700	60	825	150
N1	ASD	670	3.0	800	3.0
N2	ASD	700	3.0	800	3.0

[a] B = broadband, N = narrowband.

[b] The broadband spectral data of TM, ASTER, SPOT, AVHRR-14 and MODIS were simulated using the resampling functions of ENVI 3.5 (Research Systems ENVI 3.5) using ASD hyperspectral data, which were coded as B1, B2, B3, B4 and B5, respectively. The TM-T (coded as B6) meant that the red–NIR bands were modeled from ASD hyperspectral data using the same configurations of TM sensor except that the red band center of TM was changed to a new wavelength: 700 nm. The ASD meant that the red–NIR data were the hyperspectral bands without resampling (coded as N1 and N2).

[c] CW = center wavelength.

[d] FWHM = full width at half maximum.